Remote Sensing and Geospatial Data

Provides operational guidance on using remote sensing and geospatial data for compiling ocean accounts.

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OUTCOME

This Circular provides operational guidance on using remote sensing and geospatial data for compiling ocean accounts, establishing the spatial foundation that underpins ecosystem extent mapping, condition monitoring, and marine spatial planning analysis. Upon implementation, statistical agencies and ocean accounting practitioners will be able to:

a) Select and access appropriate satellite imagery platforms for mapping marine ecosystem extent and monitoring change, with specific attention to optical sensors (Sentinel-2, Landsat) for coastal ecosystem mapping and SAR platforms (Sentinel-1) for all-weather coverage in persistently cloudy regions;

b) Apply remote sensing classification methods and change detection workflows to produce spatially explicit ecosystem extent accounts that feed directly into TG-3.1 Asset Accounts and support ecosystem-specific guidance in TG-6.1 Coral Reef Ecosystem Accounting, TG-6.2 Mangrove and Coastal Wetland Accounting, and TG-6.3 Seagrass Ecosystem Accounting;

c) Integrate bathymetric data and seabed classification products within ocean accounting spatial frameworks, providing the depth-stratified spatial units required for marine ecosystem extent accounts and enabling three-dimensional representation of marine ecosystems as described in SEEA EA Chapter 3;

d) Delineate Basic Spatial Units (BSUs) appropriate for coastal and marine contexts, recognising that BSU resolution should reflect spatial heterogeneity and data density—finer resolution (10-30m) in data-rich coastal zones, coarser resolution in offshore areas with sparse observations—while ensuring exhaustive and mutually exclusive coverage across the Ecosystem Accounting Area;

e) Implement quality assurance procedures for geospatial data products consistent with international geospatial standards (ISO 19157) and the framework established in TG-0.7 Quality Assurance Principles, including accuracy assessment through confusion matrices, positional accuracy documentation, and validation against authoritative reference datasets; and

f) Align geospatial data workflows with the Global Statistical Geospatial Framework (GSGF) Principle 1 (fundamental geospatial infrastructure) and Principle 4 (statistical-geospatial interoperability), supporting coordination between National Statistical Offices and National Geospatial Information Agencies.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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¶1 **Framework Position**

¶2 TG-4.1 sits within Section 4 (Data Methods) and provides the foundational geospatial methods layer for ocean accounts. It owns the pathway from imagery to a quality-assured area statistic: platform and sensor selection, pre-processing, classification and accuracy assessment, change detection, managed / unmanaged attribution, BSU delineation, bathymetry and seabed mapping. It delivers those statistics with their accuracy and attribution flags; assembling them into the extent account and applying its accounting identity is **TG-3.1 Asset Accounts** Section 3.5.1, and condition variables derived from imagery enter the condition account at Section 3.5.2. Ecosystem-specific method is TG-6.1, TG-6.2 and TG-6.3; reading the resulting accounts for spatial planning is TG-1.2.

¶3 **Prerequisites: TG-0.1 General Introduction to Ocean Accounts**, **TG-0.7 Quality Assurance Principles** **Enables: TG-3.1 Asset Accounts**, **TG-3.5 Social Accounts**, **TG-6.1 Coral Reef Ecosystem Accounting**, **TG-6.2 Mangrove and Coastal Wetland Accounting**, **TG-6.3 Seagrass Ecosystem Accounting**, **TG-1.2 OA and Marine Spatial Planning**

1 Outcome

¶1 This Circular provides operational guidance on using remote sensing and geospatial data for compiling ocean accounts, establishing the spatial foundation that underpins ecosystem extent mapping, condition monitoring, and marine spatial planning analysis. Upon implementation, statistical agencies and ocean accounting practitioners will be able to:

¶2 a) Select and access appropriate satellite imagery platforms for mapping marine ecosystem extent and monitoring change, with specific attention to optical sensors (Sentinel-2, Landsat) for coastal ecosystem mapping and SAR platforms (Sentinel-1) for all-weather coverage in persistently cloudy regions;

¶3 b) Apply remote sensing classification methods and change detection workflows to produce spatially explicit ecosystem extent accounts that feed directly into **TG-3.1 Asset Accounts** and support ecosystem-specific guidance in **TG-6.1 Coral Reef Ecosystem Accounting**, **TG-6.2 Mangrove and Coastal Wetland Accounting**, and **TG-6.3 Seagrass Ecosystem Accounting**;

¶4 c) Integrate bathymetric data and seabed classification products within ocean accounting spatial frameworks, providing the depth-stratified spatial units required for marine ecosystem extent accounts and enabling three-dimensional representation of marine ecosystems as described in SEEA EA Chapter 3;[1]

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¶6 e) Implement quality assurance procedures for geospatial data products consistent with international geospatial standards (ISO 19157) and the framework established in **TG-0.7 Quality Assurance Principles**, including accuracy assessment through confusion matrices, positional accuracy documentation, and validation against authoritative reference datasets; and

¶7 f) Align geospatial data workflows with the Global Statistical Geospatial Framework (GSGF) Principle 1 (fundamental geospatial infrastructure) and Principle 4 (statistical-geospatial interoperability), supporting coordination between National Statistical Offices and National Geospatial Information Agencies.[3]

2 Requirements

¶1 This Circular requires familiarity with:

- ¶2
  TG-0.1 General Introduction to Ocean Accounts – provides foundational understanding of the Global Ocean Accounts Partnership framework, including institutional arrangements for multi-agency collaboration and the relationship between environmental and economic accounting.
- ¶3
  TG-0.7 Quality Assurance Principles – establishes the overarching quality framework for ocean accounts, including data quality dimensions, validation procedures, and documentation requirements that apply to geospatial data products described in this Circular.

2.1 Institutional Requirements

¶1 Countries implementing this Circular should:

¶2 a) Establish formal data sharing arrangements between the National Statistical Office (NSO), National Geospatial Information Agency (NGIA), and relevant hydrographic authorities – see **TG-4.7 National Data Coordination Architectures** for committee models, MOU templates, and graduated access frameworks applicable to these arrangements; and

¶3 b) Designate a technical lead with competency in geospatial data management for ocean accounting purposes.

¶4 Metadata catalogue management, satellite imagery licensing documentation, and participation in international coordination mechanisms (including the UN-GGIM Working Group on Marine Geospatial Information) are cross-cutting data governance requirements addressed in **TG-4.7** and the ISO 19115 metadata standards covered in **TG-4.6 Data Harmonisation and Interoperability**.

2.2 Technical Requirements

¶1 Countries should ensure technical capacity for:

¶2 a) Processing and analysing satellite imagery at resolutions appropriate for marine ecosystem delineation (typically 10–30m for extent mapping);

¶3 b) Handling gridded bathymetric data in formats consistent with IHO S-100 series standards;[4]

¶4 c) Managing coordinate reference systems appropriate for marine domains, including vertical datums for depth measurements;

¶5 d) Integrating vector and raster geospatial data within geographic information systems (GIS); and

¶6 e) Producing spatially explicit outputs aligned with the SEEA EA framework for ecosystem extent and condition accounts.[5]

2.3 Data Quality Requirements

¶1 All geospatial data used in ocean accounts should:

¶2 a) Include documented accuracy assessments using confusion matrices or equivalent validation approaches, assessed against the dual accuracy criteria specified in Section 3.4.3;

¶3 b) Use stratified random sampling for ground-truth validation data, meeting the normative sampling requirements set out in Section 3.4.2 Step 5;[6]

¶4 c) Specify positional accuracy in horizontal and vertical dimensions;

¶5 d) Document temporal coverage and update frequency;

¶6 e) Include provenance information traceable to source satellite platforms or survey instruments; and

¶7 f) Be validated against authoritative national or regional reference datasets where available.

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3 Guidance Material

3.1 Decision Use Cases for Remote Sensing Data in Ocean Accounting

¶1 Remote sensing and geospatial data support multiple decision-making applications within ocean accounts. Understanding these use cases helps prioritise data acquisition investments and guides compilation decisions.

3.1.1 Ecosystem Extent Monitoring

¶1 Ecosystem extent accounts require spatially explicit delineation of marine ecosystem types, with extent measured in hectares or square kilometres and tracked over accounting periods.[7] Remote sensing provides the only practical method for mapping marine ecosystems at national scales. Decision applications include:

- ¶2
  Monitoring change in mangrove extent — supporting SDG indicator 6.6.1 (change in extent of water-related ecosystems) through time-series analysis of mangrove forest area using Landsat and Sentinel-2 imagery at 30m and 10m resolution respectively. The Global Mangrove Watch dataset provides annual mangrove extent maps from 1996 onwards at 25-metre resolution, and national compilers can use this record to track long-term extent trends.[8]
- ¶3
  Mapping coral reef ecosystem assets — delineating reef extent and geomorphic zones (reef flat, reef crest, fore-reef slope) using multispectral satellite imagery and acoustic bathymetry. The Allen Coral Atlas (version 2.0, released 2022) provides standardised reef extent and geomorphic zone mapping at approximately 3.7m source resolution (Planet satellite imagery) for shallow tropical reef areas globally.[9]
- ¶4
  Tracking seagrass meadow distribution — monitoring seagrass extent using high-resolution optical imagery in clear, shallow waters. Seagrass mapping requires water clarity sufficient for optical penetration (typically Secchi depth greater than 2m) and spatial resolution fine enough to detect patchy meadow structure (sub-10m resolution preferred).

¶5 Extent accounts compiled using remote sensing data feed directly into **TG-3.1 Asset Accounts** (Section 3.4 on ecosystem asset accounts).[10]

3.1.2 Change Detection and Degradation Assessment

¶1 Change detection identifies additions and reductions in ecosystem extent between accounting periods. The resulting extent change entries are required in ecosystem asset accounts. Remote sensing provides consistent, repeatable observations suitable for multi-temporal analysis. Key applications include:

- ¶2
  Detecting conversions — identifying conversions from mangroves to aquaculture ponds, or from coral reef to rubble following bleaching mortality. Change detection methods include post-classification comparison (classifying images from two dates independently and comparing results) and direct change detection using spectral indices (e.g., differencing NDVI time series to identify vegetation loss).
- ¶3
  Monitoring coastal erosion — tracking shoreline position changes using optical and SAR imagery. Shoreline change rates inform condition assessments for coastal ecosystems and support valuation of coastal protection services described in **TG-6.1 Coral Reef Ecosystem Accounting** and **TG-6.2 Mangrove and Coastal Wetland Accounting**.
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Assessing bleaching impacts — mapping bleached coral reef areas using multispectral and hyperspectral imagery. NOAA Coral Reef Watch provides satellite-derived bleaching alerts and degree heating week (DHW) products that can be integrated with in-situ mortality surveys to estimate reef area lost through bleaching events.[11]

¶5 These change detection outputs populate the managed and unmanaged additions and reductions recorded in extent accounts, distinguishing changes resulting from deliberate human decisions (managed) from those associated with natural processes including climate-driven impacts (unmanaged), consistent with SEEA EA paragraphs 4.14-4.17.[12]

3.1.3 Basic Spatial Unit (BSU) Delineation

¶1 The SEEA EA introduces the Basic Spatial Unit (BSU) as an operational tool for implementing ecosystem asset delineation within GIS environments. A BSU is "a geometrical construct representing a small spatial area" whose purpose is to provide a fine-level data framework within which ecosystem characteristics can be attributed.[13] For ocean accounting, remote sensing pixels or national grid cells serve as BSUs, with resolution choices guided by data density and ecosystem heterogeneity:

¶2 These resolution thresholds (Outcome item d) reflect ecosystem heterogeneity and data density: finer resolution in coastal zones, coarser in offshore areas.

¶3 BSUs must be exhaustive and mutually exclusive across the Ecosystem Accounting Area. This gives complete spatial coverage without overlaps or gaps (SEEA EA para. 3.37).[14]

¶4 **Land-sea boundary interface rule (GSGF Principle 3).** Where ocean accounts adjoin terrestrial or freshwater accounts within the same national accounting system, the BSU grid should be consistent across domains to enable integrated analysis, consistent with GSGF Principle 3 (Common Geographies).[15] Where alignment to a single common grid is not feasible — for example, because terrestrial accounts already use a fixed national grid at a different resolution or projection — the following boundary interface rule applies. The land-sea delineation line (the high-water mark or mean high water line as defined in Section 3.6) determines which BSU receives a transitional pixel. The default assignment rule is **nearest grid cell**: a transitional pixel is assigned to the ocean BSU grid cell whose centre is nearest to the pixel centre.

¶5 This default may be overridden where a national policy, national geospatial norm, or national statistical norm specifying an alternative assignment has been formally documented. Where a country applies a national override, the alternative rule and the authority under which it was adopted should be documented in the metadata accompanying the accounts and disclosed in any data quality notes cross-referencing **TG-0.7 Quality Assurance Principles**.

¶6 The spatial data outputs from this Circular provide the BSU framework within which **TG-3.1 Asset Accounts** records condition variables and **TG-1.2 OA and Marine Spatial Planning** performs spatial allocation analysis.

3.2 Upward Connections: Which Accounts Consume Remote Sensing Data

¶1 Remote sensing and geospatial data produced under this Circular feed into multiple downstream account types. Understanding these upward connections helps compilers prioritise data quality investments and ensure that spatial data products meet the requirements of consuming accounts.

3.2.1 Ecosystem Extent Accounts (TG-3.1)

¶1 Ecosystem extent accounts require spatially explicit delineation of ecosystem types, with total area measured at opening and closing accounting periods and additions/reductions tracked between periods. Remote sensing provides:

- ¶2

Classified imagery — raster outputs assigning each BSU to an ecosystem type (e.g., mangrove, coral reef, seagrass, sandy substrate). Classification products should include accuracy assessments (overall accuracy, user's accuracy, producer's accuracy) derived from confusion matrix analysis with ground-truth validation data. [16]

- ¶3
  Change detection products — identifying pixels that changed ecosystem type between opening and closing dates, distinguishing managed changes (e.g., coastal development) from unmanaged changes (e.g., storm damage, natural succession).

¶4 **TG-3.1 Asset Accounts** Section 3.5.1 requires opening extent, additions, reductions, and closing extent for each ecosystem type. Remote sensing outputs populate these entries directly.

3.2.2 Ecosystem Condition Accounts (TG-3.1)

¶1 Ecosystem condition accounts record the quality of ecosystems using variables organised within the SEEA Ecosystem Condition Typology (ECT). [17] Remote sensing contributes condition variables across multiple ECT classes:

- ¶2
  Physical state characteristics (Class A1) — sea surface temperature from MODIS or VIIRS sensors; turbidity from optical imagery using Secchi depth proxies or water colour indices.
- ¶3
  Structural state characteristics (Class B2) — vegetation cover and canopy height for mangroves and coastal wetlands derived from optical imagery (cover) and LiDAR or InSAR (height); coral cover from high-resolution multispectral imagery; above-ground biomass estimated using SAR backscatter and allometric equations. SAR-derived biomass estimates are subject to saturation limits that vary by sensor band: C-band (Sentinel-1) saturates at approximately 100 Mg/ha, L-band (ALOS PALSAR-2) at approximately 200 Mg/ha, and P-band (ESA Biomass Mission) extends the range further. [18] Compilers should document the saturation limit relative to the biomass range of the ecosystem being measured and apply a data quality flag where saturation likely affects a large share of the study area.
- ¶4
  Landscape and seascape characteristics (Class C1) — fragmentation metrics (patch size distribution, edge density) derived from classified imagery; hydrological connectivity assessed by analysing tidal channel networks; spatial pattern indices quantifying ecosystem asset configuration.

¶5 The SEEA EA notes that "condition accounts are most commonly compiled using remote sensing, modelling and other techniques in combination with available direct field measures." [19] For detailed guidance on condition variable selection and indicator derivation, see **TG-3.1 Asset Accounts** Section 3.5.2.

3.2.3 Ecosystem-Specific Accounts (TG-6.1, TG-6.2, TG-6.3)

¶1 The ecosystem-specific circulars in Section 6 apply extent and condition accounting methods to particular marine ecosystem types:

- ¶2
  TG-6.1 Coral Reef Ecosystem Accounting — requires reef extent mapping at 5–30m resolution, geomorphic zone classification (reef flat, crest, slope), and condition variables including live coral cover, bleaching prevalence, and rugosity index.
- ¶3
  TG-6.2 Mangrove and Coastal Wetland Accounting — requires mangrove forest extent mapping, canopy cover estimation, canopy height measurement for above-ground biomass estimation, and change detection for tracking conversions to aquaculture or agricultural uses.
- ¶4

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TG-6.3 Seagrass Ecosystem Accounting — requires seagrass meadow extent mapping in optically clear waters, shoot density estimation from high-resolution imagery or benthic surveys, and monitoring of meadow fragmentation patterns.

¶5 These circulars reference this Circular (TG-4.1) for general remote sensing methods whilst providing ecosystem-specific technical details tailored to each habitat type.

3.2.4 IUCN Global Ecosystem Typology (GET) Classification Framework

¶1 The IUCN Global Ecosystem Typology (GET) is the international reference classification for ecosystem types in ocean accounts, consistent with SEEA EA Appendix A3.2.[20], [21] Full treatment of GET realms, biomes, and Ecosystem Functional Groups (EFGs) relevant to ocean accounting is provided in **TG-0.2 Overview of Relevant Statistical Standards**. For remote sensing and mapping purposes, the primary GET codes applied in coastal ecosystem accounts are: MFT1.2 (mangroves), M1.3 (coral reefs), M1.1 (seagrass meadows), and MFT1.3 (saltmarshes and reedbeds). Section 6 circulars identify the GET code applicable to each ecosystem type they cover.

¶2 **National crosswalk obligation.** Where a national habitat classification scheme is used instead of GET directly, compilers are required to document a formal crosswalk between national types and GET ecosystem functional groups to enable international comparability, consistent with SEEA EA paragraphs 3.22–3.24.[22] Where no direct crosswalk is possible, two endorsed intermediate classification bridges are available: CMECS for non-European contexts and EUNIS Marine Habitats Classification for European contexts. Both have published crosswalk tables to IUCN GET.[23]

3.2.5 Marine Spatial Planning Accounts (TG-1.2)

¶1 Marine spatial planning requires spatially explicit information on ecosystem distribution, human use patterns, and jurisdictional boundaries to support allocation decisions. Remote sensing data contribute:

- ¶2 **Ecosystem extent layers** — serving as the base map for spatial planning exercises, showing the distribution of benthic habitats (coral reefs, seagrass meadows, sandy substrate, rocky reef) and surface water ecosystem types (coastal waters, open ocean).
- ¶3 **Change detection outputs** — identifying areas of high ecosystem change rates that may warrant protective zoning or management intervention.
- ¶4 **Bathymetric-derived products** — depth contours, slope, and geomorphic features that inform zoning decisions (e.g., depth-based fishery management zones).

¶5 **TG-1.2 OA and Marine Spatial Planning** uses ecosystem extent maps to conduct spatial allocation analysis, including cross-tabulations of ecosystem type by designated use zone (fishery zone, marine protected area, tourism zone, port area).

3.2.6 Coastal Protection and Flood Exposure Layers (TG-3.2, TG-2.3)

¶1 A SEEA-compatible compilation of the coastal protection service needs a counterfactual: the flood or surge outcome with the ecosystem present, and again with it removed. None of the products below is mandated by SEEA EA, which is deliberately data-agnostic; these are the de facto templates national compilations have used, and the service entry they feed is specified in **TG-3.2 Flows from Environment to Economy** Section 3.3.

- ¶2 **Elevation:** CoastalDEM (Climate Central) is the standard high-resolution global coastal digital elevation product, correcting for known SRTM bias over vegetated and built-up coastlines.
- ¶3 **Benefiting-area population:** WorldPop or the Global Human Settlement Layer (GHSL) gridded population, intersected with surge-extent rasters to derive exposed population by spatial unit.

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- ¶4 **Hydrodynamic modelling for the with/without-ecosystem counterfactual:** SWAN or Delft3D for full process-based wave and surge modelling, or the InVEST Coastal Vulnerability model (Guannel et al.) for index-based first-pass screening.
- ¶5 **Asset and damage data:** national cadastre, building stock surveys, or insurance loss data to monetise avoided damages.

¶6 Where hydrodynamic modelling capacity is unavailable, TG-2.3 Section 3.4.4 sets out an interim composite indicator and the conditions for flagging it as transitional.

3.3 Satellite Imagery Sources

¶1 Remote sensing provides essential data for ocean accounting, particularly for mapping ecosystem extent, monitoring change, and deriving condition indicators. Countries should consider multiple satellite platforms depending on their specific requirements for spatial resolution, temporal frequency, spectral characteristics, and cost. [24]

3.3.1 Optical Satellite Platforms

¶1 Table 3.3.1 summarises the satellite platforms recommended for ocean accounting. Selection should be guided by spatial resolution requirements, archive depth, spectral coverage, and cost.

¶2 *Table 3.3.1: Satellite platforms for ocean accounting applications*

Platform	Operator	Resolution	Revisit	Key applications	Cost
Sentinel-2 MSI	ESA/Copernicus	10–60 m	5 days	Coastal extent mapping, water quality, change detection	Free [25]
Landsat 8/9 OLI	USGS/NASA	30 m	16 days	Long-term change analysis; archive from 1972	Free [26]
MODIS Terra/Aqua	NASA	250 m – 1 km	Daily	Ocean colour, SST, large-scale seasonal patterns	Free [27]
Planet SuperDove	Planet Labs	3–5 m	Daily	Detailed coral reef and seagrass mapping	Commercial
WorldView/Maxar	Maxar	0.3–1.2 m	Variable	Sub-metre habitat delineation	Commercial [28]

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¶3 Sentinel-2 and Landsat data are freely accessible through the Copernicus Data Space Ecosystem and USGS Earth Explorer respectively. [29]

3.3.2 Synthetic Aperture Radar (SAR)

¶1 SAR imagery provides all-weather, day-night imaging capability independent of cloud cover and sunlight. **Sentinel-1** (ESA/Copernicus, C-band, free) is the primary recommended platform for ocean accounting. Key applications include intertidal zone mapping through coherent change detection, oil spill detection, ship and fishing vessel monitoring, and coastal flood and storm surge mapping. The RADARSAT Constellation Mission (Canadian Space Agency) provides enhanced capability for ice monitoring in polar accounting regions. [30]

¶2 SAR requires specialised processing workflows but is the essential complement to optical sensors in persistently cloudy regions.

3.3.3 Data Challenges

¶1 **Persistent cloud cover.** In persistently cloudy tropical and equatorial regions — including much of equatorial Southeast Asia and West Africa — no single Sentinel-2 or Landsat scene may achieve acceptable cloud cover over the full Ecosystem Accounting Area during an appropriate tidal window. Where no single image achieves less than 20% cloud cover over the EAA, compilers are authorised to use **seasonal median compositing**: all available scenes within a defined phenological window (for example, dry season months) are composited using a pixel-wise median algorithm to produce a cloud-free or near-cloud-free composite image. The composite product metadata should document the number of input scenes, the date range, and the compositing algorithm applied. [31] Where persistent cloud cover prevents satisfactory optical compositing, Sentinel-1 SAR (Section 3.3.2) should be used as the primary source for intertidal zone delineation.

¶2 **Optical depth limitation.** Optical sensors are limited to clear, shallow waters for benthic habitat mapping — typically to 20–25 m depth under good water clarity conditions. Turbid coastal waters, high chlorophyll concentrations, and variable depth all reduce the effective mapping range. For deeper or more turbid areas, acoustic methods (multibeam sonar, sub-bottom profiler) and SAR provide the necessary complementary data.

3.3.4 Satellite-Derived Bathymetry

¶1 Satellite-derived bathymetry (SDB) techniques use optical multispectral imagery to estimate water depths in optically clear waters, typically to 20–25m depth. Methods include:

- ¶2 Ratio-based algorithms (e.g., Stumpf method using blue/green band ratios)
- ¶3 Physics-based radiative transfer models
- ¶4 Machine learning approaches combining spectral and contextual features

¶5 SDB is cost-effective for mapping shallow coastal zones but requires calibration with in-situ depth measurements and is limited by water clarity conditions. [32]

¶6 **Minimum calibration standard.** For SDB products used in ocean accounts, compilers should ensure sufficient independent validation soundings, distributed across the full depth range of application (0–25 m) and across multiple water clarity conditions representative of the study area, to enable reliable characterisation of depth error. Root mean square error (RMSE) between SDB-derived depths and validation soundings should be documented in metadata. IHO S-44 6th edition (2020) Order 1b specifies bathymetric accuracy using a Total Vertical Uncertainty (TVU) formula:

¶7 $TVU = \sqrt{(a^2 + (b \times d)^2)}$

¶8 where for Order 1b: **a = 0.5 m** (a fixed component representing equipment and data processing errors), **b = 0.013** (a depth-dependent component), and **d** is depth in metres. At 20 m depth this gives $TVU = \sqrt{(0.5^2 + (0.013 \times 20)^2)} = \sqrt{(0.25 + 0.0676)} = \sqrt{0.3176} \approx$ **0.56 m**. This TVU formula serves as the reference threshold for assessing SDB fit-for-purpose in ocean accounting contexts. [33]

3.3.5 Geospatial data platforms and global ocean datasets

¶1 Cloud-based geospatial analysis platforms have widened access to remote sensing for ocean accounting and made large-area processing more practical. Google Earth Engine (GEE) provides a planetary-scale analysis environment with access to multi-petabyte archives of satellite imagery, including the full Sentinel-2, Landsat, and MODIS collections, together with derived products such as the Global Surface Water dataset and JRC Global Forest Change maps. [34] The Copernicus Data Space Ecosystem (CDSE) at https://dataspace.copernicus.eu/ (https://dataspace.copernicus.eu/) — which replaced the earlier Data and Information Access Services in 2023 — offers direct access to all Copernicus Sentinel data alongside processing tools optimised for European and global applications. [35] Digital Earth Australia provides a national-scale example of an analysis-ready data cube built on open-source infrastructure. It illustrates one way countries can organise time-series satellite imagery for consistent national ecosystem monitoring. [36]

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¶2 For ocean accounting specifically, several global reference datasets provide foundational spatial layers. The USGS/ESRI Global Shoreline Vector provides a high-resolution coastline baseline for defining the land-sea interface. The General Bathymetric Chart of the Oceans (GEBCO) — discussed further in Section 3.5.1 — supplies global bathymetric grids essential for depth-stratified analyses. The United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) maintains authoritative global datasets on coral reefs, seagrass beds, and marine protected areas that serve as key reference layers for ecosystem extent accounts. [37]

¶3 **Global product GET crosswalks.** The Allen Coral Atlas and Global Mangrove Watch map directly to IUCN GET functional groups: Global Mangrove Watch maps to GET MFT1.2 (Intertidal forests and shrublands — mangroves). Allen Coral Atlas geomorphic zone classes collectively map to GET M1.3 (Coral reefs). [38] These global products should be used as the baseline only when no national mapping programme exists. Where national extent estimates diverge from these global products by more than 15%, compilers should document the discrepancy and its likely cause — such as differences in classification scheme, tidal correction, or spatial resolution — in the metadata accompanying the accounts.

3.4 Compilation Procedure: From Remote Sensing Data to the Extent Variables

¶1 This section describes the operational workflow for producing the ecosystem extent variables from satellite imagery. It provides step-by-step guidance that compilers can follow, from raw imagery to a quality-assured set of area and area-change statistics ready for delivery to the extent account. The five phases — from scoping the Ecosystem Accounting Area through platform selection, preprocessing, and ecosystem classification to multi-date change detection, with the accuracy assessment gate determining whether a classification proceeds, is conditionally accepted, or loops back — are summarised in Figure 4.1.1.

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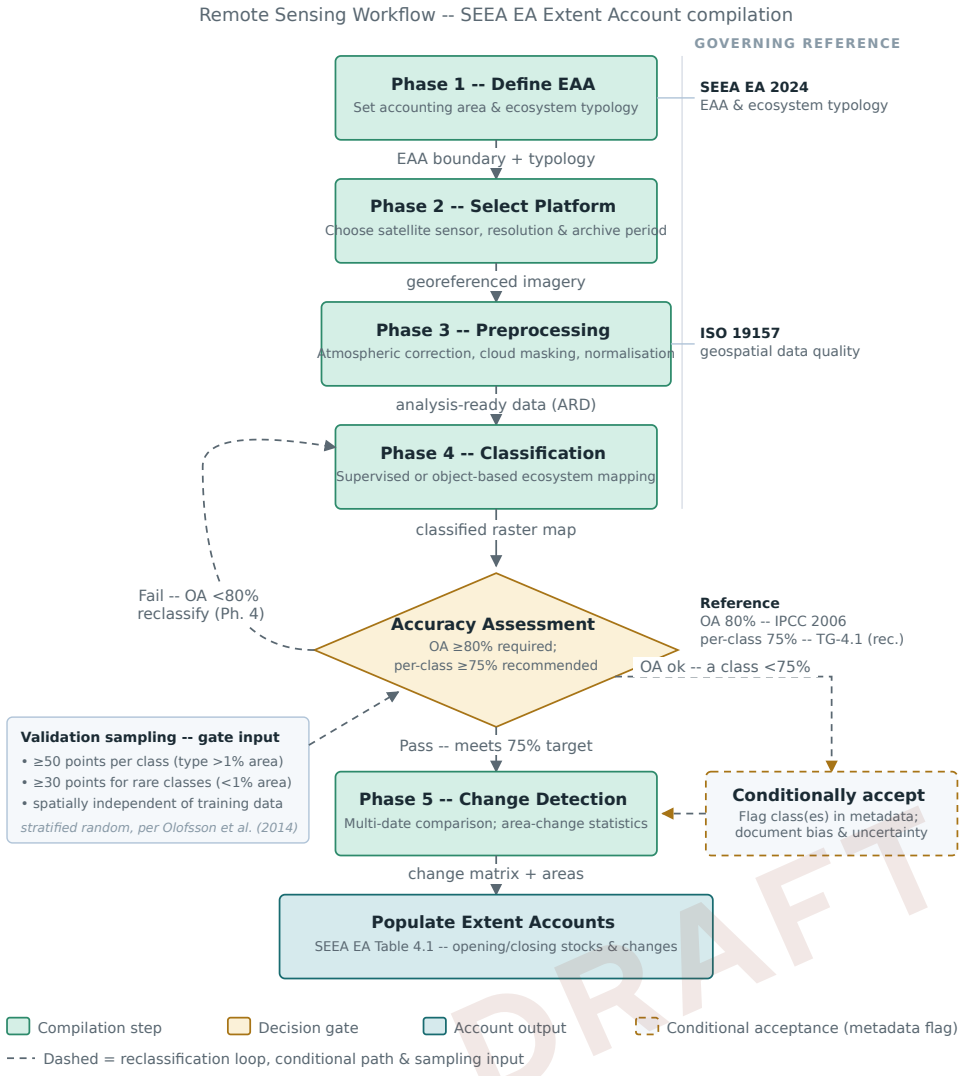


Figure 4.1.1 Five-phase remote-sensing workflow produces SEEA EA extent accounts, gated by overall and per-class accuracy tests. Products at ≥80% overall proceed; below per-class may be flagged; failing overall loops back.

Source: TG-4.1, Section 4 (remote sensing compilation workflow); dual accuracy criteria, conditional-acceptance rule, and sampling requirements per TG-4.1 Section 3.4.3 (Step 8; recommended 75% per-class target; Olofsson et al. 2014 sampling); 80% overall threshold per IPCC 2006 good practice; ISO 19157 (geospatial data quality); extent account structure per SEEA EA 2024, Table 4.1.

3.4.1 Image Acquisition and Preprocessing

¶1 **Step 1: Define the Ecosystem Accounting Area (EAA)**

¶2 The EAA boundary determines the spatial scope of accounts. For ocean accounts, the EAA typically extends from the coastline to the seaward boundary of the Exclusive Economic Zone (EEZ). Countries should define EAA boundaries using authoritative maritime limits from national hydrographic offices or international sources such as the Flanders Marine Institute (VLIZ) Maritime Boundaries Geodatabase.[39]

¶3 **Step 2: Identify Imagery Requirements**

¶4 Based on the ecosystem types to be mapped, select appropriate imagery:

- ¶5 Mangroves and coastal wetlands: Sentinel-2 (10m) or Landsat (30m) optical imagery
- ¶6 Coral reefs: High-resolution optical imagery (Planet 3-5m or commercial sub-metre)
- ¶7 Seagrass meadows: High-resolution optical imagery in clear waters
- ¶8 Offshore ecosystems: MODIS (250m-1km) for large-scale patterns

¶9 Select imagery dates that minimise cloud cover and capture ecosystems during appropriate tidal stages (low tide for intertidal ecosystems). For regions where persistent cloud cover prevents acquisition of a cloud-free single-date image, apply the seasonal median compositing protocol described in Section 3.3.3.

¶10 **Phenological considerations.** Coastal ecosystems including seagrass meadows and saltmarshes exhibit seasonal variation in canopy cover that can affect apparent extent in single-date imagery. Compilers should consider whether imagery acquisition timing is ecologically representative for the national context — for example, whether the selected date reflects peak canopy extent or a seasonal low — and document the reasoning in metadata. The decision is context-dependent and optimal timing cannot be globally standardised, but failure to consider phenology at first-compilation baseline stage can introduce systematic biases that persist across all subsequent change calculations. [40]

¶11 **Step 3: Acquire and Preprocess Imagery**

¶12 Download imagery from appropriate sources:

- ¶13 Sentinel-2: Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu/ (https://dataspace.copernicus.eu/))
- ¶14 Landsat: USGS Earth Explorer (https://earthexplorer.usgs.gov/ (https://earthexplorer.usgs.gov/))
- ¶15 Planet: Commercial access through Planet Explorer
- ¶16 Google Earth Engine: Cloud-based access to multiple archives

¶17 Apply standard preprocessing:

- ¶18 Atmospheric correction (converting top-of-atmosphere to surface reflectance)
- ¶19 Cloud and cloud shadow masking
- ¶20 Water surface glint correction for marine areas
- ¶21 Geometric correction and georeferencing

¶22 Many satellite products are now provided as analysis-ready data (ARD) with preprocessing already applied. This reduces the burden on compilers.

3.4.2 Classification and Ecosystem Type Mapping

¶1 **Step 4: Develop Classification Scheme**

¶2 Align ecosystem type classification with the IUCN Global Ecosystem Typology (GET) or a national classification crosswalked to GET. For coastal and marine ecosystems, relevant GET functional groups include:

- ¶3 M1.3 Photic coral reefs
- ¶4 MFT1.2 Intertidal forests and shrublands (mangroves)
- ¶5 MFT1.3 Coastal saltmarshes and reedbeds
- ¶6 M1.1 Seagrass meadows
- ¶7 M1.5 Photo-limited marine animal forests (temperate reef)

¶8 Document the correspondence between national ecosystem types and GET functional groups to enable international comparability.

¶9 **Step 5: Collect Training and Validation Data**

¶10 Classification requires ground-truth data. Sources include:

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- ¶11 Field surveys with GPS/GNSS positioning
- ¶12 Expert interpretation of high-resolution imagery
- ¶13 Existing habitat maps from management agencies
- ¶14 Citizen science observations (with appropriate quality control)

¶15 Split ground-truth data into training (70%) and validation (30%) subsets. Ensure that training data represent all ecosystem types and capture the spectral variability within each type.

¶16 **Normative sampling requirements.** The Olofsson et al. (2014) stratified random sampling framework is the normative standard for accuracy assessment sampling in ocean accounts.[41] Validation samples must meet the following minimum thresholds: (a) minimum 50 validation points per class for ecosystem types covering more than 1% of the mapping area, and (b) minimum 30 validation points for rare ecosystem types covering less than 1% of the mapping area. Validation samples must be spatially independent from training data, with a minimum separation distance at least equal to the spatial autocorrelation range of the landscape. These requirements apply in addition to the overall split ratio used in the worked example. The 850-point dataset in Section 4 is illustrative of one approach meeting these normative requirements, not a substitute for them.

¶17 **Step 6: Perform Classification**

¶18 Apply supervised classification methods:

- ¶19 Random forest classifier (recommended for marine habitat mapping)[42]
- ¶20 Support vector machine
- ¶21 Maximum likelihood classification

¶22 Random forest classifiers are particularly effective for marine habitat mapping because they can handle complex spectral signatures, nonlinear relationships, and mixed pixels common in coastal environments. Train the classifier using training data, then apply to the full image extent.

¶23 **Step 7: Post-Classification Refinement**

¶24 Apply spatial filters to reduce classification noise:

- ¶25 Majority filter (replaces isolated pixels with surrounding class)
- ¶26 Minimum mapping unit filter (removes patches below minimum size)
- ¶27 Manual editing in areas with known errors

¶28 Integrate ancillary data where available (e.g., bathymetry for reef mapping, LiDAR for mangrove canopy height).

3.4.3 Accuracy Assessment

¶1 **Step 8: Generate Confusion Matrix**

¶2 Using the reserved validation data, construct a confusion matrix comparing classified results to ground-truth observations. Calculate accuracy metrics:[43]

- ¶3 **Overall accuracy** – proportion of correctly classified samples across all classes
- ¶4 **User's accuracy** – probability that a mapped class represents that class on the ground (commission error)
- ¶5 **Producer's accuracy** – probability that a ground reference class is correctly classified (omission error)
- ¶6 **Kappa coefficient** – classification accuracy accounting for chance agreement

¶7 **Dual accuracy criteria.** Countries should evaluate classified ecosystem extent products used in ocean accounts against both of the following:

1. ¶8 **At least 80% overall accuracy**, a threshold conventional in land cover mapping (IPCC good practice asks for a category-by-category confusion-matrix assessment but sets no numerical threshold);[44] and

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2. ¶9 **a recommended target of 75% producer's accuracy and 75% user's accuracy for each individually reported ecosystem type.** This per-class figure is a recommendation of this guidance rather than a value carried from an adopted standard. In the absence of an agreed marine-mapping benchmark it offers a practical reliability floor for the ecologically important minority classes discussed below. A compiler may adopt a different, documented per-class target where national circumstances justify it, provided the basis is recorded in metadata.

¶10 The single 80% overall accuracy threshold was designed for terrestrial land cover mapping where class areas are broadly comparable. In marine coastal mapping, dominant classes such as sandy substrate typically represent 70–80% of total area, whilst target ecosystem types such as seagrass and coral reef represent 3–6%. A classifier achieving 80%+ overall accuracy may completely miss ecologically important minority classes, creating sign errors in the change account if a net gain is recorded where there is in fact a net loss. The recommended per-class target addresses this structural limitation.

¶11 Where a classification meets the overall accuracy threshold but falls below the recommended per-class target for one or more ecosystem types, the product should be designated **conditionally accepted**: it may be used for account compilation, but the affected class(es) should be flagged in metadata with documented bias estimates (omission and commission rates) and associated uncertainty ranges.

¶12 **Step 9: Document Accuracy Assessment**

¶13 Prepare accuracy assessment reports documenting:

- ¶14 Confusion matrix (full table showing classified vs. reference)
- ¶15 Accuracy metrics by ecosystem type
- ¶16 Description of validation data sources and sampling design
- ¶17 Known limitations and sources of classification error

¶18 This documentation supports quality assurance requirements in **TG-0.7 Quality Assurance Principles**.

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3.4.4 Change Detection

¶1 **Step 10: Repeat Classification for Closing Date**

¶2 Apply the same classification workflow to imagery from the closing accounting date. Use consistent methods, training data sources (updated for the closing date), and post-processing approaches to ensure comparability.

¶3 **Step 11: Conduct Change Detection**

¶4 **Pre-change-detection QA checklist.** Before calculating extent change statistics, compilers should verify the following conditions and document results in metadata. Failures should be flagged using **TG-0.7 Quality Assurance Principles** data quality standards:

1. ¶5
   BRDF normalisation verification – confirm that both date images have been atmospherically corrected and BRDF (bidirectional reflectance distribution function)-normalised to a common view geometry prior to post-classification comparison. BRDF artefacts arise when multi-date images are acquired under different sun-sensor geometries, causing the same surface to produce different spectral signatures that post-classification comparison can interpret as ecosystem change. [45]
2. ¶6
   Phenological matching confirmation – confirm that the two classification dates fall within the same seasonal phenological window, consistent with the phenological considerations documented for Step 2. Seasonal variation in seagrass and saltmarsh canopy cover of 15–40% be-

tween growing and senescent seasons can generate apparent extent differences that are not ecosystem change.

3. ¶7
   Minimum mapping unit consistency check — confirm that a consistent minimum mapping unit (MMU) has been applied to both date classifications before comparing. Sub-MMU classification units can change class assignment between dates due to edge effects or resampling, generating pseudo-change at sub-threshold scale. Reference thresholds: 1 ha MMU for broad ecosystem extent accounts, and 0.2 ha MMU for high-resolution intertidal accounts.

¶8 Compare opening and closing date classifications to identify pixels that changed ecosystem type. Generate change matrices showing transitions between all ecosystem type pairs:

	Opening → Closing	Mangrove	Coral Reef	Seagrass	Sandy	Developed
Mangrove		Stable	Rare	Possible	Loss	Conversion
Coral Reef		Rare	Stable	Rare	Degradation	Rare
Seagrass		Rare	Rare	Stable	Loss	Loss
Sandy		Colonization	Rare	Colonization	Stable	Conversion
Developed		Rare	Rare	Rare	Expansion	Stable

¶9 **Uncertainty propagation.** Post-classification comparison produces change maps whose error is approximately the sum of errors from both date classifications. Compilers should add a sub-step estimating propagated change uncertainty before populating extent account tables. The minimum acceptable approach is: **combined change error = sum of per-class omission and commission errors from both date classifications**. Extent change account tables should include a documented confidence interval or DQ code when change areas are derived from post-classification comparison. Cross-reference **TG-0.7 Quality Assurance Principles** for quality flag standards.[46]

¶10 **Step 12: Attribute Changes to Managed vs. Unmanaged Categories**

¶11 Using ancillary information (e.g., coastal development permits, aquaculture licenses, storm event records), classify detected changes as:

- ¶12 **Managed additions** — restoration projects, afforestation
- ¶13 **Unmanaged additions** — natural colonisation and succession
- ¶14 **Managed reductions** — coastal development, aquaculture conversion, land reclamation
- ¶15 **Unmanaged reductions** — storm damage, erosion, bleaching mortality, natural succession

¶16 This attribution supports the SEEA EA extent account structure requiring distinction between managed and unmanaged changes (SEEA EA paras. 4.14–4.17).[47]

¶17 **Fallback rule where ancillary data are unavailable.** In many lower-capacity country contexts, administrative databases such as aquaculture licenses, coastal development permits, and storm records may be incomplete, delayed, or held by agencies that do not routinely share data with statistical offices. Where ancillary administrative data required for managed/unmanaged attribution are unavailable, compilers should tentatively attribute the change as **unmanaged** and apply data quality code **DQ-Code: AU-unknown** in the metadata accompanying the affected account entry. This code signals that attribution is provisional, not verified against administrative sources. Reclassification of provisionally attributed entries is permissible in subsequent compilation cycles when improved data become available, consistent with SEEA EA revision protocols. Cross-reference **TG-0.7 Quality Assurance Principles** for metadata quality flagging standards.[48]

¶18 **Bleaching-driven loss and the managed/unmanaged distinction.** All loss driven by coral bleaching — including bleaching mortality occurring within marine protected areas or areas subject to active management interventions such as coral gardening, shading trials, or assisted evolution programmes — should be classified as an **unmanaged reduction**, consistent with SEEA EA para.

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4.17. The reduction results from a natural thermal stress process (elevated sea surface temperature), not from a deliberate human decision to reduce extent. The presence of management responses does not alter the classification of the outcome. Compilers should, however, record the presence of active management interventions in a **supplementary narrative note** to support policy interpretation of the account. For further reef-specific guidance on this distinction, see **TG-6.1 Coral Reef Ecosystem Accounting**. [49]

¶19 **Distinguishing gradual trends from acute events.** Where extent change within the accounting period includes both a gradual climate-driven trend (e.g., long-term annual coral cover decline) and an acute disturbance event (e.g., a mass bleaching episode), both components are classified as unmanaged reductions in Table 4.1. However, compilers should document each component separately in supplementary metadata to support policy interpretation. Gradual trends should be documented with trend detection statistics (linear slope, confidence interval, detection period and method). Acute events should be flagged with event date, geographic scope, duration, and linkage to observational records such as NOAA Coral Reef Watch bleaching alert archive data. Cross-reference IPCC AR6 WGII Chapter 3 for the authoritative synthesis of trend and event modes of change in ocean ecosystems. [50]

3.4.5 Delivering the Extent Variables

¶1 **Step 13: Calculate Area Statistics**

¶2 Using the classified imagery and change detection outputs, calculate area in hectares, by ecosystem type, for:

- ¶3 Area at the opening date
- ¶4 Area gained over the period, split managed and unmanaged
- ¶5 Area lost over the period, split managed and unmanaged
- ¶6 Area at the closing date

¶7 These five quantities per ecosystem type, with their accuracy statistics and attribution flags, are what this Circular delivers. Assembling them into the SEEA EA ecosystem extent account (Table 4.1), and applying the accounting identity that reconciles closing area to opening area, is done in **TG-3.1 Asset Accounts** Section 3.5.1.

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¶8 **Co-occurring ecosystem types.** In shallow tropical systems, seagrass meadows frequently grow beneath sparse coral framework, kelp canopies overlie rocky reef substrate, and mangrove pneumatophore zones contain intertidal seagrass. Optical remote sensing assigns a single dominant class to each pixel. The SEEA EA Table 4.1 area accounting structure treats ecosystem types as mutually exclusive spatial units. BSUs must be assigned to a single ecosystem type for extent account purposes. For operational accounts, compilers should assign each BSU to the dominant ecosystem type using the following classification hierarchy: coral reef > seagrass > sandy substrate, following the GET functional group hierarchy (M1.3 > M1.1 > M1.2). Co-occurrence of ecosystem types within a BSU should be documented in supplementary habitat description files and is not double-counted in area statistics. Condition accounts compiled under **TG-3.1 Asset Accounts** Section 3.5.2 can capture co-occurring species presence within a BSU as condition variables without altering extent account totals. [51]

¶9 **Step 14: Document Methods and Metadata**

¶10 Prepare metadata documentation following ISO 19115 geographic metadata standards, including:

- ¶11 Data sources (satellite platforms, dates, scenes)
- ¶12 Classification methods (algorithm, training data, accuracy)
- ¶13 Change detection methods
- ¶14 Coordinate reference system and projection

- ¶15 Known limitations and data quality considerations

¶16 This completes the data production procedure. The delivered area statistics and their metadata are the input to the extent account in **TG-3.1 Asset Accounts** Section 3.5.1,[52] and provide the spatial foundation for the condition and services accounts built on it.

3.5 Bathymetry and Seabed Mapping

¶1 Bathymetric and seabed data provide the essential three-dimensional framework for ocean accounting, particularly for accounts addressing the water column and seabed ecosystems.[53]

3.5.1 Bathymetric Data Sources

¶1 **General Bathymetric Chart of the Oceans (GEBCO)**

¶2 GEBCO provides global bathymetric grids at 15 arc-second resolution (approximately 450m at the equator), integrating multibeam sonar data, satellite altimetry-derived bathymetry, and other sources.[54] The Seabed 2030 project aims to map the entire ocean floor by 2030, which will increase data availability for ocean accounting.

¶3 **Recommended global fallback product.** When national hydrographic survey data is unavailable, GEBCO_2024 (or the most current annual release) is the recommended global fallback for ocean accounts. GEBCO is updated annually under the Seabed 2030 initiative at 15 arc-second resolution (approximately 450m at the equator) and is in the public domain. For European EEZ waters, EMODnet Bathymetry DTM (approximately 115m resolution at 1/16 arc-minute) should be preferred where it provides better coastal coverage than GEBCO. Note that SRTM15+ is a sub-component data source incorporated into the GEBCO_2024 grid and is not an independent alternative product. Compilers should not treat SRTM15+ as a standalone bathymetric source. GEBCO and EMODnet carry an explicit restriction against use for navigation. This restriction does not affect their suitability for ecosystem extent accounting. Compilers should cite the specific GEBCO release year in ISO 19115 metadata.[55]

¶4 **National Hydrographic Office Products**

¶5 National hydrographic offices produce authoritative bathymetric data for territorial waters:

- ¶6 Electronic Navigational Charts (ENCs) in S-57/S-100 formats
- ¶7 Bathymetric attributed grids (BAG files)
- ¶8 Digital terrain models of the seabed

¶9 Countries should establish data sharing arrangements with national hydrographic authorities to access best available bathymetric data.[56]

¶10 **Bathymetric data integration protocol.** When integrating national hydrographic office (NHO) data with GEBCO, compilers should apply the following prioritisation and datum-correction protocol:

1. ¶11 **Always prefer NHO data over GEBCO** where NHO coverage exists for the area, on grounds of higher spatial resolution and greater vertical accuracy.
2. ¶12 **Apply vertical datum correction** before merging sources. NHO Electronic Navigational Charts (ENCs) typically reference chart datum (usually Lowest Astronomical Tide – LAT), whilst GEBCO references mean sea level (MSL). Depths may differ by 1–3m at the tidal range. Apply correction from chart datum to MSL using national tidal models before merging NHO data with GEBCO.
3. ¶13 **Document the coverage boundary** between NHO and GEBCO data in metadata, and note any known depth discontinuities at the merge boundary.[57]

¶14 **Multibeam Echosounder Data**

¶15 High-resolution multibeam data (typically 1–50m resolution) provides:

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- ¶16 Detailed seabed morphology
- ¶17 Substrate classification through backscatter analysis
- ¶18 Identification of seabed features (reefs, sand waves, bedforms)

¶19 Processing multibeam data requires specialised software and expertise but yields the highest quality bathymetric products.

3.5.2 IHO S-100 Data Standards

¶1 The International Hydrographic Organization S-100 Universal Hydrographic Data Model provides the framework for hydrographic and marine geospatial data products, designed for interoperability with GIS systems and aligned with ISO 19100 geographic information standards. Countries should ensure ocean accounting systems can ingest S-100 compliant data products covering bathymetric surfaces, water level information, surface currents, and maritime limits.[58] For the full treatment of S-100 product specifications and broader interoperability standards relevant to ocean accounting, see **TG-4.6 Data harmonisation**.

3.5.3 Seabed Classification

¶1 Seabed substrate classification supports ecosystem extent mapping for benthic habitats:

¶2 **Acoustic Classification Methods**

- ¶3 Multibeam backscatter analysis for substrate hardness
- ¶4 Sub-bottom profiler data for sediment thickness
- ¶5 Acoustic ground discrimination systems

¶6 **Integrated Approaches**

¶7 Combining acoustic data with:

- ¶8 Grab sample analysis
- ¶9 Underwater video surveys
- ¶10 Environmental DNA sampling

¶11 Countries should document seabed classification methods and accuracy assessments in metadata accompanying ocean accounts.[59]

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3.6 Spatial Boundaries for Ocean Accounts

¶1 The spatial boundary of an ocean account is defined in the first instance by jurisdictional limits. Consistent with the SEEA Central Framework, the scope of national ecosystem accounting should extend to the boundary of the exclusive economic zone (EEZ), which under the United Nations Convention on the Law of the Sea (UNCLOS) reaches 200 nautical miles from the baseline (SEEA EA, para. 3.27).[60] Within that jurisdiction, UNCLOS distinguishes several zones — the territorial sea (12 nautical miles), the contiguous zone (24 nautical miles), and the EEZ — each carrying different sovereign rights and obligations that may be relevant for organising ocean accounts by institutional sector. Countries may also have continental shelf rights beyond 200 nautical miles where geological conditions permit, and at the global level, ocean accounts could extend into areas beyond national jurisdiction (ABNJ). The 2023 Agreement under UNCLOS on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement) provides an emerging governance framework for these areas.[61]

¶2 The ecological boundary between "ocean" and "land" is less straightforward. The Millennium Ecosystem Assessment (2005) proposed a working definition of coastal ecosystems as extending 100km inland and to a seaward depth of 50m.[62] This definition is one useful ecological framing — and has been applied in several early ocean accounting pilots — but it is not the SEEA EA standard. The SEEA EA itself leaves the precise inland coastal boundary as a national implementation decision, to be determined according to analytical requirements and the ecosystem types present. For

transitional ecosystems that span the marine-terrestrial-freshwater interface, the IUCN Global Ecosystem Typology provides purpose-built categories: MT1 (Shorelines), MFT1 (Brackish tidal systems including mangroves and saltmarshes), and FM1 (Semi-confined transitional waters such as estuaries and coastal lagoons). Using these classifications can help resolve boundary ambiguities.

¶3 **Discrete non-overlapping extent polygons.** SEEA EA ecosystem extent accounts (Table 4.1) require that all ecosystem type polygons within the Ecosystem Accounting Area be **discrete and non-overlapping**, with areas summing to the total EAA. Fuzzy set membership values from IUCN GET or other classification systems — which may assign a location membership fractions across multiple ecosystem types (e.g., 0.7 in one EFG, 0.3 in another) — cannot be used directly to populate extent account area statistics, as this would cause total area to exceed 100% of the EAA, violating the SEEA EA balance condition. Where transition zone or gradient data are available (e.g., IUCN GET fuzzy membership values, or ecotone width measurements), these should be compiled as a supplementary analytical layer and documented in metadata, but do not alter the discrete non-overlapping operational extent account layer. See Step 13 for the dominant-type assignment hierarchy for co-occurring ecosystems. [63]

¶4 **Estuarine and transitional ecosystem assignment.** Where ocean accounts adjoin terrestrial or freshwater accounts within the same national accounting system, coordination with agencies responsible for those accounts is essential. Estuarine systems grade continuously from freshwater to saltwater, and clear institutional agreements are needed to avoid both double counting and omission of these transitional areas. Compilers should apply the following three-step assignment protocol for estuarine and other transitional ecosystems spanning the ocean-terrestrial-freshwater boundary:

1. ¶5
   Primary delimiter: salinity zone or tidal influence boundary. Use available salinity data or tidal influence mapping to determine the boundary between ocean-assigned and terrestrial/freshwater-assigned areas. Areas within the zone of tidal influence and with salinity indicative of brackish or marine conditions should be assigned to ocean accounts.
2. ¶6
   Fallback where salinity data are unavailable: tidal prism limit. Where salinity zone data is unavailable, use the position of the tidal prism limit — the maximum upstream extent of tidal intrusion during spring tides — as the boundary. Areas landward of the tidal prism limit are assigned to terrestrial or freshwater accounts.
3. ¶7
   Joint metadata documentation. Document the assignment rule applied, the data source used to determine the boundary, and the institutional agreement with terrestrial/freshwater account compilers in joint metadata shared between account compilation teams. For estuarine systems containing both IUCN GET MFT1.2 (Intertidal forests and shrublands — mangroves) and FM1.2 (Estuaries) ecosystem types, the assignment of each component to ocean or freshwater accounts should be separately documented in this joint metadata. [64]

¶8 Countries are encouraged to establish explicit rules for assigning transitional ecosystem types and to disclose these rules in the metadata accompanying the accounts.

3.7 Data Gap Prioritisation

¶1 Table 3.7.1 provides a prioritised overview of common data gaps in remote sensing and geospatial data for ocean accounting. Countries may use this matrix to guide investment decisions and capacity development planning.

¶2 *Table 3.7.1: Data gap prioritisation matrix for ocean accounting geospatial data*

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Data Gap	Policy Relevance	Feasibility	Cost	Priority
Extent mapping (satellite)	High	High	Medium	1
Condition variables	High	Medium	Medium	2
Bathymetric coverage	Medium	Medium	High	3
High-resolution coastal mapping	Medium	High	High	4
Seabed substrate classification	Medium	Low	High	5

¶3 Extent mapping from satellite imagery is the highest-priority gap to address because it combines high policy relevance with high feasibility and moderate cost. Countries beginning ocean accounting programmes are advised to invest first in establishing satellite-based ecosystem extent baselines, which in turn provide the spatial framework for all subsequent accounts compiled under **TG-3.1 Asset Accounts** and the ecosystem-specific circulars in Section 6.

¶4 **Classification crosswalk bridges.** Where a national habitat classification scheme cannot be directly crosswalked to IUCN GET, compilers may use one of two endorsed intermediate classification systems as a crosswalk bridge, consistent with IUCN (2025) standards for cross-referencing ecosystem classifications.[23] For **non-European contexts**: the Coastal and Marine Ecological Classification Standard (CMECS), maintained by NOAA NCEI through a Dynamic Standard Process, has been crosswalked to IUCN GET ecosystem functional groups and provides a common schema to which more than 40 national classification schemes have been crosswalked. For **European contexts**: the EUNIS Marine Habitats Classification (2022 review), published by the European Environment Agency with open tabular crosswalk data, provides crosswalks to IUCN GET, Habitats Directive Annex I, and European Red List of Habitats at classification level 3. All crosswalk tables applied in account compilation must be documented in metadata.

3.8 Quality Assurance for Geospatial Data

¶1 Quality assurance is essential for ensuring the fitness-for-purpose of geospatial data in ocean accounts. Quality assurance procedures should be aligned with the framework established in **TG-0.7 Quality Assurance Principles** and consistent with international geospatial quality standards.[65]

3.8.1 Accuracy Assessment Framework

¶1 All classified geospatial products used in ocean accounts should include documented accuracy assessments:

¶2 **Confusion Matrix Analysis**

¶3 The confusion matrix provides the foundation for accuracy assessment of classified imagery. Countries should evaluate classifications against the dual accuracy criteria (an 80% overall-accuracy threshold and a recommended 75% per-class producer's and user's accuracy target) as specified in Step 8.[66]

¶4 **Ground Reference Data**

¶5 Accuracy assessment requires independent ground reference data:

- ¶6 Field survey data collected using GPS/GNSS positioning
- ¶7 Expert interpretation of high-resolution imagery
- ¶8 Existing authoritative habitat maps
- ¶9 Citizen science and crowdsourced observations (with appropriate quality control)

¶10 Ground reference data should meet the normative sampling requirements specified in Section 2.3 and Step 5 (Olofsson et al. 2014 stratified random sampling framework).[67]

3.8.2 Positional Accuracy

¶1 Horizontal and vertical positional accuracy should be documented for all geospatial data:

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¶2 **Horizontal Accuracy**

- ¶3 Satellite imagery: typically 10–50m for medium resolution sensors
- ¶4 National orthophotography: typically sub-metre
- ¶5 GPS field surveys: sub-decimetre with appropriate techniques

¶6 **Vertical Accuracy**

- ¶7 Bathymetric data: varies from decimetre (multibeam) to metres (satellite-derived)
- ¶8 Digital elevation models: typically 1–10m vertical RMSE
- ¶9 Tidal corrections: essential for integrating datasets from different tidal states

¶10 **Vertical datum standard.** Ocean accounts should use **Mean Sea Level (MSL)** as the primary vertical datum for integrating satellite-derived intertidal and bathymetric data. Imagery used for intertidal ecosystem mapping must be acquired within one hour of Mean Low Water (MLW), or tidal correction must be applied to imagery acquired at other tidal stages. All bathymetric data should be corrected to MSL before integration into account datasets. The tidal model or tide gauge reference used for corrections must be documented in ISO 19115 metadata. [68]

¶11 Countries should ensure vertical datums are clearly documented and consistently applied across ocean accounts.

¶12 **Tidal datum epoch transitions.** In long-term intertidal ecosystem extent time-series accounts spanning multiple decades, tidal datum epoch transitions introduce a source of systematic bias that must be managed. Tidal datums are computed as averages over a defined 19-year epoch to capture the 18.6-year lunar nodal cycle. When the epoch is updated (e.g., NOAA NTDE 1983–2001 to NTDE 2002–2020, or equivalent national epoch revision periods), published datum values shift at tide gauge stations. A compiler using the same nominal datum (e.g., MSL) across a multi-decade time-series may unknowingly compare intertidal extent maps referenced to different physical water levels, introducing a systematic bias in opening-to-closing stock changes for mangroves, saltmarshes, and tidal flats. Where an accounting time-series spans more than one national tidal datum epoch, compilers must:

- ¶13 Document the datum epoch applied to each compilation period in metadata; and
- ¶14 Apply national geodetic datum shift corrections (e.g., NOAA VDatum or the national equivalent) where an epoch transition falls within the accounting time-series, before comparing extent values across the transition.

¶15 Reference the NOAA National Tidal Datum Epoch framework and the IOC GLOSS/PSMSL framework as authoritative references for datum-corrected sea-level time-series. [69]

3.8.3 Temporal Considerations

¶1 Geospatial data quality includes temporal aspects: currency, update frequency, temporal resolution, and seasonal variation. Temporal quality flags follow ISO 19115-1 temporal metadata elements and the quality flag standards in **TG-4.6 Data Harmonisation and Interoperability** §3.1, which provides the full treatment of temporal alignment for multi-source integration.

3.8.4 Data Integration and Interoperability

¶1 For remote sensing products, the key interoperability considerations are coordinate reference system consistency (WGS84 horizontal, MSL vertical as specified in §3.8.2) and the tidal datum corrections addressed in that section. General data format standards (OGC Web Services, GeoPackage, GeoJSON, Cloud Optimized GeoTIFF, NetCDF-CF), metadata standards (ISO 19115/19139), and the full stack of SDMX and OGC interoperability protocols are addressed in full in **TG-4.6 Data Harmonisation and Interoperability** §§3.1–3.6. This section does not repeat that guidance.

3.8.5 GSGF Alignment

¶1 Alignment of ocean accounting data workflows with the five principles of the Global Statistical Geospatial Framework (GSGF) — including the self-assessment tool and institutional readiness assessment — is addressed in **TG-4.6 Data Harmonisation and Interoperability** §3.1 and **TG-4.7 National Data Coordination Architectures**. Remote-sensing-specific GSGF obligations are confined to Outcome item f of this Circular: GSGF Principle 1 (fundamental geospatial infrastructure, including NSO–NGIA coordination) and Principle 4 (statistical-geospatial interoperability, including BSU alignment and coordinate reference system consistency).

4 Worked Example: RS-Derived Extent Change Detection for a Coastal Area

¶1 This worked example demonstrates the compilation of ecosystem extent accounts using satellite remote sensing data for a hypothetical coastal region in Southeast Asia. The example follows the compilation procedure described in Section 3.4 and illustrates the key steps from image acquisition to populated extent accounts.

4.1 Setting and Scope

¶1 **Ecosystem Accounting Area (EAA):** A 2,500 km² coastal area including mangroves, coral reefs, seagrass meadows, and sandy/muddy coastal substrates. The EAA extends from the coastline (high-water mark) to 12 nautical miles offshore (territorial sea limit).

¶2 **Accounting Period:** Calendar years 2019 (opening) to 2024 (closing). A 5-year period is adopted for this example. Data availability constraints of this kind are typical of initial ecosystem accounting compilations.

¶3 **Ecosystem Types:** Following IUCN GET classification:

- ¶4 MFT1.2 Intertidal forests and shrublands (mangroves)
- ¶5 M1.3 Photic coral reefs
- ¶6 M1.1 Seagrass meadows
- ¶7 M1.2 Subtidal sandy substrates

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4.2 Image Acquisition and Preprocessing (Steps 1-3)

¶1 **Opening Date Classification (2019)**

¶2 Selected Sentinel-2 imagery acquired January 2019 (dry season, minimal cloud cover):

- ¶3 Tile: 48MYU
- ¶4 Date: 2019-01-15
- ¶5 Cloud cover: 3%
- ¶6 Products: Level-2A (surface reflectance, atmospherically corrected)

¶7 **Closing Date Classification (2024)**

¶8 Selected Sentinel-2 imagery acquired January 2024 (same season):

- ¶9 Tile: 48MYU
- ¶10 Date: 2024-01-12
- ¶11 Cloud cover: 5%
- ¶12 Products: Level-2A (surface reflectance, atmospherically corrected)

¶13 Preprocessing applied: Cloud masking using Sentinel-2 Scene Classification Layer, water surface glint correction using sun-glint angle, geometric co-registration between dates to ensure pixel-level alignment (RMSE < 0.5 pixel).

¶14 **Phenological note:** January was selected as it corresponds to the dry season in this Southeast Asian context and represents ecologically representative conditions for the ecosystem types mapped. This timing is documented in metadata consistent with the phenological considerations in Step 2.

4.3 Classification and Ecosystem Type Mapping (Steps 4-7)

¶1 **Training Data Collection**

¶2 Collected 850 ground-truth points distributed across ecosystem types:

- ¶3 Mangroves: 250 points (field GPS surveys)
- ¶4 Coral reefs: 200 points (expert interpretation of Planet 3m imagery)
- ¶5 Seagrass: 180 points (combination of field surveys and high-resolution imagery)
- ¶6 Sandy substrate: 220 points (acoustic ground-truth from bathymetric surveys)

¶7 Split: 595 training points (70%), 255 validation points (30%).

¶8 Per-class validation counts: Mangroves 75 points, Coral Reefs 60 points, Seagrass 50 points, Sandy Substrate 70 points. All classes exceed the normative minimum thresholds specified in Section 2.3 (50 points for classes exceeding 1% of mapping area, though these values are illustrative of one compliant dataset, not a prescriptive target).

¶9 **Classification Method**

¶10 Applied random forest classifier with following parameters:

- ¶11 Number of trees: 500
- ¶12 Maximum depth: 15
- ¶13 Minimum samples per leaf: 5
- ¶14 Features: All 10 Sentinel-2 bands at 10m and 20m resolution

¶15 Applied majority filter (3x3 window) to reduce salt-and-pepper noise. Applied minimum mapping unit of 0.25 ha (approximately 28 pixels at 10m resolution).

¶16 **Classification Results**

¶17 Opening date (2019) classification:

Ecosystem Type	Area (hectares)	Percent of EAA
Mangroves	42,500	17.0%
Coral Reefs	15,800	6.3%
Seagrass Meadows	8,200	3.3%
Sandy Substrate	183,500	73.4%
Total	**250,000**	**100.0%**

¶18 Closing date (2024) classification:

Ecosystem Type	Area (hectares)	Percent of EAA
Mangroves	41,850	16.7%
Coral Reefs	14,950	6.0%
Seagrass Meadows	8,100	3.2%
Sandy Substrate	185,100	74.0%
Total	**250,000**	**100.0%**

4.4 Accuracy Assessment (Steps 8-9)

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¶1 **Confusion Matrix (2024 classification)**

	Classified →	Mangrove	Coral Reef	Seagrass	Sandy	Total	Producer's Acc.
Reference ↓							
Mangrove		68	0	2	5	75	90.7%
Coral Reef		1	52	3	4	60	86.7%
Seagrass		3	2	38	7	50	76.0%
Sandy		3	1	4	62	70	88.6%
Total		75	55	47	78	255	
User's Acc.		90.7%	94.5%	80.9%	79.5%		**86.3%**

¶2 Overall Accuracy: 86.3% (220 correct / 255 total) Kappa Coefficient: 0.81

¶3 **Dual accuracy assessment:** Overall accuracy of 86.3% exceeds the 80% minimum. All four classes meet the recommended 75% per-class target for both producer's and user's accuracy, and the classification is fully accepted. Seagrass has the lowest producer's accuracy (76.0%) due to spectral confusion with sandy substrate in optically deeper water where seagrass cover is sparse. This limitation is documented in metadata.

4.5 Change Detection (Steps 10–12)

¶1 **Pre-change-detection QA checklist results:**

- ¶2 BRDF normalisation: Both dates processed as Sentinel-2 Level-2A products with consistent atmospheric correction. BRDF normalisation confirmed.
- ¶3 Phenological matching: Both dates are January acquisitions (dry season). Phenological window confirmed consistent.
- ¶4 MMU consistency: 0.25 ha MMU applied to both date classifications. Consistency confirmed.

¶5 **Change Matrix**

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Opening (2019) → Closing (2024)	Mangrove	Coral Reef	Seagrass	Sandy	Opening Total
Mangrove	40,800	0	150	1,550	42,500
Coral Reef	0	14,950	0	850	15,800
Seagrass	0	0	7,850	350	8,200
Sandy	1,050	0	100	182,350	183,500
Closing Total	41,850	14,950	8,100	185,100	250,000

¶6 **Uncertainty propagation:** For this post-classification comparison, combined change error for the coral reef loss row (Coral Reef → Sandy: 850 ha) is estimated using the sum of per-class omission and commission errors from both date classifications. This produces a documented confidence interval of approximately ±15% on the key change statistics, which is reported as a DQ code in the account metadata. For full uncertainty tables, see metadata documentation.

¶7 **Attribution of Changes**

¶8 Using ancillary data (aquaculture licensing records, coastal development permits, typhoon track data), changes were attributed as follows.

Ecosystem	Change	Area (ha)	Category	Source
Mangroves	Conversion to aquaculture ponds	800	Managed reduction	Aquaculture license database

Ecosystem	Change	Area (ha)	Category	Source
Mangroves	Erosion and storm damage (Typhoon Ketsana, Sept 2022)	750	Unmanaged reduction	Typhoon track records
Mangroves	Transition to seagrass habitat	150	Unmanaged reduction	Classification
Mangroves	Government restoration programme	600	Managed expansion	Forestry department records
Mangroves	Natural colonization (abandoned aquaculture)	450	Unmanaged expansion	Classification
Coral Reefs	Bleaching mortality (March 2023; NOAA CRW DHW > 8)	850	Unmanaged reduction	NOAA Coral Reef Watch
Coral Reefs	Recovery	0	–	Recovery operates over multi-decadal timescales
Seagrass	Sediment burial from coastal construction	350	Unmanaged reduction	Coastal development permits
Seagrass	Natural colonization from sandy substrate	100	Unmanaged expansion	Classification
Seagrass	Colonization of former mangrove areas	150	Unmanaged expansion	Classification

¶9 The coral reef loss is classified as an unmanaged reduction consistent with SEEA EA para. 4.17. The affected area falls within a marine protected area with an active coral gardening programme, which is noted in supplementary metadata for policy interpretation but does not alter the classification. Background trend analysis using the 1990–2024 Landsat archive indicates a separate gradual decline of approximately 0.3% per year in coral cover, and this is documented with trend detection statistics in the supplementary metadata.

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4.6 Delivering the Extent Variables (Steps 13-14)

¶1 **Measured area and area change, 2019-2024**

Measured variable	Mangroves (ha)	Coral Reefs (ha)	Seagrass (ha)	Total (ha)
Area at opening date (2019)	42,500	15,800	8,200	66,500
Area gained – managed	600	0	0	600
Area gained – unmanaged	450	0	250	700
Area lost – managed	800	0	0	800
Area lost – unmanaged	900	850	350	2,100
Area at closing date (2024)	41,850	14,950	8,100	64,900

¶2 Note: These statistics are consistent with the detailed change matrix in Section 4.5. The 150 ha mangrove-to-seagrass transition is recorded as an unmanaged loss for mangroves and an unmanaged gain for seagrass. Co-occurrence of seagrass and coral within reef framework BSUs (observed in approximately 8% of reef BSUs) has been resolved using the dominant-type hierarchy (coral reef > seagrass) and documented in supplementary habitat files.

¶3 This table is the handover point. Arranging these variables as extent account rows, applying the accounting identity, and deriving net change is done in **TG-3.1 Asset Accounts** Section 3.5.1.

4.7 Attribution Quality of the Delivered Variables

¶1 The managed / unmanaged split is the attribution judgement this Circular is responsible for, and its quality should be reported with the variables. In this example the coral loss is attributed entirely to thermal stress and so recorded as unmanaged; the dominant driver of mangrove loss is aquaculture conversion, evidenced by licence records, and so recorded as managed; the 600 ha mangrove gain is evidenced by a restoration programme register. The seagrass loss is attributed to sedimentation from coastal construction on modelled rather than administrative evidence, and carries **DQ-Code: AU-unknown** accordingly.

¶2 The delivered variables and their attribution flags feed **TG-3.1 Asset Accounts** — extent under Section 3.5.1, condition under Section 3.5.2 — and the ecosystem-specific accounts in **TG-6.1** and **TG-6.2**. Reading the resulting account for policy is **TG-1.2 OA and Marine Spatial Planning**.

5 Acknowledgements

¶1 This Circular draws upon the work of the United Nations Expert Group on the Integration of Statistical and Geospatial Information (EG-ISGI), the UN-GGIM Working Group on Marine Geospatial Information, and the SEEA Ecosystem Accounting Technical Committee.

¶2 The guidance incorporates standards developed by the International Hydrographic Organization (IHO), the Open Geospatial Consortium (OGC), and the International Organization for Standardization (ISO TC 211).

¶3 The IUCN Commission on Ecosystem Management Red List of Ecosystems Thematic Group provided the foundation for ecosystem classification recommendations.

¶4 **Authors:** [To be confirmed]

¶5 **Reviewers:** [To be confirmed]

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6 References

¶1 EMODnet (2024). *EMODnet Bathymetry DTM 2024 Release*. European Marine Observation and Data Network. Available at: https://emodnet.ec.europa.eu/en/bathymetry (https://emodnet.ec.europa.eu/en/bathymetry)

¶2 GEBCO (2024). *The GEBCO_2024 Grid*. General Bathymetric Chart of the Oceans. Available at: https://www.gebco.net (https://www.gebco.net)

¶3 International Hydrographic Organization (2023). *S-100 Universal Hydrographic Data Model*, Edition 5.1.0. Monaco: IHO. Available at: https://iho.int/en/s-100-universal-hydrographic-data-model (https://iho.int/en/s-100-universal-hydrographic-data-model)

¶4 IPCC (2006). *Guidelines for National Greenhouse Gas Inventories*, Volume 4: Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds.). Hayama, Japan: IGES.

¶5 IUCN (2025). *Standards, Methods and Guidelines for Cross-Referencing Ecosystem Classifications*. Gland, Switzerland: IUCN.

¶6 Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. and Kingsford, R.T. (eds.) (2020). *The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups*. Gland, Switzerland: IUCN. DOI: https://doi.org/10.2305/IUCN.CH.2020.13.en (https://doi.org/10.2305/IUCN.CH.2020.13.en)

¶7 Millennium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Current State and Trends*, Volume 1, Chapter 19: Coastal Systems. Washington, DC: Island Press.

¶8 NOAA (2024). *National Tidal Datum Epoch (NTDE) 2002–2020 Factsheet*. Silver Spring, MD: NOAA Center for Operational Oceanographic Products and Services. Available at:

https://tidesandcurrents.noaa.gov (https://tidesandcurrents.noaa.gov)

¶9 NOAA NCEI. *Coastal and Marine Ecological Classification Standard (CMECS)*. Available at: https://www.ncei.noaa.gov/products/coastal-marine-ecological-classification-standard (https://www.ncei.noaa.gov/products/coastal-marine-ecological-classification-standard)

¶10 Olofsson, P., Foody, G.M., Herold, M., Stehman, S.V., Woodcock, C.E. and Wulder, M.A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, pp. 42–57.

¶11 Seabed 2030. *The Nippon Foundation-GEBCO Seabed 2030 Project*. Available at: https://seabed2030.org (https://seabed2030.org)

¶12 United Nations (2021). *System of Environmental-Economic Accounting — Ecosystem Accounting*. New York: United Nations. Available at: https://seea.un.org/ecosystem-accounting (https://seea.un.org/ecosystem-accounting)

¶13 United Nations (2022). *Guidelines on Biophysical Modelling for Ecosystem Accounting*. New York: United Nations Department of Economic and Social Affairs, Statistics Division. Available at: https://seea.un.org/ecosystem-accounting/biophysical-modelling (https://seea.un.org/ecosystem-accounting/biophysical-modelling)

¶14 United Nations (2022). *Operational Framework for Integrated Marine Geospatial Information Management (IGIF-H)*. Working Group on Marine Geospatial Information. Available at: https://ggim.un.org/ (https://ggim.un.org/)

¶15 United Nations (2023). *Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction*. New York: United Nations.

¶16 United Nations (2025). *The Global Statistical Geospatial Framework*, Second Edition. New York: United Nations Statistics Division. Available at: https://ggim.un.org/GSGF/ (https://ggim.un.org/GSGF/)

FOOTNOTES

1. ¶1 SEEA EA, para. 3.11-3.12 addresses three-dimensional representation of marine ecosystems and the recommendation that marine ecosystem assets within the continental shelf be delineated based on seabed ecosystem types.
2. ¶2 SEEA EA, para. 3.72 describes the BSU as "a geometrical construct representing a small spatial area" that provides a fine-level data framework. Para. 3.37 requires that BSUs be exhaustive and mutually exclusive.
3. ¶3 Global Statistical Geospatial Framework (GSGF), Second Edition, 2025. The GSGF provides the overarching framework for integrating statistical and geospatial information. Principle 1 addresses fundamental geospatial infrastructure, and Principle 4 addresses interoperability.
4. ¶4 IHO S-100 Universal Hydrographic Data Model provides the framework for hydrographic and marine geospatial data standards.
5. ¶5 SEEA EA Chapter 4 specifies requirements for ecosystem extent accounts requiring spatially explicit delineation of ecosystem types.
6. ¶6 Olofsson, P., Foody, G.M., Herold, M., Stehman, S.V., Woodcock, C.E. and Wulder, M.A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, pp. 42–57. The normative thresholds (50 points per class >1% area, and 30 points for rare classes <1% area) are derived from the sample size requirements and statistical properties discussed in this reference.
7. ¶7 SEEA EA, para. 4.1: "Ecosystem extent is the size of an ecosystem asset. It is usually measured in terms of spatial area."
8. ¶8 Global Mangrove Watch (https://www.globalmangrovewatch.org/ (https://www.globalmangrovewatch.org/)) provides annual mangrove extent maps from 1996 onwards derived from Landsat imagery. The dataset is maintained by Aberystwyth University and supported by multiple international partners.
9. ¶9 Allen Coral Atlas, version 2.0 (2022), available at https://allencoralatlas.org/ (https://allencoralatlas.org/). The Atlas is a partnership between Arizona State University, Vulcan Inc., and multiple coral reef research institutions.
0. ¶10 SEEA EA, Table 4.1 presents the ecosystem extent account structure with opening stock, additions (managed and unmanaged), reductions (managed and unmanaged), and closing stock.
1. ¶11 NOAA Coral Reef Watch provides satellite coral bleaching monitoring products at https://coralreefwatch.noaa.gov/ (https://coralreefwatch.noaa.gov/), including 5km daily sea surface temperature, bleaching alert levels, and degree heating weeks.
2. ¶12 SEEA EA, para. 4.14-4.17 distinguishes managed changes (resulting from deliberate decisions) and unmanaged changes (associated with natural processes, including those influenced by anthropogenic pressures such as climate change).

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3. ¶13 SEEA EA, para. 3.72.
4. ¶14 SEEA EA, para. 3.37.
5. ¶15 GSGF Second Edition, 2025, Principle 3 (Common Geographies) specifies that statistical and geospatial systems should use consistent geographic frameworks across domains to enable integrated analysis. SEEA EA para. 3.72 also addresses BSU alignment requirements.
6. ¶16 Guidelines on Biophysical Modelling for Ecosystem Accounting, Table 8, provides definitions of confusion matrix accuracy metrics.
7. ¶17 SEEA EA, Chapter 5, paras. 5.30-5.40, presents the SEEA Ecosystem Condition Typology (ECT) with six classes organised into abiotic, biotic, and landscape-level characteristics.
8. ¶18 ALOS PALSAR-2 is a JAXA L-band SAR sensor with mangrove biomass saturation at approximately 200 Mg/ha, consistent with published literature on L-band backscatter saturation. The ESA Biomass Mission (P-band SAR) was launched in April 2025 and is operational. P-band radar penetrates dense forest canopies more effectively than C- or L-band, extending the biomass estimation range beyond that achievable with current operational sensors.
9. ¶19 SEEA EA, para. 5.19.
0. ¶20 SEEA EA (2021), Appendix A3.2: "The ecosystem type reference classification used in the SEEA EA is based on the IUCN Global Ecosystem Typology 2.0." The GET provides the internationally agreed reference for ecosystem functional group definitions used across ocean accounts.
1. ¶21 Keith, D.A., Ferrer-Paris, J.R., Nicholson, E. and Kingsford, R.T. (eds.) (2020). *The IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups*. Gland, Switzerland: IUCN. DOI: 10.2305/IUCN.CH.2020.13.en (https://doi.org/10.2305/IUCN.CH.2020.13.en). Accessible at iucnget.org (https://www.iucnget.org).
2. ¶22 SEEA EA (2021), paras. 3.22–3.24: "Where countries have existing national ecosystem classifications… the correspondence between national types and GET EFGs should be documented." The crosswalk enables comparisons across national accounts.
3. ¶23 NOAA NCEI. *Coastal and Marine Ecological Classification Standard (CMECS)*. FGDC-endorsed standard (2012) with ongoing updates through a Dynamic Standard Process. More than 40 national marine classification schemes are crosswalked to CMECS, which functions as a bridge to IUCN GET. EEA (2022). *EUNIS Marine Habitat Classification Review 2022*. Open crosswalk tables to IUCN GET available at level 3. IUCN (2025). *Standards, Methods and Guidelines for Cross-Referencing Ecosystem Classifications*. Gland, Switzerland: IUCN. This provides the formal protocol governing crosswalk quality and documentation.
4. ¶24 Guidelines on Biophysical Modelling for Ecosystem Accounting, Chapter 4, provides detailed guidance on remote sensing for ecosystem extent mapping.
5. ¶25 The tiered approach to biophysical modelling (Tier 1, 2, 3) is defined in the Guidelines on Biophysical Modelling for Ecosystem Accounting, Section 3.1.3.
6. ¶26 USGS Landsat Science. The Landsat programme provides the longest continuous satellite record of Earth observation data.
7. ¶27 FAO FAOSTAT Land Cover domain includes SEEA-MODIS land cover products crosswalked to SEEA classification.
8. ¶28 Commercial imagery costs should be evaluated against alternative approaches including aerial survey and national satellite programmes.
9. ¶29 Copernicus Sentinel-2 User Guide. Available at: https://sentiwiki.copernicus.eu/web/s2-mission (https://sentiwiki.copernicus.eu/web/s2-mission)
0. ¶30 European Space Agency, Sentinel-1 SAR User Guide. SAR requires specialized processing software such as ESA SNAP or commercial alternatives.
1. ¶31 ESA / Copernicus. *Sentinel-2 Level-2A Product Specification*. The Level-2A product provides atmospherically corrected surface reflectance at 10m resolution and includes the Scene Classification Layer (SCL) used for cloud masking in compositing workflows.
2. ¶32 Satellite-derived bathymetry is most reliable in clear water conditions with depths less than 25m and requires calibration with in-situ measurements.
3. ¶33 IHO S-44 (Standards for Hydrographic Surveys), 6th edition (2020), Order 1b, specifies bathymetric accuracy using the Total Vertical Uncertainty (TVU) formula $TVU = \sqrt{(a^2 + (b \times d)^2)}$, where for Order 1b a = 0.5 m and b = 0.013. At 20 m depth TVU ≈ 0.56 m. This TVU formula is referenced here as the minimum fitness-for-purpose threshold for SDB used in ocean accounts. It does not imply that SDB can substitute for dedicated hydrographic surveys for navigational purposes.
4. ¶34 Google Earth Engine provides access to over 80 petabytes of geospatial data and runs analyses on Google's cloud infrastructure. See Gorelick, N. et al. (2017), 'Google Earth Engine: Planetary-scale geospatial analysis for everyone', *Remote Sensing of Environment*, 202, pp. 18–27.
5. ¶35 The Copernicus Data Space Ecosystem (CDSE) replaced the earlier Data and Information Access Services (DIAS) in 2023. CDSE provides free and open access to Copernicus Sentinel data with integrated processing tools. See https://dataspace.copernicus.eu/ (https://dataspace.copernicus.eu/)
6. ¶36 Digital Earth Australia is managed by Geoscience Australia and provides analysis-ready satellite data for the Australian continent and coastal waters. See https://www.dea.ga.gov.au/ (https://www.dea.ga.gov.au/)
7. ¶37 UNEP-WCMC maintains the World Database on Protected Areas, the Global Distribution of Coral Reefs, and the Global Distribution of Seagrasses, among other reference datasets. See https://www.unep-wcmc.org/ (https://www.unep-wcmc.org/)

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8. ¶38 IUCN GET v2.0/2.1: MFT1.2 covers intertidal forests and shrublands including mangroves. M1.3 covers photic coral reefs. Allen Coral Atlas geomorphic zones (reef flat, reef crest, fore-reef slope, back reef, lagoon, shallow lagoon, terrestrial reef flat, sheltered reef slope, outer reef flat, reef perimeter) collectively describe the GET M1.3 functional group. Global Mangrove Watch uses binary mangrove/non-mangrove classification that maps directly to GET MFT1.2.
9. ¶39 Flanders Marine Institute (VLIZ). (2023). *Maritime Boundaries Geodatabase*, version 12. Available at https://www.marineregions.org/ (https://www.marineregions.org/). The database provides EEZ boundaries, territorial seas, and other maritime limits derived from national and international sources.
0. ¶40 Guidelines on Biophysical Modelling Section 4; SEEA EA para. 4.1. See also Section 3.3.1 on Sentinel-2 compositing capabilities. Phenological timing decisions at first-compilation baseline stage create systematic biases that propagate into all subsequent change detection calculations, making this a disproportionately important decision despite its context-dependent nature.
1. ¶41 Olofsson, P., Foody, G.M., Herold, M., Stehman, S.V., Woodcock, C.E. and Wulder, M.A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote Sensing of Environment*, 148, pp. 42–57. See also Guidelines on Biophysical Modelling, Table 8.
2. ¶42 Random forest classification creates decision trees based on training data, then assigns subsequent pixels based on spectral signatures. The method is robust to noise and handles nonlinear relationships effectively.
3. ¶43 Guidelines on Biophysical Modelling, Table 8, provides definitions of confusion matrix accuracy metrics consistent with international remote sensing standards.
4. ¶44 IPCC (2006). *Guidelines for National Greenhouse Gas Inventories*, Volume 4 (Agriculture, Forestry and Other Land Use), Chapter 3, Annex 3A.2.4 ("Evaluation of mapping accuracy"): inventory compilers should estimate map accuracy category by category from a confusion matrix. The Guidelines do not set a numerical overall-accuracy threshold; the 80% figure is a mapping convention adopted by this Circular.
5. ¶45 CEOS WGCV LPV (2025). *Land Cover and Change Map Accuracy Assessment Protocol*. Committee on Earth Observation Satellites Working Group on Calibration and Validation. BRDF artefacts are a documented systematic bias in multi-temporal classification comparison.
6. ¶46 SEEA EA Table 4.1; Guidelines on Biophysical Modelling Section 4. The uncertainty propagation formula (combined change error = sum of per-class omission and commission errors from both date classifications) provides a conservative upper-bound estimate consistent with the error propagation properties of post-classification comparison.
7. ¶47 SEEA EA, para. 4.14–4.17.
8. ¶48 SEEA EA paras. 4.14–4.17; TG-0.7 Quality Assurance Principles for DQ-Code standards and quality flag metadata requirements. The DQ-Code AU-unknown is adopted consistently with TG-0.7 quality reporting norms.
9. ¶49 SEEA EA, para. 4.17: "Unmanaged changes in ecosystem extent include those associated with natural processes, including those that are associated with anthropogenic pressures such as climate change." For bleaching-driven loss specifically, the reduction originates in natural thermal stress regardless of management context. See TG-6.1 Coral Reef Ecosystem Accounting for further reef-specific guidance.
0. ¶50 IPCC AR6 WGII (2022). Chapter 3: Oceans and Coastal Ecosystems and their Services. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Cambridge University Press. NOAA Coral Reef Watch bleaching alert archive: https://coralreefwatch.noaa.gov (https://coralreefwatch.noaa.gov). From January 2023 to September 2025, bleaching-level heat stress affected approximately 84.4% of global coral reef area, demonstrating the scale at which acute events now operate as near-permanent stressors superimposed on long-term decline trends.
1. ¶51 IUCN GET functional groups M1.3 (Coral reefs) and M1.1 (Seagrass meadows) are frequently co-located in shallow tropical waters. The dominant-type hierarchy (coral reef > seagrass > sandy substrate) follows the ecological significance ordering of GET functional groups for extent accounting purposes. SEEA EA Table 4.1 structure requires non-overlapping area statistics summing to total EAA.
2. ¶52 SEEA EA, Table 4.1.
3. ¶53 Operational Framework for Integrated Marine Geospatial Information Management (IGIF-H) emphasizes the importance of integrating bathymetric data into marine spatial frameworks.
4. ¶54 GEBCO, the General Bathymetric Chart of the Oceans, provides the most complete global bathymetric dataset. The Seabed 2030 project aims for complete ocean floor mapping by 2030. As of 2024, 26.1% of the global seabed is mapped from direct measurement.
5. ¶55 GEBCO (2024). *The GEBCO_2024 Grid*. GEBCO is updated annually under the Seabed 2030 initiative. GEBCO_2024 incorporates SRTM15+ v2.6 as a base layer and integrates EMODnet and national data contributions. EMODnet (2024). *EMODnet Bathymetry DTM 2024 Release*. Both GEBCO and EMODnet carry explicit restrictions against use for navigation. This does not affect their suitability for ecosystem extent accounting.
6. ¶56 National hydrographic offices typically produce authoritative bathymetric data under mandate from national governments.
7. ¶57 IHO S-100 series standards address interoperability of hydrographic data products. For vertical datum conversion protocols, compilers should consult national geodetic authority guidance and appropriate tidal model documentation.
8. ¶58 IHO S-100, Edition 5.1.0, provides the contemporary hydrographic geospatial data standard aligned with ISO 19100 series. Relevant product specifications include S-102 (Bathymetric Surface — gridded bathymetric data products), S-104 (Water Level Information — tidal and non-tidal water levels), S-111 (Surface Currents — ocean surface current data), and S-121 (Maritime Limits and Boundaries — jurisdictional boundaries). S-100 Part 8 specifies imagery

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and gridded data formats including bathymetric surfaces. See TG-4.6 for full treatment of these and related geospatial interoperability standards.

9. ¶59 Seabed classification methods should be documented in metadata following ISO 19157 data quality standards.
0. ¶60 SEEA EA, para. 3.27: "Consistent with the scope of the SEEA Central Framework, the scope of national jurisdictions for ecosystem accounting should include all ecosystems across the terrestrial, freshwater and marine realms to the boundary of the exclusive economic zone (EEZ)." See also UNCLOS Articles 55–75 on the EEZ regime.
1. ¶61 The BBNJ Agreement, adopted in June 2023, establishes a legal framework for the conservation and sustainable use of marine biological diversity in areas beyond national jurisdiction. It provides mechanisms for area-based management tools and environmental impact assessments that could inform future global-level ocean accounts.
2. ¶62 Millennium Ecosystem Assessment (2005), *Ecosystems and Human Well-being: Current State and Trends*, Volume 1, Chapter 19. The 100km/50m definition was adopted as an operational boundary for the assessment's coastal chapter, not as a universal standard.
3. ¶63 IUCN (2020). *Global Ecosystem Typology 2.0*. The fuzzy set membership approach assigns ecosystem locations fractional membership across multiple EFGs to represent ecological gradients. SEEA EA (2021) Table 4.1 structure is confirmed to require non-overlapping area statistics summing to total EAA. A supplementary gradient layer approach is consistent with both SEEA EA structure and standard landscape ecology practice for ecotone zones.
4. ¶64 SEEA EA paras. 3.22-3.30: "national implementations should document assignment rules for transitional areas." Para. 3.28 specifically addresses coordination where administrative boundaries partition contiguous ecosystem areas. IUCN GET functional groups MFT1.2 (mangroves) and FM1.2 (estuaries) confirmed as appropriate categories for the coastal-freshwater transitional zone.
5. ¶65 TG-0.7 Quality Assurance Principles provides the overarching quality framework for ocean accounts.
6. ¶66 Guidelines on Biophysical Modelling, Table 8, provides definitions of confusion matrix accuracy metrics.
7. ¶67 Olofsson et al. (2014), op. cit. Stratified random sampling designed for minority-class accuracy is essential in marine habitat mapping where target ecosystem types may cover less than 5% of the mapping area.
8. ¶68 IHO S-104 (Water Level Information for Surface Navigation) provides the framework for tidal water level data products referenced in tidal correction workflows.
9. ¶69 NOAA (2024). *National Tidal Datum Epoch (NTDE) 2002–2020 Factsheet*. NOAA NTDE is updated when MSL shifts by 0.10 ft (approximately 0.03 m) at the national gauge network. Transition from the 1983–2001 NTDE to the 2002–2020 NTDE is confirmed and in progress. IOC/PSMSL. *Global Sea Level Observing System (GLOSS)*. The IOC GLOSS framework and PSMSL dataset provide the international standard for datum-corrected sea-level time-series. NOAA VDatum is the geodetic transformation tool for the United States, and national equivalents exist in other jurisdictions.

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Survey Methods for Ocean Economic Activity

Provides guidance on survey methods for collecting data on ocean economic activity.

Version 0.7.0 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on survey methods for collecting data on ocean economic activity. Readers will understand how to design and implement business surveys targeting ocean-related establishments, conduct household surveys capturing ocean-related employment and consumption, apply appropriate sampling designs for the ocean economy, and ensure quality in survey-based ocean data. By applying this guidance, statistical offices can generate reliable estimates of the ocean economy's contribution to employment, production, and income that are suitable for integration with broader national accounts frameworks and ocean accounting systems. These survey methods support three principal decision use cases: ocean economy measurement for compiling the accounts described in TG-3.3 Economic Activity Relevant to the Ocean and TG-2.5 Structure and Function of the Ocean Economy, employment surveys for deriving labour market indicators under TG-3.3 Economic Activity Relevant to the Ocean and TG-2.5 Structure and Function of the Ocean Economy, and tourism expenditure surveys for measuring coastal and marine tourism's economic contribution. The sampling designs in Section 3.3 and quality assurance procedures in Section 3.4 align with the overarching quality framework established in TG-0.7 Quality Assurance. Where survey-based approaches intersect with administrative data, readers should also consult TG-4.3 Administrative Data Sources for guidance on integration strategies. Key terms introduced here are defined in TG-0.6 Glossary.

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ABOUT THIS CIRCULAR

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¶1 **Framework Position**

¶2 TG-4.2 sits within Section 4 (Data Methods). It owns the survey instrument for ocean economic activity: the business and household frames, stratification and sample allocation, questionnaire content, non-response and validation, and the estimates and sampling errors those designs deliver — output, employment, value added and ocean share by industry. It does not own the tables those estimates enter. The supply and use table structure and the industry classification are **TG-3.3 Economic Activity Relevant to the Ocean**; the ocean economy indicators derived from them are **TG-2.5 Structure and Function of the Ocean Economy**.

1. Outcome

¶1 This Circular provides guidance on survey methods for collecting data on ocean economic activity. Readers will understand how to design and implement business surveys targeting ocean-related establishments, conduct household surveys capturing ocean-related employment and consumption, apply appropriate sampling designs for the ocean economy, and ensure quality in survey-based ocean data. By applying this guidance, statistical offices can generate reliable estimates of the ocean economy's contribution to employment, production, and income that are suitable for integration with broader national accounts frameworks and ocean accounting systems.

¶2 These survey methods support three principal decision use cases: ocean economy measurement for compiling the accounts described in **TG-3.3 Economic Activity Relevant to the Ocean** and **TG-2.5 Structure and Function of the Ocean Economy**, employment surveys for deriving labour market indicators under **TG-3.3 Economic Activity Relevant to the Ocean** and **TG-2.5 Structure and Function of the Ocean Economy**, and tourism expenditure surveys for measuring coastal and marine tourism's economic contribution. The sampling designs in Section 3.3 and quality assurance procedures in Section 3.4 align with the overarching quality framework established in **TG-0.7 Quality Assurance**. Where survey-based approaches intersect with administrative data, readers should also consult **TG-4.3 Administrative Data Sources** for guidance on integration strategies. Key terms introduced here are defined in **TG-0.6 Glossary**.

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2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** — provides the conceptual framework and key components of Ocean Accounts, including the relationship between environmental and economic accounting frameworks that survey data are designed to populate.
- ¶3 **TG-0.2 Overview of Relevant Statistical Standards** — establishes the statistical classification standards, including ISIC, that underpin the industry identification and coding procedures described in this Circular.
- ¶4 **TG-0.7 Quality Assurance** — establishes the quality framework governing all ocean accounting data, including the principles of accuracy, coherence, and fitness-for-use that guide the survey design and quality assurance procedures described in this Circular.
- ¶5 **TG-3.3 Economic Activity Relevant to the Ocean** — defines the industry scope of ocean accounts and the classification framework that determines which industries require ocean share estimation and how survey results are integrated into account tables.

3. Guidance Material

¶1 Survey methods are central to measuring the ocean economy. Whilst administrative data sources are valuable, surveys provide the detailed information required to measure economic activity across ocean-related industries, capture employment characteristics, and understand household consumption patterns linked to the ocean. This Circular addresses business surveys (Section 3.1), household surveys (Section 3.2), sampling design considerations (Section 3.3), and quality assurance procedures specific to survey data (Section 3.4). For guidance on data quality considerations applicable across all ocean accounting work, see **TG-0.7 Quality Assurance**.

¶2 Data needs for ocean accounting span multiple domains. Each requires different survey instruments and sampling approaches. Table 3.0 summarises the primary survey types used to collect data on key ocean variables, the sampling frames from which respondents are drawn, and the principal variables of interest.

¶3 *Table 3.0: Ocean data survey type matrix*

Data Need	Primary Survey Type	Sample Frame	Key Variables	Used In
Ocean GVA	Business surveys	Enterprise register	Output, costs, employment	TG-2.5, TG-3.3
Fish catch	Catch surveys	Vessel register	Species, weight, location	TG-3.3
Marine recreation	Visitor surveys	Tourism statistics	Visits, expenditure, activities	TG-2.5
Household dependence	Household surveys	Census	Income, consumption, assets	TG-2.3
Employment	Labour force surveys	Household sample	Jobs, hours, wages	TG-3.3, TG-2.5

3.1 Business Surveys

¶1 Business surveys are essential for measuring the production, employment, and value added of establishments engaged in ocean-related economic activities. The design of business surveys for ocean accounting builds upon established practices in economic statistics whilst addressing the specific characteristics of ocean industries.

The role of business registers

¶1 The statistical business register is the foundation for business surveys targeting ocean industries. A business register is a central listing, usually maintained by the national statistical office or taxation authority, that contains information on all establishments and enterprises within an economy[1]. For each unit, the register typically records industry classification, geographic location, employment size, turnover, and ownership characteristics[2].

¶2 The *UN Guidelines on Statistical Business Registers* provides best practices for the development and maintenance of business registers[3]. For ocean accounting purposes, the business register serves three functions, summarised in Table 3.1.1 below.

Function	Description
Frame population	Identifying the universe of ocean-related establishments from which samples can be drawn.
Stratification variables	Providing size and location information for designing efficient samples.
Auxiliary information	Supplying data for non-response adjustment and estimation.

¶3 Within the structure of a business register, establishments classified to ocean-relevant industries can be identified using the International Standard Industrial Classification (ISIC)[4]. For the authoritative enumeration of ocean-relevant ISIC classes and the survey-approach treatment for each (full

coverage vs. ocean-share supplementary questions), compilers should consult **TG-3.3 Economic Activity Relevant to the Ocean**. For guidance on how these classifications are applied within ocean accounting more broadly, see **TG-0.2 Overview of Relevant Statistical Standards** and **TG-4.6 Data harmonisation** [5].

¶4 The ocean-relevant classes cited here reflect ISIC Revision 4, which remains the current operational classification for most national statistical systems. ISIC Revision 5 was endorsed by the UN Statistical Commission in March 2024 with national implementation expected from 2027. Rev.5 introduces structural changes to the classification of fishing and aquaculture activities and adds new categories for renewable energy generation that are directly relevant to offshore wind and wave power. Compilers currently using ISIC Rev.4 should begin mapping their ocean-relevant industry codes to Rev.5 equivalents using the UN correspondence tables published alongside the Rev.5 classification. In the transition year, run parallel coding for ocean-relevant ISIC classes using dual-coded questionnaires or post-coding via the correspondence table, and publish a methodological note documenting the break point and its effect on ocean economy aggregates. Survey-approach treatment applies equivalently to Rev.4 and Rev.5 equivalent codes. See **TG-0.2 Overview of Relevant Statistical Standards** for further guidance on managing classification transitions [6].

Ocean share estimation for partially ocean-related industries

¶1 Beyond the directly identifiable core ocean industries (see TG-3.3), many establishments have partial ocean-related activity that cannot be captured through industry classification alone. For example, a construction company may undertake both land-based and marine construction projects. For such partially ocean-related industries, supplementary survey questions are required to determine the ocean share of economic activity [7].

¶2 When estimating ocean shares, compilers should apply the following standards:

- ¶3 **Inclusion threshold:** Establishments where the self-reported ocean share is less than 5% of total activity, and whose industry is not a core ocean industry, may be excluded from ocean accounts. This threshold should be documented in metadata.
- ¶4 **Administrative validation:** Self-reported ocean shares should be cross-checked against administrative data where available (landing receipts, maritime licences, port records) to assess plausibility.
- ¶5 **Metadata documentation:** Ocean share ratios must be recorded in metadata and reviewed across survey cycles for stability. Unexplained shifts in ratios between cycles should trigger follow-up with respondents.
- ¶6 **Geographic sub-stratification:** Ocean share ratios should be estimated separately for geographically stratified sub-groups where there is reason to believe that coastal and non-coastal establishments within the same ISIC class have substantially different ocean shares (see Section 3.3 for stratification guidance).

¶7 For the classification framework that determines which industries fall within the scope of ocean accounts and which require ocean share estimation, see **TG-3.3 Economic Activity Relevant to the Ocean** [8].

Geographic scope of ocean economy surveys

¶1 The geographic scope of ocean economy surveys follows the economic territory of the compiling country as defined in the System of National Accounts (SNA residency principle), not the physical location of operations. Business surveys must therefore capture all marine economic activity by resident establishments regardless of where in the ocean that activity occurs, including operations in the domestic Exclusive Economic Zone (EEZ), foreign EEZs under access agreements, and the high seas.

¶2 Surveys should include a supplementary geographic breakdown variable distinguishing:

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- ¶3 Domestic EEZ operations
- ¶4 Foreign EEZ operations (under access agreement)
- ¶5 High-seas operations

¶6 This breakdown supports analytical use of ocean accounts in trade, access agreement, and international governance contexts without altering the residency-based aggregate totals. For the spatial scope framework governing ocean accounts, see **TG-0.1 General Introduction to Ocean Accounts**[9].

Survey design for tourism industries

¶1 The tourism sector presents particular challenges for ocean accounting because tourism is defined by the characteristics of the visitor, not by a distinct set of industries[10]. The *International Recommendations for Tourism Statistics 2008* (IRTS 2008) and the *Statistical Framework for Measuring the Sustainability of Tourism* (SF-MST) provide guidance on survey methods for tourism establishments[11].

¶2 Within the structure of a business register, establishments classified as tourism industries can be assessed using variables such as industry class, size in terms of turnover or employment, employment characteristics, ownership (resident or non-resident), and legal entity type[12]. For coastal and marine tourism specifically, geographic location becomes a determining variable. Establishments should be flagged as "coastal" using the following operational criterion: establishments located within a nationally defined coastal zone, or where no such zone exists, within 10 km of the mean high-water line consistent with SEEA-Ocean spatial boundary guidance. This criterion should be documented in metadata and applied consistently across survey cycles to preserve time-series comparability. Cross-reference **TG-0.2 Overview of Relevant Statistical Standards** for spatial boundary standards[13].

¶3 The SF-MST framework provides the basis for compiling thematic and extended accounts for tourism that integrate environmental dimensions. Coastal and marine tourism measurement within ocean accounts should draw on the SF-MST methodology for defining tourism industries and measuring their economic contribution. Where countries develop dedicated ocean tourism accounts, the survey instruments described in this section supply the primary data inputs. For the broader framework within which tourism data are organised, see **TG-3.3 Economic Activity Relevant to the Ocean**.

¶4 Generalised annual economic surveys typically provide information on the number of establishments classified by industry, output by source of revenue, intermediate consumption, employment and compensation of employees, and investment[14]. Tourism-specific surveys may nonetheless be required to capture the share of output attributable to visitors and to distinguish between domestic, inbound, and outbound tourism expenditure.

Survey content for ocean industries

¶1 Business surveys targeting ocean industries should collect the following categories of information:

¶2 **Economic variables:**

- ¶3 Output/turnover by product type
- ¶4 Intermediate consumption by category
- ¶5 Compensation of employees
- ¶6 Gross fixed capital formation
- ¶7 Inventories

¶8 **Employment variables:**

- ¶9 Number of jobs (full-time equivalent)

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- ¶10 Employment by occupation
- ¶11 Employment by sex
- ¶12 Casual and seasonal employment patterns

¶13 **Ocean-specific variables:**

- ¶14 Share of activity directly ocean-related
- ¶15 Geographic location of operations (including at-sea activities and geographic breakdown per Section 3.1 above)
- ¶16 Type of marine resources used or accessed
- ¶17 Environmental management practices

¶18 The *Tourism Satellite Account: Recommended Methodological Framework 2008* (TSA:RMF 2008) provides a template for organising data on tourism industries that can be adapted for broader ocean economy thematic and extended accounting [15] . Table 5 of the TSA:RMF records production by tourism industries. That table details the tourism characteristic products produced by each industry and summary measures of economic performance. For detailed guidance on compiling ocean economy accounts, see **TG-3.3 Economic Activity Relevant to the Ocean**.

Informal economy considerations

¶1 In many countries, an important contribution to ocean economic activity comes from the informal economy where there is no registration of economic units [16] . Small-scale fisheries, informal coastal tourism services, and subsistence activities may be economically significant but are typically not captured in business registers. Conceptually, informal activity and the economic units involved (commonly households) are within the measurement scope, but in practice their inclusion in statistics may not be possible through conventional business surveys [17] .

¶2 Where informal ocean activities are significant, compilers should apply the following minimum standards:

- ¶3 **Estimation requirement:** Where informal ocean activity is estimated to constitute more than 10% of total ocean activity in the compiling country, it must be estimated rather than simply excluded. Omission without estimation in this case would materially understate the ocean economy aggregate.
- ¶4 **Combination methods:** For countries where direct measurement is not feasible, recommended approaches include ratio expansion from area survey data (e.g., landing site surveys grossed to the national fleet) and cross-validation with FAO small-scale fisheries datasets.
- ¶5 **Disclosure requirement:** Where informal sector coverage is below 80% of estimated total ocean activity, a mandatory metadata flag must be included: "Informal sector partially excluded — estimated coverage [X]%." This flag ensures that users of ocean accounts can assess comparability across countries.

¶6 For countries where small-scale fisheries constitute a large share of ocean activity, complementary data collection approaches that may be used alongside or instead of conventional business surveys include:

- ¶7 Household surveys with questions on informal economic activity (see Section 3.2)
- ¶8 Area-based surveys at landing sites, ports, and coastal markets
- ¶9 Key informant interviews with industry associations and cooperatives
- ¶10 Administrative data from fishing licences and vessel registrations [18]

3.2 Household Surveys

¶1 Household surveys provide essential data for ocean accounting that cannot be obtained from business surveys or administrative sources. They capture the demand perspective of ocean eco-

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nomic activity, including household consumption of ocean-related goods and services, employment characteristics of workers in ocean industries, and household dependence on ocean resources.

Labour force surveys

¶1 Household labour force surveys are an important data source that can in principle cover the entire population of a country, all industries, and all categories of workers, including the self-employed and casual workers [19]. They can capture economic activity in both formal and informal sectors, as well as informal employment arrangements that are common in many ocean industries, particularly fisheries and coastal tourism [20].

¶2 Labour force surveys collect data from individuals and thus provide information on persons who may be employed in more than one job (multiple-job holders) and in different industries [21]. Multiple job-holding is particularly relevant for the ocean economy, where seasonal patterns may lead workers to combine ocean employment with other activities throughout the year.

¶3 For ocean accounting, labour force surveys can provide estimates of:

- ¶4 Total employment in ocean industries (using ISIC-coded occupation and industry data)
- ¶5 Employment characteristics including hours worked, earnings, and job tenure
- ¶6 Self-employment and casual work patterns
- ¶7 Multiple job-holding across ocean and non-ocean sectors
- ¶8 Informal employment in ocean-related activities

¶9 The collection of data on employment in the tourism industries should be integrated in the regular national statistical system [22]. By its nature, employment in tourism industries can be undertaken either in paid employment or self-employment, and it is unlikely that a complete picture can be obtained from a single statistical source.

¶10 Where labour force surveys do not provide sufficient ISIC detail to isolate ocean employment, compilers should apply a tiered approach:

1. ¶11 **4-digit ISIC available:** Use ISIC codes directly to identify ocean industries (e.g., 0311 Marine fishing vs. 0312 Freshwater fishing; 5011 Sea and coastal passenger transport vs. 5021 Inland passenger water transport).
2. ¶12 **2-digit ISIC only:** Use ISCO-08 occupational codes as a proxy, applying the tiered approach described in the labour force surveys subsection above (ISCO 6221, 8350, 3151). These codes capture the majority of directly ocean-dependent occupations even where industry coding is insufficient.
3. ¶13 **Neither available:** Design a dedicated ocean employment module for periodic attachment to the labour force survey. The module should include industry and occupation questions at sufficient detail to isolate ocean-related work [23].

Household consumption surveys

¶1 Household budget surveys or consumption expenditure surveys provide data on household purchases of ocean-derived products. Standard household budget survey product classification systems (COICOP 01.1.4 Fish and seafood) do not separate marine from freshwater species. To disaggregate ocean-related consumption:

- ¶2 **Direct survey disaggregation:** Include a question in the HBS module asking whether fish purchased was marine (sea-caught or sea-farmed) or freshwater (lake, river, or freshwater-farmed). This question may be asked at the point of purchase recall or as a species-identification supplement.
- ¶3 **Supply-side ratio method:** Where direct survey disaggregation is not feasible, construct post-hoc marine/freshwater disaggregation ratios using supply-side data, specifically national catch composition statistics and trade records showing the marine share of total fish supply. Apply these ratios to COICOP 01.1.4 aggregate consumption figures.

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- ¶4 **COICOP mapping:** The marine share of COICOP 01.1.4 should be documented in metadata. Marine products also appear in COICOP 01.1.9 (other food products) for processed marine items and COICOP 09.1.4 (recreational and sporting goods) for marine recreational equipment. The COICOP marine product codes cover supplements, recreational goods, and tourism services as listed in the codes above. [24]

Domestic tourism surveys

¶1 Household surveys based on a stratified sample using spatial, demographic, and socio-economic criteria can be efficient and suitable instruments for measuring domestic tourism activity and related expenditure [25]. They can provide information on both same-day and overnight visitors to coastal and marine areas.

¶2 Household surveys make it possible to observe round trips taken by visitors, which gives a fuller view of tourism behaviour than surveys conducted at the destination [26]. For ocean accounting, household tourism surveys can capture:

- ¶3 Trips to coastal and marine destinations
- ¶4 Expenditure on ocean-related tourism activities (boat trips, diving, beach recreation)
- ¶5 Consumption of ocean-derived products (seafood at restaurants, marine souvenirs)
- ¶6 Time spent in marine and coastal environments

¶7 Sample size and design are strongly related to the significance and accuracy of the variables to be estimated. Two issues need consideration when designing domestic surveys to analyse coastal and marine tourism: the unequal distribution of such tourism over the national territory and the high degree of heterogeneity of the population in terms of tourism behaviour [27].

Survey instruments for household surveys

¶1 For household surveys targeting ocean-related topics, questionnaire design should consider:

¶2 **Trip-based modules** (for tourism surveys):

- ¶3 Identification of coastal/marine destinations
- ¶4 Purpose and duration of trips
- ¶5 Transport modes including water transport
- ¶6 Accommodation types in coastal areas
- ¶7 Expenditure categories with ocean-specific detail

¶8 **Employment modules** (for labour force surveys):

- ¶9 Industry of employment with sufficient detail to identify ocean sectors (see tiered approach above)
- ¶10 Occupation with detail on fishing, seafaring, and marine occupations (using the ISCO codes specified in the tiered approach above: 6221, 8350, 3151)
- ¶11 Location of work including at-sea activities
- ¶12 Seasonality and casualness of employment

¶13 **Consumption modules** (for budget surveys):

- ¶14 Detailed product codes for fish and seafood with marine/freshwater split
- ¶15 Services related to ocean recreation
- ¶16 Purchases during coastal tourism trips

3.3 Sampling Design

¶1 Effective sampling design underpins reliable estimates of ocean economic activity. The ocean economy presents distinctive challenges including geographic concentration along coastlines, high variability in establishment size, and seasonal patterns in many ocean industries.

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Frame coverage and maintenance

¶1 The quality of the sampling frame is fundamental to survey accuracy. For business surveys, the sampling frame is typically derived from the business register. A systematic approach should be in place for updating survey frames to ensure accurate coverage of the target population [28]. Information gathered during surveys should be used to assess and improve the quality of the frame, especially regarding coverage and the quality of contact variables and auxiliary information [29].

¶2 For ocean industries specifically, frame coverage issues may include:

- ¶3 **Undercoverage of small units** – small fishing vessels and informal operators may not appear in the business register
- ¶4 **Classification errors** – establishments may be misclassified to non-ocean industries
- ¶5 **Geographic coding errors** – coastal location may be incorrectly recorded
- ¶6 **Outdated information** – high entry and exit rates in some ocean industries

¶7 An appropriate sampling frame, drawn representatively from the business register, is particularly important for ocean surveys. If samples are drawn on the basis of turnover, employment, or value added alone, there is a risk that information relevant to ocean activity is not representative [30].

¶8 For the marine fishing sector specifically, the general business register may provide incomplete coverage of small-scale and artisanal operators. Vessel registries maintained by fisheries management authorities and fishing licence databases administered by maritime agencies can serve as supplementary frames. These specialised registers typically contain information on vessel characteristics (length, tonnage, gear type), port of registration, and licence holder that are not available in business registers. Where available, a dual-frame design (combining the business register for larger commercial operations with the vessel or licence register for smaller operators) can substantially improve coverage.

¶9 Compilers should assess the overlap between frames and apply one of the following estimation approaches to avoid double-counting units appearing in both frames:

- ¶10 **Screening (domain identification):** The preferred approach where the overlap between frames can be directly verified by matching units via a common identifier (tax ID, vessel registration number, business licence number). Units identified in both frames are assigned to one frame only before sampling and estimation.
- ¶11 **Weight adjustment (Hartley estimator):** Where direct matching is not feasible, apply weight adjustment using the Hartley estimator or analogous multiple-frame estimator. Under this approach, each sampled unit from the overlap domain receives a fractional weight that accounts for its probability of selection under both frames, preventing double-counting in the aggregate estimate.

¶12 The choice of estimator should be documented in survey methodology metadata. For further guidance on integrating administrative and survey data sources, see **TG-4.3 Administrative Data Sources** [31].

Stratification strategies

¶1 Stratified sampling improves efficiency by ensuring representation across important subgroups. For ocean economy surveys, stratification variables should include:

¶2 **Size stratification:**

- ¶3 Annual turnover or output (preferred for GVA and output estimation)
- ¶4 Number of employees or full-time equivalents (preferred for employment estimation)
- ¶5 Vessel tonnage (for fishing and shipping industries)

¶6 The choice of stratification variable should match the target statistic: use turnover or vessel capacity (GRT) as the primary stratification variable when the survey aims to estimate GVA or output.

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Use employment count when the primary objective is employment estimation. Where a survey estimates both, use turnover as the primary stratification variable with employment as a secondary sort within strata.

¶7 **Geographic stratification:**

- ¶8 Coastal region or port
- ¶9 Distance from coastline, defined as the nationally defined coastal zone where one exists, or a 10 km buffer from the mean high-water line where no national coastal zone definition is available (consistent with SEEA-Ocean spatial boundary guidance and the coastal tourism criterion in Section 3.1). The same spatial criterion must be applied consistently across business and household surveys to support integration of results [32].
- ¶10 Marine area of operation (for fishing vessels)

¶11 **Industry stratification:**

- ¶12 ISIC class or national equivalent
- ¶13 Type of ocean activity (fishing, aquaculture, shipping, tourism, offshore extraction)

¶14 Appropriate sampling techniques should be used to minimise sample sizes whilst achieving the target level of accuracy [33]. For ocean industries characterised by high variability, oversampling of large units (take-all strata) combined with probability sampling of smaller units is typically efficient.

Sample allocation

¶1 Sample allocation across strata should balance:

- ¶2 **Precision requirements** – larger samples where greater precision is needed
- ¶3 **Variability** – larger samples in more heterogeneous strata
- ¶4 **Cost** – consideration of differential data collection costs across strata
- ¶5 **Domain estimates** – allocation to support estimates for geographic areas and industry groups

¶6 For ocean economy surveys, the geographic dimension often requires explicit consideration. If estimates are required for specific coastal regions or ports, sample allocation must ensure adequate representation in each domain.

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Temporal considerations

¶1 Many ocean industries exhibit strong seasonal patterns that affect survey design:

- ¶2 **Fishing** – seasonal variation in catches by species and fishing ground
- ¶3 **Coastal tourism** – concentration in summer months in temperate climates
- ¶4 **Offshore energy** – weather-related operational patterns
- ¶5 **Shipping** – trade cycle variations

¶6 For first-time ocean economy surveys with limited budget, a tiered approach to temporal design is recommended:

1. ¶7 **Minimum viable (resource-constrained setting):** Repeated cross-sections at two strategically chosen reference periods (peak season and off-peak season), with estimates averaged or weighted by season duration to produce annual totals. This approach captures the most important seasonal variation at manageable cost.
2. ¶8 **Recommended where resources allow:** Continuous surveys where daily variability is high (e.g., coastal tourism and artisanal fishing), with data collection distributed throughout the year to support more precise seasonal adjustment.
3. ¶9 **For multi-year accounts:** Panel surveys following the same units over time, which measure change in business performance directly instead of inferring it from cross-sectional comparison.

¶10 The choice of temporal design should be documented in methodology metadata and applied consistently across compilation cycles [34].

Household survey sampling

¶1 For household surveys measuring ocean-related topics, sampling design considerations include:

¶2 As noted in Section 3.2, household surveys with stratified spatial and demographic design are efficient instruments for tourism measurement. [35] For coastal and marine tourism measurement, geographic stratification is particularly important: households in coastal areas may have different patterns of ocean-related consumption and recreation than inland households.

¶3 Where ocean-related activities are concentrated in specific population subgroups (e.g., fishing communities), screening approaches or oversampling of relevant areas may be required to obtain sufficient sample sizes for detailed analysis.

3.4 Quality Assurance for Survey Data

¶1 Quality assurance for survey data encompasses all procedures designed to ensure that survey results are accurate, reliable, and fit for their intended uses. The *UN National Quality Assurance Framework Manual* (UN NQAF) provides the overarching framework for statistical quality, with specific guidance applicable to surveys [36]. For the broader quality framework governing ocean accounting, see **TG-0.7 Quality Assurance**.

Sampling and non-sampling errors

¶1 Survey quality is affected by both sampling errors (arising from observing only a sample rather than the entire population) and non-sampling errors (arising from all other sources).

¶2 **Sampling errors** should be measured, evaluated, and documented for all survey estimates [37]. Standard errors or confidence intervals should be calculated and published alongside point estimates. For complex survey designs (stratified, clustered, or multi-stage samples), appropriate variance estimation methods must be employed.

¶3 **Non-sampling errors** include:

- ¶4 **Coverage errors** — differences between the frame population and target population
- ¶5 **Measurement errors** — differences between collected and true values due to questionnaire design, respondent error, or interviewer effects
- ¶6 **Processing errors** — errors introduced during coding, editing, or data entry
- ¶7 **Non-response errors** — bias arising from non-participation

¶8 Sources of possible sampling error should be identified and described, and non-sampling errors identified, described, and evaluated. Information about both should be made available to users as part of metadata [38].

Non-response handling

¶1 Proper follow-up procedures should be planned and implemented in cases of non-response [39]. Non-response in ocean industry surveys may arise from:

- ¶2 **Unit non-response** — establishments or households that do not participate at all
- ¶3 **Item non-response** — individual questions left unanswered
- ¶4 **Operational non-contact** — inability to reach at-sea operations or mobile fishing vessels during the survey reference period

¶5 Operational non-contact is structurally different from ordinary non-response. Vessels at sea are unreachable during the reference period, and their absence from the returns does not indicate refusal. Because vessels operating at sea during the reference period are likely to have higher catch

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volumes than those in port, standard non-response adjustment methods applied without modification would systematically underestimate production.

¶6 Compilers should treat operational non-contact as a distinct category with its own adjustment procedure:

- ¶7 **Where VMS or logbook data are available:** Use vessel monitoring system data or fishing logbooks from fisheries management authorities as auxiliary information to impute activity levels for non-contacted vessels. This is the preferred approach as it uses operational data that directly captures the activity being measured.
- ¶8 **Where VMS is unavailable:** Apply donor-based hot-deck imputation stratified by gear type and season, with donors drawn from vessels with similar operational characteristics to the non-contacted unit.
- ¶9 **Reporting:** Non-contact rates must be reported separately from refusal rates in survey metadata, as they carry different analytical implications and require different adjustment strategies.

¶10 Cross-reference **TG-4.3 Administrative Data Sources** for guidance on VMS and logbook data integration [40].

¶11 Generic prevention measures (clear communication, respondent-friendly design, multiple contact attempts), adjustment measures (weighting, imputation), and statistical editing follow the UN NQAF framework as applied in **TG-0.7 Quality Assurance Principles** [41], [42].

Data validation

¶1 Data validation procedures should identify potential problems, errors, and discrepancies such as outliers, missing data, and miscoding [43]. For ocean economy surveys, validation checks include:

¶2 **Range checks:**

- ¶3 Are reported values within plausible bounds for the industry?
- ¶4 Are employment figures consistent with establishment size?
- ¶5 Are output values consistent with industry averages?

¶6 **Consistency checks:**

- ¶7 Do components sum to reported totals?
- ¶8 Are ratios (value added to output, wages to employment) plausible?
- ¶9 Are reported activities consistent with ISIC classification?

¶10 For first compilation, compilers should use national accounts SNA supply-use table ratios as initial plausibility bounds for value-added-to-output and wages-to-output ratios. For fishing industries specifically, FAO's Techno-Economic Performance Reports provide value-added-to-output ratios by fleet type that serve as external validation benchmarks. From the second compilation cycle onward, use the prior cycle's stratum means as a rolling baseline, and flag any observation deviating more than two standard deviations from the stratum mean for follow-up with the respondent. No GOAP-specific reference ranges are prescribed given the high variability across national contexts [44].

¶11 **Longitudinal checks:**

- ¶12 Are changes from previous periods plausible?
- ¶13 Are large changes supported by known economic events?

¶14 **Cross-source validation:**

- ¶15 Are survey results consistent with administrative data (tax records, fishing licences)?
- ¶16 Do aggregated survey results align with independent benchmarks?

Integration of multiple data sources

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¶1 The general principles and workflow for integrating data from multiple ocean accounting sources (including classification alignment, linkage quality testing, and metadata requirements) are covered in **TG-4.6 Data Harmonisation and Interoperability**. In the survey context, the key survey-specific point is that administrative data from fisheries management systems (catch reporting, VMS, observer records) often capture landing volumes more completely than business surveys, whilst survey data remain essential for the economic dimensions (value added, employment, costs) that administrative systems do not cover. See **TG-4.3 Administrative Data Sources** for the full multi-source reconciliation workflow. [45]

Quality documentation

¶1 General quality documentation requirements for ocean accounting data (covering methodology description, accuracy measures, comparability notes, and fitness-for-use guidance) are set out in **TG-0.7 Quality Assurance Principles** and the UN NQAF dimensions described in **TG-4.5 Research Data §3.3.1**. Survey-specific quality considerations not covered by those circulars (including sampling and non-sampling error estimation, non-response handling for at-sea operations, and cross-source validation against administrative and fisheries management data) are addressed in Sections 3.3 and 3.4 above [46].

4. Worked Examples

4.1 Ocean economy survey module design — synthetic worked example

¶1 A national statistical office seeks to compile ocean economy thematic accounts for the first time. The office decides to augment the existing annual economic survey with a supplementary module targeting establishments in partially ocean-related industries to estimate the ocean share of their activity. The compilation procedure follows this sequence:

¶2 **Step 1: Industry scope determination.** Working with **TG-3.3 Economic Activity Relevant to the Ocean**, the compiler identifies ISIC classes that require ocean share estimation. These include:

- ¶3 ISIC 1020 (Processing and preserving of fish) — may process both marine and freshwater fish
- ¶4 ISIC 5510 (Short-term accommodation) — coastal establishments serve both marine tourism and other visitors
- ¶5 ISIC 4721 (Retail sale of food) — coastal fish markets and seafood retailers

¶6 **Step 2: Survey instrument design.** For each target industry, a short supplementary questionnaire is designed asking:

1. ¶7 What percentage of your total output/turnover in the reference year was directly related to ocean or marine activities? (0-100%)
2. ¶8 What percentage of your employment was engaged in ocean or marine activities? (0-100%)
3. ¶9 Please describe the nature of the ocean-related activity (open text)

¶10 **Step 3: Survey administration.** The supplement is included in the annual economic survey mailout for the 850 establishments in the target industries. Response rate is 78% (663 usable responses).

¶11 **Step 4: Compilation and validation.** For each industry class, the weighted mean ocean share is computed across responding establishments. For ISIC 1020, the mean ocean share is 72%. For coastal ISIC 5510, the mean is 45%, and for ISIC 4721, the mean is 28%.

¶12 Before applying class-level means, compilers should check for high within-class variance. Where the coefficient of variation of the ocean share within a stratum exceeds 0.5, estimate ratios separately for geographically stratified sub-groups (coastal vs. non-coastal establishments within the same ISIC class) rather than applying a single class-level mean. For ISIC 5510 in this example,

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beachfront accommodation and inland-city hotels are both classified to the same code. Geographic sub-stratification ensures that the 45% class mean is not applied uniformly to establishments with no proximity to the coast.

¶13 Ocean share ratios are then applied to the full industry output and employment aggregates from the annual economic survey to derive ocean economy estimates. Ratios with a coefficient of variation exceeding 0.5 that could not be sub-stratified should be flagged in metadata.

¶14 **Step 5: Account integration.** The ocean share estimates are combined with the output, intermediate consumption, and employment data for the partially ocean-related industries. These are then aggregated with data for wholly ocean-related industries (fishing, aquaculture, maritime transport) to produce the ocean economy totals that feed into **TG-2.5 Structure and Function of the Ocean Economy** indicators.

¶15 This module-augmentation approach scales to other partially ocean-related industries and adapts to different national contexts.

4.2 Stratified sampling for marine fishing establishments

¶1 A national statistical office seeks to estimate gross output and employment for the marine fishing industry. The business register contains 2,400 fishing enterprises classified to ISIC 0311 (Marine fishing). Register data indicate high skewness in the size distribution: 150 large operations account for 65% of total industry employment.

¶2 **Frame preparation:**

- ¶3 The register is cleaned to remove ceased operations and update contact information
- ¶4 Enterprises are geocoded to coastal regions

¶5 **Stratification:**

¶6 This example uses employment as the stratification variable because the primary survey objective is employment estimation. Where the objective is GVA or output estimation, annual turnover or vessel capacity (GRT) should be used as the primary stratification variable instead (see Section 3.3). Where both employment and output estimates are required, stratify on turnover as the primary variable with employment as a secondary sort within strata.

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Stratum	Employment range	Population (N)	Sampling fraction	Sample (n)
Take-all	50+ employees	150	100%	150
Large	10-49 employees	450	40%	180
Medium	3-9 employees	800	20%	160
Small	1-2 employees	1,000	10%	100
Total		**2,400**		**590**

¶7 **Table 4.1: Sample allocation for marine fishing survey**

¶8 **Estimation:** Estimates are calculated using Horvitz-Thompson estimators with design weights equal to the inverse of the sampling fraction. Variance estimates account for the stratified design.

4.3 Household survey module for coastal tourism

¶1 A household tourism survey includes a module to measure visits to coastal and marine destinations. The module asks:

1. ¶2 In the past 12 months, did you take any trips (overnight or same-day) to coastal or beach destinations?
2. ¶3 [If yes] How many trips to coastal/beach destinations did you take?
3. ¶4 For your most recent coastal trip:

- ¶5 Main destination (locality/region)
- ¶6 Duration (number of nights, or same-day)
- ¶7 Main purpose (holiday, visiting friends/relatives, business, other)
- ¶8 Activities undertaken (beach recreation, swimming, diving/snorkelling, fishing, boat trips, other)
- ¶9 Total expenditure on the trip
- ¶10 Breakdown by category: accommodation, food/drink, transport, activities, shopping

¶11 Survey results are weighted using household sampling weights and grossed to the national population. Expenditure estimates are compared with administrative data from accommodation establishments in coastal areas for validation.

5. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

6. References

1. ¶1 SF-MST (2024), para 3.20. Data on the characteristics of tourism establishments is most readily organised by utilising and extending the information available in a business register.
2. ¶2 SF-MST (2024), para 3.21. Within the structure of a business register, establishments classified as being involved in tourism industries can be assessed using variables such as industry class, size of establishment, employment, ownership, and legal entity.
3. ¶3 2025 SNA, Chapter 28, para 28.4. Best practices in the development and maintenance of business registers are presented in the UN Guidelines on Statistical Business Registers.
4. ¶4 ISIC Rev.4 (2008), Introduction. The International Standard Industrial Classification of All Economic Activities (ISIC) provides the framework for classifying economic activities.
5. ¶5 ISIC Rev.4 (2008), Detailed Structure, Sections A, B, C, H, and M. Core ocean ISIC classes include 0311 (Marine fishing), 0321 (Marine aquaculture), 3011 (Ship and floating structure building), 5011/5012 (Sea and coastal passenger/freight water transport), 5222 (Services incidental to water transportation), and 5224 (Cargo handling at ports) — all surveyed under full coverage. Partially ocean-related classes requiring ocean-share supplementary questions include 1020 (Fish processing), 3511/3512 (Offshore renewables), 7210 (Marine R&D), and 0910 (Support to offshore petroleum and gas). For the complete authoritative industry scope of ocean accounts and the survey-approach treatment for each class, see TG-3.3; for the canonical treatment of standards relevant to ocean accounting more generally, see TG-4.6.
6. ¶6 ISIC Rev.5 (2024), endorsed by the UN Statistical Commission at its 55th session. Implementation expected from 2027, with transitional correspondence tables to be provided by the UN Statistics Division. See TG-0.2 for guidance on managing classification transitions in ocean accounting.
7. ¶7 SF-MST (2024), para 3.19. The measurement of the economic activity of tourism focuses on tourism establishments. For ocean accounting, the broader challenge of identifying partially ocean-related activity across all industries requires supplementary survey questions to determine the ocean share of economic activity at the establishment level.
8. ¶8 TG-3.3 Economic Activity Relevant to the Ocean, Section 3.1. The industry classification framework and criteria for inclusion of partially ocean-related industries are defined in TG-3.3.
9. ¶9 SNA 2025, Chapter 3 (economic territory and residence); SEEA-Ocean (2021), Chapter 2; UNCLOS (1982), Part VII (high seas). The residency-based scope ensures consistency between ocean economy accounts and the broader national accounts framework.
0. ¶10 IRTS 2008, para 2.9. Tourism is a social, cultural and economic phenomenon related to the movement of people to places outside their usual place of residence.
1. ¶11 SF-MST (2024), para 1.1. The Statistical Framework for Measuring the Sustainability of Tourism provides a framework for integrating tourism statistics with the SEEA.
2. ¶12 SF-MST (2024), para 3.21.
3. ¶13 SF-MST (2024), para 3.25. Where available, business registers are most commonly developed at a national level with the relevant data derived mainly from administrative data sources and business statistics. The 10 km buffer criterion is consistent with SEEA-Ocean (2021) Chapter 2 spatial boundary guidance.
4. ¶14 IRTS 2008, para 6.57. Generalised annual surveys will usually provide economic information on establishments, including the number of units, classified by industry, output by source of revenue or main product and intermediate consumption.

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5. ¶15 TSA:RMF 2008, Table 5. Production accounts of tourism industries and other industries.
6. ¶16 SF-MST (2024), para 3.18. In many instances, there may be an important contribution to tourism activity from the informal economy where there is no registration of economic units.
7. ¶17 SF-MST (2024), para 3.18.
8. ¶18 ILO (2018), *Women and Men in the Informal Economy: A Statistical Picture*. 3rd edition. Geneva: ILO; FAO (2015), *Voluntary Guidelines for Small-Scale Fisheries*. Rome: FAO. The 10% and 80% thresholds are operational guidance values; compilers may adopt more conservative thresholds based on national context.
9. ¶19 IRTS 2008, para 7.30.
0. ¶20 IRTS 2008, para 7.30.
1. ¶21 IRTS 2008, para 7.31.
2. ¶22 IRTS 2008, para 7.29. The collection of data on employment in the tourism industries should be integrated in the regular national statistical system.
3. ¶23 ILO (2013), *Resolution Concerning Statistics of Work, Employment and Labour Underutilization*, 19th ICLS. Geneva: ILO; ISCO-08 (ILO, 2012). The ISCO codes cited (6221, 8350, 3151) are indicative of the most common ocean-related occupations; compilers should review the full ISCO-08 structure for their national context.
4. ¶24 COICOP 2018, Class 01.1.4 (Fish and seafood) and subclasses; UN Statistics Division. The supply-side ratio method is appropriate where HBS sample sizes in coastal fish-consuming households are insufficient for direct statistical estimation.
5. ¶25 IRTS 2008, para 2.72. Household surveys based on a stratified sample using spatial, demographic and socio-economic criteria can be efficient and suitable instruments for measuring domestic tourism activity and related expenditure.
6. ¶26 IRTS 2008, para 2.74. From a general household survey perspective, it is possible to observe round trips taken by visitors and not only visits as is the case when observing visitors during their trips.
7. ¶27 IRTS 2008, para 2.73. Sample size and design are strongly related to the significance and accuracy of the variables to be estimated. Two different issues need to be taken into consideration when designing domestic surveys to analyse tourism.
8. ¶28 UN NQAF Manual (2019), Requirement 10.4. A systematic approach is in place for updating the survey frames to ensure accurate coverage of the target population.
9. ¶29 UN NQAF Manual (2019), Requirement 10.4. Information gathered during the conduct of surveys is used to assess and improve the quality of the frame, especially with regard to its coverage.
0. ¶30 SEEA Technical Note on Water Accounts, para on sampling frame. The need for an appropriate sampling frame which draws a representative picture of water supply and use from the business register.
1. ¶31 Hartley, H.O. (1962), "Multiple frame surveys," *Proceedings of the American Statistical Association, Social Statistics Section*, pp. 203-206; Lohr, S.L. & Rao, J.N.K. (2006), "Estimation in multiple-frame surveys," *Journal of the American Statistical Association* 101(475), pp. 1019-1030. The screening approach is generally preferred as it avoids the need for complex weight adjustment formulas.
2. ¶32 SEEA-Ocean (2021), Chapter 2 (spatial extent of ocean accounts); TG-0.2 Overview of Relevant Statistical Standards; UN NQAF Manual (2019), Requirement 10.4.
3. ¶33 UN NQAF Manual (2019), Requirement 11.1. Appropriate sampling techniques are used to minimise sample sizes to achieve the target level of accuracy.
4. ¶34 UN NQAF Manual (2019), Requirement 11; IRTS 2008, para 2.73; FAO (2001), *Guidelines for the Routine Collection of Capture Fishery Data*, Chapter 4. The two-reference-period approach is standard practice in fisheries production surveys where year-round continuous surveys are not feasible.
5. ¶35 IRTS 2008, para 2.72.
6. ¶36 UN NQAF Manual (2019), Overview. The UN National Quality Assurance Framework Manual provides guidance on assuring the quality of official statistics.
7. ¶37 UN NQAF Manual (2019), Requirement 15.2. Sampling errors are measured, evaluated and documented.
8. ¶38 UN NQAF Manual (2019), Requirement 15.2. Non-sampling errors are described and, when possible, estimated. Information about the sampling and non-sampling errors is made available to users as part of the metadata.
9. ¶39 UN NQAF Manual (2019), Requirement 10.1. Proper follow-up procedures are planned and implemented in cases of non-response.
0. ¶40 FAO (2001), *Guidelines for the Routine Collection of Capture Fishery Data*, Chapter 5; TG-4.3 Administrative Data Sources. VMS-based imputation for at-sea non-contact is consistent with established practice in European and Pacific fisheries survey programmes.
1. ¶41 UN NQAF Manual (2019), Requirement 10.1. Statistical editing procedures and imputation methods are based on sound methodology.
2. ¶42 UN NQAF Manual (2019), Requirement 12.2. The effects of data editing and imputation are analysed as part of assessing the quality of the data collection.
3. ¶43 UN NQAF Manual (2019), Requirement 12.2. Data of all data sources are reviewed and validated to identify potential problems, errors and discrepancies such as outliers, missing data and miscoding.
4. ¶44 FAO (various years), *Techno-Economic Performance of the European Fishing Fleets*. Annual report series. Rome: FAO; SNA 2025, Chapter 28 (supply-use tables and industry ratios). The two-standard-deviation flag rule is a standard statistical editing practice; compilers may tighten or loosen the threshold based on prior knowledge of variability in their industry sample.

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5. ¶45 FAO. (2001). *Guidelines for the Routine Collection of Capture Fishery Data*. FAO Fisheries Technical Paper No. 382. Rome: FAO. The integration of administrative catch data with survey-based economic data is recommended practice in fisheries statistics, where landings records provide volume benchmarks and surveys supply value-added dimensions.
6. ¶46 UN NQAF Manual (2019), Chapter 3. The concept of data quality for official statistics encompasses factors of relevance, timeliness, accuracy, coherence, interpretability, and accessibility.

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Administrative Data Sources

Provides guidance on the use of administrative data sources for the compilation of Ocean Accounts.

Version 0.7.1 **Status** Draft **Stability** Applied

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Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

OUTCOME

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This Circular provides guidance on the use of administrative data sources for the compilation of Ocean Accounts. Administrative data (records collected by government agencies and other organisations in the course of their regular operations) are a cost-effective and often wide-ranging source of information for ocean accounting, particularly for maritime activities subject to regulatory oversight. Such data sources include permits and licences for fishing and aquaculture, customs and trade records, vessel registration systems, and vessel tracking data from Automatic Identification Systems (AIS) and Vessel Monitoring Systems (VMS).

Administrative data offer several advantages for ocean accounting programmes: they reduce respondent burden compared to purpose-designed surveys, provide near-complete population coverage for regulated activities, and support temporal and spatial granularity that would be prohibitively expensive to collect through primary data collection. Whilst these advantages are substantial, administrative data also present challenges of coverage, concepts, and quality that must be addressed through systematic quality assurance procedures.

Administrative data and purpose-designed surveys are complementary approaches, not substitutes. Administrative sources perform best where regulatory frameworks produce consistent records (licensed commercial fishing, international trade, and vessel movements). Surveys remain necessary where administrative coverage is incomplete: subsistence and recreational fisheries, informal-sector maritime activities, and emerging ocean economy sectors not yet subject to licensing requirements. A well-designed ocean accounting programme identifies which activities are best captured through administrative sources and where targeted surveys are needed to fill gaps, using the accounting framework itself to detect coverage deficiencies through supply-use confrontation. The methodology for designing such complementary surveys is addressed in TG-4.2 Survey Methods.

Readers of this Circular will gain an understanding of the main types of administrative data relevant to ocean accounting, the institutional arrangements necessary to access such data, methods for integrating administrative records with statistical frameworks, quality assurance procedures to ensure fitness for purpose, and practical workflows for transforming regulatory records into accounting entries. The guidance serves national statistical offices, fisheries management agencies, maritime authorities, and customs administrations seeking to contribute to or compile Ocean Accounts. The foundational concepts of Ocean Accounts are established in TG-0.1 General Introduction to Ocean Accounts, and the governance structures required for multi-agency data collaboration are set out in TG-0.7 Institutional Arrangements.

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¶1 **Framework Position**

¶2 TG-4.3 sits within Section 4 (Data Methods). It owns the administrative source: custodian identification and legal access basis, extraction, deduplication across agencies, cleaning, classification mapping, coverage assessment, and the quality statement that accompanies each variable delivered — catch, licence receipts, customs quantities and values, and vessel register attributes. It does not own the accounts those variables populate. Placing them in the supply and use table, and choosing the price basis for a monetary cell, is **TG-3.3 Economic Activity Relevant to the Ocean**; fleet capital stock and resource rent are **TG-3.1 Asset Accounts** Sections 3.3 and 3.6.

1. Outcome

¶1 This Circular provides guidance on the use of administrative data sources for the compilation of Ocean Accounts. Administrative data (records collected by government agencies and other organisations in the course of their regular operations) are a cost-effective and often wide-ranging source of information for ocean accounting, particularly for maritime activities subject to regulatory oversight[1]. Such data sources include permits and licences for fishing and aquaculture, customs and trade records, vessel registration systems, and vessel tracking data from Automatic Identification Systems (AIS) and Vessel Monitoring Systems (VMS).

¶2 Administrative data offer several advantages for ocean accounting programmes: they reduce respondent burden compared to purpose-designed surveys, provide near-complete population coverage for regulated activities, and support temporal and spatial granularity that would be prohibitively expensive to collect through primary data collection[2]. Whilst these advantages are substantial, administrative data also present challenges of coverage, concepts, and quality that must be addressed through systematic quality assurance procedures.

¶3 Administrative data and purpose-designed surveys are complementary approaches, not substitutes. Administrative sources perform best where regulatory frameworks produce consistent records (licensed commercial fishing, international trade, and vessel movements). Surveys remain necessary where administrative coverage is incomplete: subsistence and recreational fisheries, informal-sector maritime activities, and emerging ocean economy sectors not yet subject to licensing requirements. A well-designed ocean accounting programme identifies which activities are best captured through administrative sources and where targeted surveys are needed to fill gaps, using the accounting framework itself to detect coverage deficiencies through supply-use confrontation. The methodology for designing such complementary surveys is addressed in **TG-4.2 Survey Methods**.

¶4 Readers of this Circular will gain an understanding of the main types of administrative data relevant to ocean accounting, the institutional arrangements necessary to access such data, methods for integrating administrative records with statistical frameworks, quality assurance procedures to ensure fitness for purpose, and practical workflows for transforming regulatory records into accounting entries. The guidance serves national statistical offices, fisheries management agencies, maritime authorities, and customs administrations seeking to contribute to or compile Ocean Accounts. The foundational concepts of Ocean Accounts are established in **TG-0.1 General Introduction to Ocean Accounts**, and the governance structures required for multi-agency data collaboration are set out in **TG-0.7 Institutional Arrangements**.

2. Requirements

¶1 This Circular requires familiarity with:

- ¶2
  TG-0.1 General Introduction to Ocean Accounts — provides foundational understanding of Ocean Accounts components and the relationship between environmental and economic

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accounting frameworks, including the conceptual distinctions between physical and monetary accounts that administrative data must support.

- ¶3
  TG-0.7 Institutional Arrangements — establishes the governance structures, data sharing agreements, and inter-agency coordination mechanisms that are prerequisites for accessing administrative data held by regulatory authorities.

¶4 **Related Circulars:**

- ¶5 **TG-1.5 OA and Fisheries Management** — application of accounts to fisheries policy, including treatment of aquatic resources as environmental assets
- ¶6 **TG-3.3 Economic Activity Relevant to the Ocean** — classification of ocean-related industries and businesses for economic accounts
- ¶7 **TG-3.4 Flows from Economy to Environment** — recording of residuals and pressures using permit data on authorised discharges
- ¶8 **TG-4.2 Survey Methods** (statistical survey methodology for filling gaps in administrative coverage) — design of complementary surveys where administrative coverage is incomplete
- ¶9 **TG-4.1 Remote Sensing and Geospatial Data** (earth observation and remote sensing data for spatial attribution and vessel tracking pattern validation) — independent validation of vessel presence and activity from satellite and aerial imagery
- ¶10 **TG-6.7 Fisheries Accounting** — integration of fisheries license data with stock assessment and catch accounts
- ¶11 **TG-4.6 Data Harmonisation and Interoperability** — OBS_STATUS codelist conventions and SDMX metadata standards applied to administrative data quality flags (see Section 3.4.3)
- ¶12 **TG-6.10 Maritime Transport and Ports** — use of port records and vessel tracking data for maritime accounts

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3. Guidance Material

3.1 Permits and Licenses

¶1 Permit and licence data provide basic information on the population of economic units authorised to undertake ocean-related activities. Such administrative systems are maintained by government agencies responsible for regulating access to marine resources and maritime space[3]. The data captured through these systems support the compilation of economic accounts by identifying the universe of producers, and enable physical flow accounts by providing authorised extraction or emission levels.

¶2 In practice, the terms “permit” and “licence” are used with varying specificity across jurisdictions. Some countries use “licence” for the general authorisation to engage in an activity (such as commercial fishing) and “permit” for specific conditions attached to that authorisation (such as access to a particular zone or species). Other jurisdictions use the terms interchangeably. For ocean accounting purposes, both instruments serve the same function: they generate administrative records that identify economic units, authorised activities, and regulatory conditions. Compilers should document the national terminology and map permit and licence categories to the relevant accounting classifications, so that the scope of administrative data is clearly understood regardless of local naming conventions. This mapping matters in the Pacific Islands context, where regional organisations such as the Pacific Community (SPC) and the Forum Fisheries Agency (FFA) coordinate data across jurisdictions with differing regulatory terminology.

3.1.0 Administrative Data Custodians and Multi-Agency Deduplication

¶1 An **administrative data custodian** is the agency with statutory authority to issue, amend, or revoke the regulatory instrument in question. Most ocean-related activities are subject to oversight by more than one custodian, and compilers must establish a clear record-authority hierarchy before integrating data across registers.

¶2 **Record authority hierarchy by data type:**

Data type	Primary custodian
Production licenses, catch quotas, vessel licenses	Fisheries agency
Environmental discharge permits, coastal zone allocation consents	Environment or coastal zone management ministry
Vessel registration, safety certificates, flag State documentation	Maritime authority

¶3 For multi-agency situations (for example, aquaculture operations holding a production license from the fisheries ministry, a discharge permit from the environment ministry, and a site lease from the coastal zone management authority), the issuing agency for the primary licensed activity takes precedence for record authority, and secondary agencies supply supplementary fields (discharge limits, site coordinates) into the integrated record.

¶4 **Deduplication decision tree:** records describing the same operator across multiple registers are linked using a shared operator identifier (the tax registration number or national business identifier as the primary link key). Where the same activity appears in more than one register, the most recently updated record from the primary custodian takes precedence, with secondary-custodian fields appended where they extend rather than contradict the primary record. The formal multi-agency data-sharing agreement template is set out in **TG-0.7 Institutional Arrangements**.

3.1.1 Fishing Permits and Licenses

¶1 National fisheries authorities typically maintain registers of fishing vessels and operators authorised to harvest aquatic resources within territorial waters and the exclusive economic zone (EEZ). Under the United Nations Convention on the Law of the Sea (UNCLOS), coastal States have sovereign rights to manage living resources within their EEZ, which extends up to 200 nautical miles from baselines [4]. This jurisdictional framework underpins the licensing systems that regulate access to fisheries.

¶2 The treatment of fish and aquatic resources within the SEEA framework is detailed in **TG-6.7 Fisheries Accounting**, which explains how licence data feed into asset accounts for natural aquatic resources. The distinction between capture fisheries (ISIC group 031) and aquaculture (ISIC group 032) is fundamental to both regulatory frameworks and accounting treatment [5].

¶3 Key data elements captured in fishing license systems typically include:

Data Element	Accounting Application	Related Circular
License holder identification	Links to business registers for economic unit classification	TG-2.5
Vessel characteristics (length, tonnage, engine power)	Measures of fishing capacity and capital stock	TG-3.1
Authorized fishing area	Spatial attribution of catches to marine zones	TG-2.2
Authorized gear types	Classification of fishing methods and environmental pressure	TG-3.3
Target species or quotas	Expected extraction levels for stock accounts	TG-6.7
License fees paid	Government revenue from natural resource access	TG-3.3

Data Element	Accounting Application	Related Circular
Validity period	Temporal scope of authorized activity	-

¶4 **Live-weight conversion of quota data.** Quota volumes must be converted to live-weight equivalent using the source hierarchy described in Section 3.2.1. For Pacific tuna quotas issued under FFA Vessel Day Scheme (VDS) arrangements (recorded as fishing days rather than tonnage), apply the FFA-published species-specific catch-per-vessel-day coefficients (updated annually by FFA/SPC) to convert vessel-day quotas to live-weight equivalent tonnes. [6]

¶5 For countries with quota-based fisheries management, license data include allocated catch limits that can be compared against reported landings to assess compliance and sustainable yield. Where individual transferable quotas (ITQs) exist, records of quota trades provide additional information on the economic value of access rights [7]. This valuation information is relevant to the compilation of monetary asset accounts as discussed in **TG-3.1 Asset Accounts**.

¶6 A common challenge in using licence databases for accounting purposes is the presence of inactive records (vessels that remain on the register but are no longer operational). Licence registers may include vessels that have been decommissioned, sold outside the jurisdiction, or have simply ceased fishing activity without formally surrendering their licence. For accounting purposes, compilers should distinguish between the 'registered' fleet (all current licence holders) and the 'active' fleet (vessels that reported activity during the accounting period). That distinction can be established by cross-referencing licence registers with landing declarations, vessel tracking data, or annual renewal records.

¶7 **Materiality threshold for inactive vessels.** An inactive-vessel share exceeding **10% of the registered fleet** triggers a register audit conducted jointly with the fisheries management agency, with results documented in the source register maintained under Section 3.7. Inactive vessels are retained in capital stock accounts as idle capacity, flagged with an "inactive" status attribute in the vessel register extract, consistent with SNA 2025 para. 20.14 on the treatment of idle fixed assets [8]. They are not excluded from the fleet capital stock but are reported separately in a memorandum row to enable over-capacity assessment. See **TG-3.1 Asset Accounts** for the capital stock recording conventions.

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¶8 **Decision use cases for fishing license data:**

1. ¶9
   Stock assessment calibration — Licence records establish the upper bound of fishing capacity. Fisheries scientists use that bound to calibrate effort estimates and to detect unreported fishing where observed catches exceed licensed capacity.
2. ¶10
   Economic activity measurement — Licence fee revenues and vessel characteristics feed directly into supply-use tables for the fishing industry, supporting measurement of government revenue from natural resource access and the capital stock of fishing enterprises.
3. ¶11
   Spatial attribution — Authorised fishing areas in licence records enable attribution of catches to specific marine zones for spatially disaggregated asset accounts. Such attribution matters for countries with large EEZs where different zones support different fisheries.

3.1.2 Aquaculture Licenses

¶1 Aquaculture operations (the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants) are typically subject to environmental permits that authorise the location, scale, and species cultivated [9]. These permits capture information essential for compiling asset accounts for cultivated biological resources.

¶2 Administrative records for aquaculture commonly include:

- ¶3 Site location and authorised production area (hectares or volume)
- ¶4 Species authorised for cultivation
- ¶5 Production capacity (tonnes per annum)
- ¶6 Environmental conditions and discharge limits
- ¶7 Biosecurity requirements
- ¶8 Ownership and corporate structure

¶9 Aquaculture licensing data support both physical and monetary accounts. Production capacity figures provide the basis for estimating potential output, whilst environmental discharge limits enable recording of flows from economy to environment, including nutrient loads and organic wastes[10]. The methodology for recording such flows is addressed in **TG-3.4 Flows from Economy to Environment**.

¶10 Integrated multi-trophic aquaculture (IMTA) systems present a specific accounting consideration. In IMTA operations, waste outputs from one cultured species (for example, nutrient-rich effluent from finfish cages) serve as inputs for another species (such as seaweed or filter-feeding shellfish). The net discharge to the marine environment is reduced by the amount absorbed by the co-cultured species, and permits for IMTA operations may specify both gross discharge limits and expected uptake by extractive species.

¶11 **Recording IMTA flows — net entry with mandatory gross memorandum.** The net recording approach for IMTA internal nutrient transfers is a practical approximation permissible where permit data explicitly cover internal recycling flows. Whilst that approximation is accepted, SEEA CF physical flow accounts are gross by design to preserve the supply-use identity[11], and gross flows must therefore also be recorded as a memorandum item alongside the net entry. The following two-row recording convention applies:

Row	Entry type	Description
1	Primary — residual flow account	Net discharge to the marine environment after subtracting nutrient absorption by co-cultured extractive species
2	Memorandum — gross flows	(a) Gross finfish-cage discharge; (b) gross nutrient absorption by co-cultured filter-feeders / seaweed, with a reconciliation note confirming Row 1 = (a) − (b)

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¶12 IMTA recording is flagged as a known area where national practice may deviate from the SEEA CF gross-recording standard, and the deviation must be documented in account metadata. See **TG-3.4 Flows from Economy to Environment** for the authoritative SEEA CF residual flow recording convention.

¶13 **Decision use cases for aquaculture license data:**

1. ¶14
   Nutrient loading estimates — Permit discharge limits combined with production data enable estimation of nutrient contributions to coastal eutrophication. Those estimates populate water quality accounts and SDG indicator 14.1.1 on coastal eutrophication.
2. ¶15
   Production monitoring — Licensed production capacity provides a benchmark against which reported output can be assessed. Systematic under-reporting indicates either data quality issues or informal sector activity requiring supplementary surveys.
3. ¶16
   Coastal zone planning — Spatial distribution of aquaculture licenses informs marine spatial planning by identifying areas of intensive use and potential conflicts with other activities.

3.1.3 Offshore Activity Permits

¶1 Maritime jurisdictions regulate offshore activities beyond fishing. Table 3.1.3 below summarises the main permit categories and their accounting relevance.

Permit category	Description
Hydrocarbon exploration and production licenses	Petroleum and natural gas extraction in territorial waters and on the continental shelf is subject to licensing regimes that specify exploration blocks, production sharing arrangements, and environmental management conditions; relevant to mineral and energy resource accounts. [12]
Renewable energy permits	Offshore wind farms, wave energy installations, and tidal power facilities require permits that specify location, capacity, and environmental mitigation measures; these emerging activities represent growing components of the ocean economy.
Marine mining permits	Extraction of aggregates (sand and gravel), mineral sands, and deep-sea minerals is regulated through permits that specify extraction volumes and areas.
Dumping permits	Disposal of waste materials at sea, including dredge spoil, is regulated under international conventions (the London Convention and Protocol) implemented through national permit systems; permit data on authorised dumping volumes are relevant to **TG-3.4 Flows from Economy to Environment**. [13]
Marine scientific research authorisations	Research activities in the EEZ by foreign vessels require authorisation from the coastal State under UNCLOS Article 246. [14]

¶2 **Deep-sea mineral permits — two-category treatment.** Deep-sea mining of polymetallic nodules, seafloor massive sulphides, and cobalt-rich crusts is an emerging category requiring a clear accounting-boundary rule:

- ¶3 **Category A — National jurisdiction.** Permits issued by the national authority for extraction within the territorial sea, EEZ, or on the continental shelf are recorded in national mineral asset accounts under SEEA CF paras. 5.19–5.22 [15].
- ¶4 **Category B — The Area (ISA contracts).** Exploration and exploitation contracts issued by the International Seabed Authority for extraction in the Area under UNCLOS Part XI fall outside the national accounting boundary and are excluded from national mineral asset accounts. Where the country is an ISA contractor-sponsoring state (currently including Nauru, Tonga, Kiribati, and Cook Islands), the ISA contract data may be noted as supplementary information in a memorandum table.

¶5 **Decision use cases for offshore permits:**

1. ¶6
   Residual flow accounting — Dumping permits specify authorised disposal volumes, and those volumes give a direct measurement of waste flows to the marine environment that populate residual flow accounts under SEEA CF.
2. ¶7
   Capital formation — Offshore energy permits track investment in marine renewable energy infrastructure. That investment feeds capital formation accounts for the ocean economy.
3. ¶8
   Environmental pressure indicators — Aggregation of permit data across offshore activities enables compilation of spatial pressure maps showing cumulative impacts on marine ecosystems.

3.2 Customs and Trade Data

¶1 Customs administrations generate detailed data on international trade in goods, including seafood products, maritime equipment, and other ocean-related commodities. These data are essential for compiling supply and use tables, physical flow accounts for traded products, and balance of payments statistics [16].

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3.2.1 Seafood Trade Statistics

¶1 Customs records for fish and fishery products provide detailed information on:

- ¶2 Product classification (Harmonized System codes at 6-digit or national tariff line detail)
- ¶3 Volume (tonnes) and value (FOB/CIF)
- ¶4 Country of origin/destination
- ¶5 Port of entry/exit
- ¶6 Importer/exporter identification

¶7 The SEEA AFF recommends that physical flow accounts for fish products record imports and exports in live weight equivalent to ensure consistency with domestic production statistics[17]. Conversion factors must be applied to transform processed product weights (fillets, frozen, canned) to the comparable live weight measure.

¶8 **Live-weight conversion factor source hierarchy.** The choice of conversion factor materially affects total live-weight equivalent trade volumes and the supply-use balance, particularly for seafood-exporting countries. Compilers should apply the following three-step adaptation protocol:

1. ¶9 **Primary — FAO Fisheries and Aquaculture Department live-weight conversion factor database** (FAO 1994, updated). Search the database for the exact species (FAO ASFIS alpha-3 code) and processing form (whole, gutted, fillets, canned, etc.).
2. ¶10 **Secondary — ICES Working Group on Fisheries Acoustics, Science and Technology (WGFAST) technical report series**, used for processed and value-added products not adequately covered by FAO factors. National fisheries institute conversion factors may also be applied at this tier, provided the source name and vintage year are recorded in the source register (Section 3.7).
3. ¶11 **Default — nearest taxonomic group factor** from the FAO database, applied where neither a species-specific FAO factor nor a national factor is available. Estimates produced at this tier must be flagged as **provisional** in account metadata.

¶12 **Worked example.** A national customs system records 1,000 tonnes (net product weight) of canned skipjack tuna exports. Applying the FAO factor of 1.9 for canned tuna (drained-weight basis), the live-weight equivalent for the physical export account is **1,000 × 1.9 = 1,900 tonnes**.

¶13 This conversion workflow is consistent with the parallel live-weight conversion of quota data described in Section 3.1.1. Both pathways must apply the same factor source for a given species and processing form to preserve supply-use consistency.

¶14 For island nations and coastal States where fisheries are economically significant, customs data serve multiple accounting purposes:

¶15 **Supply-use balancing** — Exports and imports provide the external trade components necessary to balance domestic production against consumption and intermediate use[18]. The integration of trade data with production data is discussed in **TG-6.7 Fisheries Accounting**.

¶16 **Trade in fish caught by foreign vessels** — When foreign-flagged vessels harvest fish in a country's EEZ under access agreements, the transhipment or landing of catches may be recorded in customs statistics, supporting the distinction between catches from national waters and catches by national fishing vessels[19]. This distinction matters for Pacific Island Countries where distant-water fishing nations operate under access agreements.

¶17 For Pacific Island Countries, reconciliation between national customs records and regional databases maintained by the Forum Fisheries Agency (FFA) requires systematic attention. FFA compiles catch and effort data reported under regional fisheries management arrangements, which may differ from national customs records through differences in timing (landing date versus export date), valuation (access fees versus market price), and coverage (transhipments at sea versus port

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landings). Compilers should establish regular data confrontation between customs and FFA sources, and should document the reconciliation procedures and any systematic differences. The FFA's Regional Fisheries Surveillance Centre also maintains vessel day scheme data that can cross-validate customs records for purse seine fisheries. Institutional arrangements for accessing FFA data are facilitated through national fisheries agencies and should be formalised under the frameworks described in **TG-0.7 Institutional Arrangements**.

¶18 **Illegal, unreported and unregulated (IUU) fishing indicators** — Comparison of import volumes with reported exports from origin countries can reveal discrepancies indicative of unreported catches or trade in IUU-sourced products [20] . SDG indicator 14.6.1 tracks progress in combating IUU fishing, which can be supported by trade data analysis.

¶19 **Decision use cases for customs trade data:**

1. ¶20
   Supply-use balancing — Customs data provide the import and export components of seafood supply-use tables. Discrepancies that emerge in balancing may indicate unreported production or consumption.
2. ¶21
   IUU fishing detection — Trade flow analysis comparing bilateral import-export data identifies anomalies consistent with illegal fishing, which supports SDG 14.6.1 monitoring.
3. ¶22
   Value chain analysis — Product-level trade data reveal the structure of seafood value chains, including which species are exported fresh and which are processed domestically. That structure informs industrial development policy.

3.2.2 Maritime Equipment and Inputs

¶1 Customs data also capture trade in goods used as inputs to ocean industries:

- ¶2 Fishing vessels and parts (relevant to capital formation accounts)
- ¶3 Marine engines and propulsion equipment
- ¶4 Fishing gear (nets, lines, traps)
- ¶5 Aquaculture equipment (cages, feeders, aeration systems)
- ¶6 Fuel and lubricants (with marine-specific customs categories)
- ¶7 Ice and refrigeration equipment

¶8 These data support the compilation of intermediate consumption and capital formation components of ocean economy supply-use accounts.

3.2.3 Port Statistics and Maritime Transport

¶1 Port authorities and customs administrations generate data on vessel movements and cargo throughput that are central to measuring maritime transport activity:

- ¶2 Vessel arrivals and departures by flag state, vessel type, and tonnage
- ¶3 Cargo handled (tonnes, container TEUs, passengers)
- ¶4 Port service revenues

¶5 These data feed into both national accounts (transport sector output) and physical flow accounts (material throughput through maritime logistics). Detailed guidance on compiling maritime transport accounts is provided in **TG-6.10 Maritime Transport and Ports**.

3.3 Vessel Tracking (AIS/VMS)

¶1 Vessel tracking systems provide spatially explicit data on maritime activity that improve the attribution of economic activity and environmental pressures to specific marine locations. Two pri-

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mary systems are relevant. All inter-agency data sharing agreements required by this section should be established under the framework in **TG-0.7 Institutional Arrangements**.

3.3.1 Automatic Identification System (AIS)

¶1 The Automatic Identification System is an automatic tracking system mandated by the International Maritime Organization (IMO) for vessels engaged in international voyages and for all passenger vessels, cargo vessels of 300 gross tonnage and above, and fishing vessels above certain size thresholds (varying by jurisdiction)[21]. AIS transponders broadcast vessel identity, position, course, and speed at regular intervals.

¶2 Key data elements from AIS include:

Data Field	Description
MMSI	Maritime Mobile Service Identity
Position (lat/lon)	GPS-derived location
Speed over ground	Vessel velocity
Course over ground	Direction of travel
Vessel type	Classification code
Destination	Reported port
Timestamp	Date and time

¶3 AIS data are now widely available through satellite reception and coastal base stations, and they enable:

¶4 **Fishing effort estimation** — Analysis of vessel tracks can identify fishing behaviour from speed and movement patterns, which yields estimates of fishing effort by area that complement or substitute for vessel logbook data[22]. This spatial effort data supports the compilation of catch accounts by marine zone.

¶5 **Spatial attribution** — Catches can be attributed to specific marine zones (territorial sea, EEZ zones, high seas) based on vessel positions during fishing activity, supporting spatially explicit asset accounts. This aligns with the spatial framework described in **TG-2.2 Macro-economic Dependencies on Ocean Ecosystems**.

¶6 **Fleet characterisation** — Analysis of active vessel populations, activity levels, and spatial patterns provides information on the structure of fishing industries beyond what license registers capture[23].

¶7 **Environmental pressure mapping** — Combining vessel activity data with emission factors enables spatial mapping of pressures from shipping emissions, underwater noise, and collision risk with marine mammals. These pressure indicators feed into **TG-3.4 Flows from Economy to Environment**.

¶8 A material limitation of AIS data is gaps caused by vessels that disable their transponders (so-called 'dark' vessels) or operate in areas with limited satellite or terrestrial receiver coverage. AIS gaps may be intentional (vessels seeking to conceal unauthorised fishing activity) or unintentional (equipment failure, signal interference, or gaps in satellite coverage in remote ocean areas).

¶9 **Tiered AIS gap decision framework.** Compilers should apply the following tiered method, choosing the tier based on the duration and pattern of the observed gap:

Tier	Gap duration	Method
(a)	Under 24 hours	Linear position interpolation between the last and next valid AIS fix; interpolated positions are recorded with a provisional flag.

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Tier	Gap duration	Method
(b)	1–7 days	Statistical estimation using the ratio of observed vessel-days to expected vessel-days. Expected coverage is derived from a satellite AIS coverage model — the Copernicus Marine Service AIS density product or the Global Fishing Watch coverage layer. The expected coverage rate is documented in account metadata.
(c)	Over 7 days, or any duration where dark behaviour is suspected (vessel stationary or anomalous speed change immediately preceding the gap)	Cross-reference VMS if available under the access hierarchy in Section 3.3.2; otherwise flag the vessel-period as missing data with OBS_STATUS = "M".

¶10 **Materiality threshold.** Where gap-adjusted fishing effort exceeds **3% of unadjusted total effort**, a mandatory quality note must accompany the published account.

¶11 **Worked example.** A purse-seiner experiences a 5-day AIS gap in a zone with documented 70% expected satellite coverage. Tier (b) statistical estimation yields:

```
adjusted vessel-days = AIS-observed vessel-days / 0.70
```

¶12 where "AIS-observed vessel-days" is the count of days with valid AIS position fixes received within the reference zone during the gap-adjusted period.

¶13 A ±15% uncertainty range is documented in metadata to reflect typical variance in satellite-AIS coverage models.

¶14 Independent validation of vessel presence in areas with suspected AIS gaps can be obtained from remote sensing data. See **TG-4.1 Remote Sensing and Geospatial Data** for earth observation methods supporting AIS validation.

3.3.2 Vessel Monitoring System (VMS)

¶1 Vessel Monitoring Systems are fisheries-specific tracking systems required by many fisheries management authorities for licensed fishing vessels. Unlike AIS, VMS data are typically transmitted only to fisheries management agencies and are not publicly available. VMS systems often require more frequent position reporting than AIS (commonly every 1-2 hours, or more frequently during fishing activity).

¶2 VMS data provide fisheries managers with:

- ¶3 Verification that vessels are operating in authorised zones
- ¶4 Records of fishing effort by location for quota management
- ¶5 Evidence for enforcement actions against zone violations

¶6 For ocean accounting purposes, VMS data (where accessible under data sharing arrangements) provide higher-quality information on fishing vessel activity than AIS, particularly for smaller vessels not subject to AIS carriage requirements [24].

¶7 **VMS access fallback hierarchy.** In many jurisdictions VMS data are classified as law-enforcement sensitive and fisheries agencies are legally constrained in sharing them with statistical offices. Compilers should pursue the following access hierarchy:

1. ¶8 **Individual vessel VMS microdata under inter-agency data sharing agreement** — preferred.
2. ¶9 **Aggregated VMS effort grids** from the fisheries agency — accepted for spatial attribution accounts (zone-level effort totals) but not for individual vessel effort analysis or capital stock accounts.

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3. ¶10 **AIS-only compilation** with documented VMS non-availability, including a stated uncertainty range on effort estimates recorded in account metadata.

¶11 **Model confidentiality clause for VMS data sharing agreements.** The following clause is recommended for insertion into inter-agency agreements:

> *VMS data transferred to the [national statistical office] shall be: used exclusively for statistical compilation purposes; stored in a secure, access-controlled environment; not disclosed at the individual vessel level in any published account output; and subject to the same statistical confidentiality provisions as individual tax records.*

3.3.3 Integration with Other Data Sources

¶1 The value of vessel tracking data for ocean accounting is maximised when integrated with other administrative and statistical sources:

- ¶2 **Vessel registers** link tracking data to vessel characteristics, ownership, and license conditions
- ¶3 **Landing declarations** link fishing activity locations to catch species and volumes
- ¶4 **Customs data** complete the picture of international trade flows
- ¶5 **Business registers** enable classification of vessel operators within standard industry classifications

¶6 Such integration requires unique vessel identifiers (IMO number, national registration number, MMSI) that are consistently applied across data sources. The development of a unified vessel identifier system is recommended as part of the institutional arrangements for ocean accounting.

¶7 **Small vessel identification (sub-IMO fleet).** The IMO ship identification number scheme covers vessels of 100 gross tonnage and above in international service, and the voluntary IMO fishing vessel numbering scheme covers vessels above certain thresholds. The bulk of artisanal and small-scale fishing vessels (typically under 12 m length overall or under 100 GT) fall outside both schemes. For these vessels:

- ¶8 **National vessel register numbers** serve as the primary identifier where IMO numbers are absent. NSOs should work with fisheries agencies to assign permanent unique identifiers to all licensed vessels during register digitisation. The FAO Vessel Identification and Automated Sequencing (VIAS) scheme is recommended as a proven model for national identifier assignment.
- ¶9 **AIS-based linking is not feasible** for sub-12 m vessels (which are not legally required to carry AIS transponders). VMS matching (where available under the access hierarchy in Section 3.3.2) or **landing declaration matching** (vessel name + departure port + departure date) must serve as the primary integration mechanism for small-scale fleets.
- ¶10 **Unmatched small-vessel landing records** should be aggregated to species-zone-period totals rather than discarded, preserving total catch coverage in SEEA AFF physical flow accounts.

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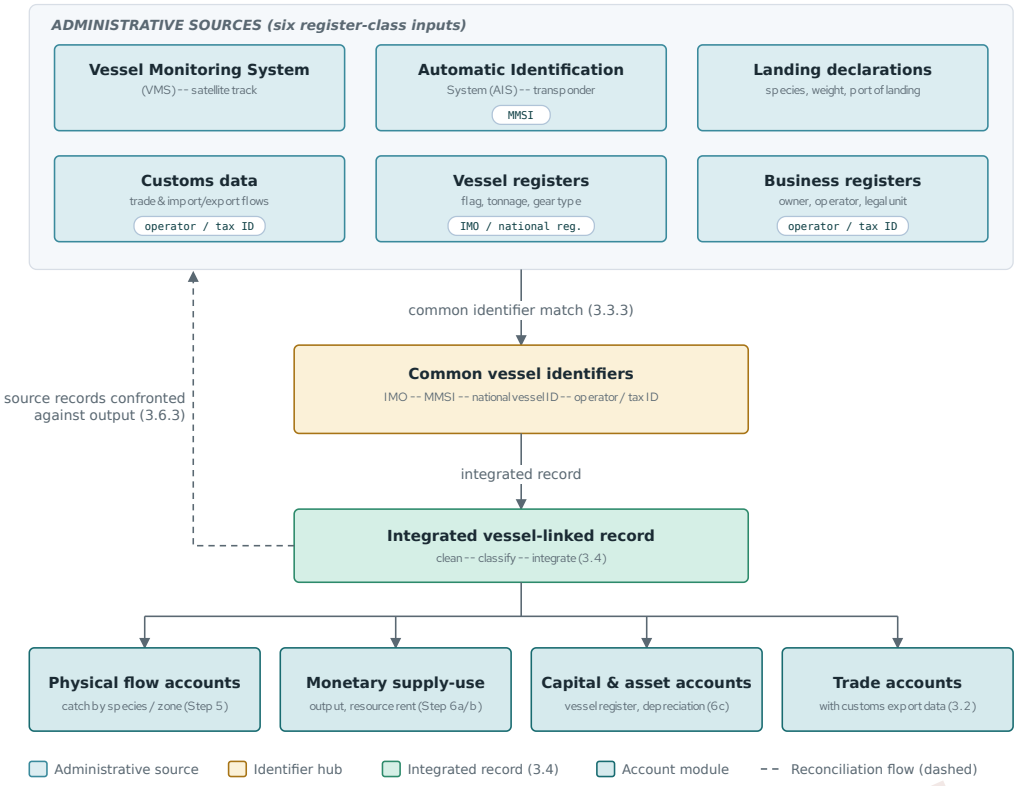


Figure 4.3.1 Six administrative sources resolve through a common-identifier hub into four vessel-linked ocean-account modules. Sources include VMS, AIS, landings, customs, and registers. Dashed reconciliation confronts sources against outputs.

Source: TG-4.3, Sections 3.3.3 (linkage keys), 3.4 (compilation workflow), 3.5 (worked example, Steps 5--6), 3.6.3 (data confrontation); UN GSBPM v5.1 Phases 4--5 (Process and Analyse); OECD Quality Framework for Statistical Activities (data integration principles).

¶11 Figure 4.3.1 traces the full integration pathway. Each of the six administrative sources carries a different linkage key. AIS broadcasts an MMSI, vessel registers record the IMO or national registration number, and customs and business registers are keyed to the operator's tax or business identifier rather than to the vessel itself (Section 3.1.0), so a common-identifier match is required before records can be combined. The matched records resolve into a single integrated vessel-linked record, which is then cleaned, classified, and integrated through the compilation workflow set out in Section 3.4. That enriched record carries catch, capacity, ownership, and price fields alongside the identifiers used to build it, and it yields the four variable sets set out in the worked example in Section 3.5: catch by species and zone (Step 5), ex-vessel prices and licence fee receipts (Steps 6(a)–(b)), vessel register attributes (Step 6(c)), and trade quantities and values, the last of these when combined with customs export data (Section 3.2). Each is delivered to the account that uses it rather than tabulated here. The dashed return flow denotes the data confrontation step (Section 3.6.3), in which source records such as landing declarations are reconciled against the integrated outputs. The broader set of account components that administrative data support beyond this vessel-identifier pathway is mapped in Section 3.7.

¶12 **Decision use cases for vessel tracking data:**

1. ¶13

Effort-based catch estimation — For data-poor stocks lacking complete landing records, AIS/VMS-derived fishing effort by zone can be combined with catch-per-unit-effort estimates to produce spatially disaggregated catch estimates.

2. ¶14
MPA compliance monitoring — Vessel tracking data enable detection of incursions into marine protected areas. These incursion records feed ecosystem condition accounts that quantify fishing pressure in protected zones.

3. ¶15
Emissions attribution — Combining vessel tracks with engine characteristics and speed-dependent emission factors enables spatial attribution of shipping emissions to coastal zones and high-traffic areas.

3.4 Administrative Data Compilation Workflow

¶1 Transforming administrative records from their source format into account-ready data requires systematic procedures. This section presents a general compilation workflow applicable across different administrative sources [25].

3.4.1 Pre-compilation Assessment

¶1 Before initiating compilation, compilers should assess:

¶2 **Data availability** — Which administrative systems exist, which agencies hold the data, and under what legal authority can the data be accessed. A systematic inventory of administrative sources relevant to ocean accounting should be prepared as part of the institutional arrangements described in **TG-0.7 Institutional Arrangements**.

¶3 **Data scope and coverage** — What population of economic units or activities is covered by the administrative system, and what known gaps exist. For example, a fishing license register covers commercial fishing but typically excludes subsistence fishing and recreational fishing.

¶4 **Update frequency and timeliness** — How often are administrative records updated, and what lag exists between the reference period and data availability. Port statistics may be available monthly with a 2-month lag, whilst annual fishing license renewals provide data only once per year.

¶5 **Data format and structure** — Whether data are available in machine-readable formats (databases, spreadsheets) or only as paper records or PDFs requiring manual extraction.

3.4.2 Data Access and Extraction

¶1 The framework for formal data sharing agreements is set out in **TG-4.7 National Data Coordination Architectures** Section 3.2, covering scope, frequency, quality standards, confidentiality regimes (statistical confidentiality, commercial sensitivity, and personal data protection), exchange formats, and dispute resolution. That guidance applies directly to agreements with fisheries departments, customs administrations, and port authorities.

¶2 Once data sharing arrangements are established, extraction procedures should be documented: database queries or API calls used to extract records, file naming and versioning conventions, storage locations and backup procedures, and any manual interventions required.

3.4.3 Data Cleaning and Validation

¶1 General data cleaning and validation procedures follow the classify-map-validate-integrate workflow in **TG-4.6 Data Harmonisation and Interoperability** Section 3.5 (Phase 3: Validate), covering missing values, inconsistent formats, duplicate records, out-of-scope records, and implausible values. The documentation requirements for quality assurance procedures (automated rules, manual review protocols, imputation decisions, and adjustments) are set out in **TG-0.7 Quality Assurance Principles**.

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¶2 **Critical fields and imputation rules — administrative data.** For ocean accounting, "critical fields" are defined as: vessel identifier, catch volume (tonnes), catch species (FAO ASFIS alpha-3 code), fishing zone code, and reporting period (year or quarter). Imputation is acceptable for critical fields only where record-level missingness does not exceed **5% of records within a species-zone-period cell**. Above this threshold the data source is rated as not fit for direct compilation, and supplementary estimation methods (e.g., sample survey expansion) must be applied instead. The default imputation method is **nearest-neighbour hot-deck imputation**, with donor pools defined by matching on vessel class, season, and fishing zone, the three variables most predictive of catch composition. All imputed values in account output tables must carry an OBS_STATUS attribute of "E" (estimated), consistent with the SDMX OBS_STATUS codelist and the conventions of TG-4.6.

3.4.4 Classification Mapping

¶1 The concordance development process (structural comparison, conceptual alignment, mapping relationships, documentation, and validation) and the management of temporal concordances across ISIC and CPC revisions are covered in **TG-4.6 Data Harmonisation and Interoperability** Section 3.4. The following example illustrates the application of that concordance process to fisheries administrative categories.

¶2 **Example: Fishing license type to ISIC mapping**

License Type (Administrative)	ISIC Rev.4	ISIC Description
Commercial fishing license	0311	Marine fishing
Coastal fishing license	0311	Marine fishing
Aquaculture license - finfish	0321	Marine aquaculture
Aquaculture license - shellfish	0321	Marine aquaculture
Recreational fishing permit	(Not in ISIC — household production)	-

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3.4.5 Preparing Records for Delivery

¶1 Once administrative data are cleaned and classified, they are prepared for delivery to the compiling circular. Preparation procedures include:

¶2 **Business register matching** — Linking licence holders or permit applicants to business register entries using business identifiers (tax numbers, registration numbers). Matching on a shared business identifier enables consistent industry classification and aggregation with other business statistics.

¶3 **Temporal alignment** — Aligning administrative reference periods (license validity periods, customs clearance dates) with accounting periods (typically calendar years).

¶4 **Unit conversion** — Converting administrative units (license counts, permit capacities) to accounting units (number of enterprises, production volumes, capital stock values).

¶5 **Aggregation and tabulation** — Aggregating individual administrative records to the reporting level the account requires (industry totals, product categories, geographic zones), so that the variable is delivered at the granularity the account table expects. Placing the aggregates into account rows, and any balancing that follows, is done in the compiling circular — **TG-3.3 Economic Activity Relevant to the Ocean** for ocean industry flows, **TG-3.1 Asset Accounts** for asset entries.

3.4.6 Compilation Documentation

¶1 Compilation documentation requirements follow the general quality documentation framework in **TG-0.7 Quality Assurance Principles** and the metadata standards in **TG-4.6 Data Harmonisation and Interoperability** Section 3.6, covering data sources, cleaning procedures, classification mappings, assumptions, known limitations, and comparisons with previous rounds.

The source register template in Section 3.7.1 below provides the administrative-data-specific documentation format for recording custodian details, legal access basis, and quality ratings for each administrative source.

3.5 Worked Example: Fisheries Licensing Data for Catch Accounts

¶1 This section presents a synthetic worked example illustrating how fishing license data can be integrated with catch reporting data to populate physical flow accounts for capture fisheries, and how the same administrative data are extended to populate monetary production accounts. The example demonstrates the complete workflow from administrative records to account entries.

Context

¶1 The national fisheries authority maintains a database of commercial fishing licenses. Each license record includes vessel identification, authorised fishing areas, target species, and gear types. Vessel operators are required to submit monthly catch reports specifying species caught, volumes, and fishing locations. The national statistical office seeks to compile annual physical flow accounts for capture fisheries showing catch by species and marine zone, and to extend these into monetary supply-use entries.

Step 1: Data Access

¶1 A formal data sharing agreement is established between the statistical office and fisheries authority, specifying quarterly transfer of:

- ¶2 License register extract (all active licenses for the accounting year)
- ¶3 Catch reports database (all submitted reports for the accounting year)
- ¶4 Vessel register (vessel characteristics for all licensed vessels)

¶5 Data are transferred as CSV files via secure file transfer protocol.

Step 2: Data Extraction

¶1 **License register extract** (sample records):

License_ID	Vessel_ID	Operator_Name	Valid_From	Valid_To	Zone_Code	Species
LIC-2023-0147	VES-0893	Blue Seas Fishing Ltd	2023-01-01	2023-12-31	EEZ-NORTH	TUN
LIC-2023-0148	VES-0722	Ocean Harvest Co	2023-01-01	2023-12-31	EEZ-SOUTH	SNA,GR
LIC-2023-0149	VES-1054	Coastal Catch Ltd	2023-01-01	2023-12-31	TS-WEST	MUL

¶2 **Catch reports database** (sample records):

Report_ID	Vessel_ID	Report_Month	Species_Code	Catch_Tonnes	Zone_Code	
CR-2023-01-0147	VES-0893	2023-01	TUN	12.4	EEZ-NORTH	
CR-2023-02-0147	VES-0893	2023-02	TUN	8.7	EEZ-NORTH	
CR-2023-01-0148	VES-0722	2023-01	SNA	3.2	EEZ-SOUTH	
CR-2023-01-0148	VES-0722	2023-01	GRO	1.8	EEZ-SOUTH	

Step 3: Data Cleaning and Validation

¶1 **Check 1: Coverage completeness**

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```
Licensed vessels with no catch reports: 12 vessels (8% of register)
Catch reports from unlicensed vessels: 0 (good)
```

¶2 Interpretation: 12 vessels licensed but not reporting catches may be inactive or non-compliant. Flag for follow-up with fisheries authority.

¶3 **Check 2: Spatial compliance**

```
Catch reports from zones outside licensed areas: 3 reports (0.5% of total)
```

¶4 Interpretation: Small number of zone violations detected. These catches are included in accounts but flagged for enforcement follow-up.

¶5 **Check 3: Temporal alignment**

```
Late reports (submitted >60 days after reference month): 47 reports (8% of total)
```

¶6 Interpretation: Most reports submitted on time. Late reports are included in annual accounts but noted for quality documentation.

¶7 **Check 4: Plausibility**

```
Reports with catch > vessel hold capacity: 2 reports
Reports with implausible coordinates: 5 reports
```

¶8 Interpretation: 7 reports flagged for manual review. After consultation with fisheries authority, 5 corrected, 2 excluded as data errors.

Step 4: Classification Mapping

¶1 **Species code to ISSCAAP mapping** (International Standard Statistical Classification of Aquatic Animals and Plants):

Fisheries Authority Code	ISSCAAP Code	Common Name	Scientific Name
TUN	36	Tuna	Thunnus spp.
SNA	33	Snapper	Lutjanus spp.
GRO	33	Grouper	Epinephelus spp.
MUL	34	Mullet	Mugil spp.

¶2 **Zone code to marine spatial unit mapping:**

Fisheries Authority Zone	Marine Spatial Unit	Area (km²)
EEZ-NORTH	EEZ Zone 1 (Northern)	425,000
EEZ-SOUTH	EEZ Zone 2 (Southern)	380,000
TS-WEST	Territorial Sea (West)	12,000

Step 5: Delivering the Physical Catch Variable

¶1 **Aggregation of catch reports to annual totals:**

Species_Code	Zone_Code	Total_Catch_Tonnes
TUN	EEZ-NORTH	1,247
SNA	EEZ-SOUTH	382
GRO	EEZ-SOUTH	198

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Species_Code	Zone_Code	Total_Catch_Tonnes
MUL	TS-WEST	456

¶2 **Link to business register for industry classification:**

¶3 Using Vessel_ID → Operator_Name → Business_Register_ID matching:

- ¶4 138 licensed vessels matched to 47 fishing enterprises
- ¶5 12 vessels with no catch reports correspond to 8 enterprises (likely inactive)
- ¶6 All enterprises classified as ISIC 0311 (Marine fishing)

¶7 **Variable delivered:**

Industry (ISIC)	Product (ISSCAAP)	Spatial Unit	Catch (tonnes)
0311 Marine fishing	36 Tuna	EEZ Zone 1	1,247
0311 Marine fishing	33 Snapper/Grouper	EEZ Zone 2	580
0311 Marine fishing	34 Mullet	Territorial Sea (West)	456
Total catch			**2,283**

¶8 Catch is delivered by industry, product and spatial unit, with the coverage and quality statement from Step 7. Entering it in the physical supply and use table is done in **TG-3.3 Economic Activity Relevant to the Ocean**; the corresponding stock entries are in **TG-3.1 Asset Accounts** Section 3.4.1.

Step 6: Delivering the Monetary and Capital Variables

¶1 The same administrative records yield three further variables. This Circular is responsible for extracting them, documenting their coverage and stating their basis; the valuation conventions that turn them into monetary account entries are applied in the compiling circular.

¶2 **(a) Ex-vessel prices.** Fish market transaction records (or, where unavailable, fisheries agency price surveys) give an observed ex-vessel price per species-zone cell — for the worked example, USD 3,400 per tonne for tuna. Deliver the price with its source, reference period, and whether it is inclusive or exclusive of taxes on products, so that the account can place it on the required price basis. Valuing output is **TG-3.3 Economic Activity Relevant to the Ocean**, which applies the SNA basic-price convention.[26]

¶3 **(b) Licence fee receipts.** Annual licence fee receipts are read directly from the fisheries agency revenue system and delivered as a government receipt series, identified by the access right they are charged for. Whether they are recorded as rent on a natural asset or as a tax on production is an accounting classification, taken in **TG-3.3** for the transaction and in **TG-3.1 Asset Accounts** Section 3.3 where they inform resource rent.

¶4 **(c) Vessel register attributes.** Gross registered tonnage, vessel age and service status are extracted per vessel. Inactive vessels identified under the 10% threshold in Section 3.1.1 are flagged rather than removed, so the account can decide their treatment. Applying a depreciation profile to derive written-down capital stock is **TG-3.1 Asset Accounts** Section 3.6.

Step 7: Quality Assessment and Documentation

¶1 **Coverage estimate:**

```
Licensed vessels: 150
Vessels reporting catches: 138 (92%)
Estimated coverage of commercial fishing: 90-95%
```

¶2 Known gaps:

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- ¶3 Subsistence fishing (not licensed): estimated 200-300 tonnes annually based on household surveys
- ¶4 Recreational fishing (licensed but not included in commercial statistics): estimated 50-100 tonnes annually
- ¶5 Unreported commercial fishing (IUU): unknown, likely <5% based on enforcement records

¶6 **Data quality flags:**

- ¶7 License register: Good quality, updated annually, 92% reporting rate
- ¶8 Catch reports: Moderate quality, 8% late submission, 0.5% spatial violations, <1% plausibility issues
- ¶9 Classification: Standard ISSCAAP codes used, consistent with international reporting

¶10 **Comparability with previous years:**

- ¶11 2022 total catch: 2,156 tonnes
- ¶12 2023 total catch: 2,283 tonnes (6% increase)
- ¶13 Change consistent with license register growth (5 additional licenses issued in 2023)

¶14 **Integration with other accounts:**

¶15 This physical catch account feeds into:

- ¶16 Fisheries asset accounts (extraction component, see **TG-6.7 Fisheries Accounting**)
- ¶17 Supply-use tables (domestic production of seafood products, see **TG-3.3 Economic Activity**)
- ¶18 Trade accounts (when combined with customs export data, see Section 3.2)

Lessons from the Example

1. ¶1
   Integration requires unique identifiers — Vessel_ID enabled linking across the licence register, catch reports, and business register. Consistent identifiers are a prerequisite.
2. ¶2
   Coverage gaps and data confrontation — Some licensed vessels will not report. Cross-checking against licensed zones and vessel capacities identifies implausible records. Document known gaps for users.
3. ¶3
   Mappings and documentation must be maintained — Species and zone codes require translation to standard classifications, and full source documentation is essential for fitness-for-use assessment and future revision.

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3.6 Quality Assurance for Administrative Data

¶1 The generic data-quality framework (UN NQAF dimensions: assessment, documentation, uncertainty) is in **TG-0.7 Quality Assurance Principles**. The subsections below address quality issues specific to administrative-data reuse: coverage gaps from regulatory scope, IUU adjustment, conceptual alignment with SNA, and data confrontation against survey benchmarks.

3.6.1 Coverage and Completeness

¶1 Administrative coverage depends on regulatory scope. Under-coverage arises for subsistence and recreational fishing without licensing, small vessels exempt from AIS, and informal-sector activities outside business registers. Over-coverage from inactive licence holders is handled via the materiality threshold and register audit in Section 3.1.1. SEEA AFF requires IUU fishing to be reflected in catch statistics where feasible, often via model-based estimation[27].

¶2 **Tiered IUU estimation approach.** Compilers should apply the following tiered methodology to produce IUU adjustment estimates:

1. ¶3 **Primary — AIS dark-vessel analysis.** Where national or regional surveillance data are available, use AIS dark-vessel analysis (Global Fishing Watch or equivalent national system) to identify non-reporting periods and estimate unreported effort.
2. ¶4 **Secondary — catch reconstruction.** Where catch reconstruction data exist (e.g., Sea Around Us national reconstruction series), apply the reconstruction methodology to produce an IUU adjustment estimate and reconcile against reported landing declarations.
3. ¶5 **Default — regional governance proxy.** For data-poor contexts lacking both surveillance and reconstruction data, apply a default IUU adjustment factor of **15–30% of reported catch**, calibrated to regional enforcement-capacity proxies (e.g., OECD/FAO Fisheries Outlook governance indicators), and flag the estimate as a modelled default.

¶6 Regardless of tier, IUU estimates must be: (a) labelled as "modelled — IUU adjustment" in account tables; (b) published with explicit uncertainty intervals; (c) recorded in a separate account row from directly observed catch data, not merged into reported totals. SDG indicator 14.6.1 addresses the complementary trade-based dimension of IUU detection discussed in Section 3.2.1.

¶7 For small-scale and artisanal fisheries that are often under-represented in administrative data, complementary survey methods may be required, as discussed in **TG-4.2 Survey Methods**. Specific methods for estimating the contribution of the informal sector to fisheries output include:

- ¶8 **Frame surveys** — Periodic enumeration of landing sites, vessels, and fishing gear to establish the population of informal operators. Frame surveys are particularly effective in the Pacific Islands context where artisanal fisheries are concentrated at known landing points. The survey establishes a sampling frame from which regular catch monitoring can be conducted.
- ¶9 **Catch assessment surveys** — Systematic sampling of landings at selected sites over defined periods, with results raised to the total population using frame survey estimates. The FAO recommends stratified sampling by landing site, vessel type, and season to capture the variability inherent in small-scale fisheries [28].
- ¶10 **Household surveys** — Labour force surveys or household income and expenditure surveys that include questions on fishing activity, catch quantities, and disposal (sale, subsistence consumption, barter). These surveys capture the full population of fishing households, including those not registered in any administrative system.
- ¶11 **Key informant estimation** — For the smallest-scale activities, community-level estimates from fisheries officers or village leaders can provide plausibility bounds when more rigorous methods are not feasible.

¶12 Compilers should document the methods used to estimate informal sector contributions and the associated uncertainty, and flag the resulting estimates as modelled rather than directly observed.

3.6.2 Conceptual Alignment

¶1 Administrative concepts may not align with statistical definitions:

¶2 **Timing differences** — Administrative records may be dated by registration rather than occurrence (e.g., landing date versus catch date)

¶3 **Valuation differences** — Customs values (CIF/FOB) may differ from the transaction prices required for national accounts

¶4 **Classification differences** — Administrative product codes may not correspond to statistical classifications (CPC, HS)

¶5 **Geographic scope** — Jurisdictional boundaries for regulation may differ from accounting territories

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¶6 Conceptual alignment requires documentation of differences and systematic bridging procedures that transform administrative data to statistical frameworks [29].

¶7 **Valuation basis of customs records.** Customs records report CIF values for imports and FOB values for exports, whilst SNA supply-use tables require flows valued at basic prices. Compilers should deliver customs-sourced trade variables in their **recorded basis, labelled as CIF or FOB**, together with the freight, insurance, margin and product-tax fields needed to convert them. Choosing and applying the price basis for the supply-use cell is a valuation decision taken in the account: see **TG-3.3 Economic Activity Relevant to the Ocean**, and SNA 2025 Chapter 15 paras. 15.36–15.42 with IMTS 2010 Chapter 4 for the underlying conventions. [30] The trade margin coefficients and product-tax rates required for that conversion should be obtained from the national accounts unit responsible for the published supply-use tables rather than estimated within the source-processing step.

3.6.3 Data Confrontation

¶1 The general data confrontation framework, comprising internal consistency checks, cross-source reconciliation, benchmark comparison, and physical plausibility assessment, is covered in **TG-4.6 Data Harmonisation and Interoperability** Section 3.5 (Phase 3: Validate) [31]. For administrative data specifically, confrontation of landing declarations against customs export records and vessel-capacity range checks against catch reports are the most productive cross-source checks. These are illustrated in the worked example in Section 3.5. [32], [33]

3.6.4 Temporal Consistency

¶1 Time series analysis of administrative data should identify:

- ¶2 Breaks in series due to changes in regulatory scope or concepts
- ¶3 Changes in reporting compliance over time
- ¶4 Effects of digitisation or administrative reforms on data availability

¶5 Where discontinuities exist, back-casting or adjustment procedures may be required to produce consistent time series for accounting purposes.

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3.6.5 Institutional Arrangements for Data Access

¶1 Access to administrative data for statistical purposes requires legal authority, data sharing agreements, secure transfer infrastructure, and confidentiality protocols. [34] Template agreements and the full governance framework are in **TG-0.7 Institutional Arrangements** and **TG-4.7 National Data Coordination Architectures**.

3.7 Upward Connections to Account Uses

¶1 Administrative data flow into multiple components of Ocean Accounts and support several analytical uses. Understanding these upward connections helps compilers prioritize data development efforts and communicate the value of administrative data integration to custodian agencies. Table 3.7.1 maps the main administrative sources to the account components they populate and the policy uses they support.

¶2 *Table 3.7.1: Administrative data sources, account components, and policy uses*

Administrative Source	Account Component	Policy Use
Fishing licenses	Fisheries asset accounts (vessel capacity, fleet structure)	Fleet management, overcapacity assessment, license allocation policy
Landing declarations	Physical flow accounts (catch by species and zone)	Stock status monitoring, SDG 14.4.1 reporting, quota compliance
Aquaculture permits	Cultivated asset accounts (production capacity, spatial distribution)	Aquaculture development planning, coastal zone management

Administrative Source	Account Component	Policy Use
Customs trade data	Supply-use tables (imports/exports by product)	Trade policy, value chain development, IUU fishing detection
Vessel tracking (AIS/VMS)	Pressure accounts (fishing effort, shipping emissions by zone)	Marine spatial planning, MPA effectiveness, SDG 14.5 indicators
Offshore permits	Mineral asset accounts (reserves, extraction), residual flow accounts	Resource management, environmental impact assessment, dumping regulation
Port statistics	Maritime transport accounts (cargo throughput, vessel movements)	Port infrastructure investment, shipping efficiency, connectivity indices

¶3 These connections indicate that administrative data serve several account purposes at once. For example, fishing licence data feed into both asset accounts (measuring the capital stock of the fishing fleet) and pressure accounts (measuring fishing effort by zone). Because a single source serves several account domains, investment in improving administrative data quality generates benefits across all of them.

¶4 Compilers should maintain a register of administrative sources showing which account components depend on each source, the update frequency required, and the priority for quality improvement. This register supports dialogue with custodian agencies and demonstrates the value of their data systems for national statistical programmes, whilst enabling coordinated improvements in data infrastructure.

3.7.1 Administrative Source Register — Minimum-Fields Template

¶1 To support comparability across countries and regional benchmarking, the source register should capture the following ten minimum fields for each administrative source:

#	Field	Description
1	Source ID	Unique alphanumeric identifier assigned by the compiling agency
2	Source name	Common name of the register or dataset
3	Custodian agency	Agency with statutory authority over the source (per Section 3.1.0)
4	Legal access basis	Citation of legislation or reference to inter-agency data-sharing agreement
5	Data elements available	List of fields supplied to the compiling agency
6	Update frequency	Annual / quarterly / continuous
7	Typical lag (months)	Months from reference-period close to data availability
8	Format	Relational database / spreadsheet / PDF / API endpoint
9	Account components populated	Cross-referenced to account-table rows that depend on the source
10	Data quality rating	1–5 against NQAF dimensions; date last reviewed

¶2 **Example completed row — national fishing license register:**

#	Field	Entry
1	Source ID	NLR-FISH-001
2	Source name	National Fishing License Register
3	Custodian agency	Ministry of Fisheries — Licensing Division
4	Legal access basis	Statistics Act s.24 + MoU between NSO and Ministry of Fisheries (2024)

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#	Field	Entry
5	Data elements available	License ID, vessel ID, operator name, valid-from/to dates, authorised zone, target species, gear type, license fee paid
6	Update frequency	Annual (with quarterly amendments file)
7	Typical lag (months)	3 months
8	Format	Relational database extract (CSV via SFTP)
9	Account components populated	Fisheries asset accounts (capital stock); supply-use (government revenue); physical flow (capacity benchmark)
10	Data quality rating	4 / 5 (high accuracy, moderate timeliness); reviewed 2025-11

¶3 The source register should be maintained under the governance framework set out in **TG-0.7 Institutional Arrangements** and reviewed at each annual inter-agency data-governance meeting.

4. Summary

¶1 Administrative data sources provide essential inputs for Ocean Accounts and offer wide coverage of regulated maritime activities at relatively low cost. These three data categories together describe the population, scope, flows, and activity patterns of ocean-related maritime activity. Effective use of these data sources requires attention to quality assurance, conceptual alignment with statistical frameworks, and institutional arrangements for data sharing. The accounting framework itself provides a mechanism for confronting data from multiple sources and identifying inconsistencies that can then be resolved through consultation with data custodians.

¶2 National statistical offices and ocean accounting agencies should develop systematic programmes to identify, access, and integrate administrative data sources, working collaboratively with regulatory authorities to improve data quality and expand coverage over time. The compilation workflow presented in Section 3.4 and the worked example in Section 3.5 provide practical guidance for transforming administrative records into account-ready data, including the physical-to-monetary extension, whilst Section 3.7 demonstrates the multiple account uses that administrative data support and provides a minimum-fields template for the source register that anchors inter-agency data governance.

¶3 Administrative data are a foundation for ocean accounting, particularly in countries where statistical capacity is limited and survey programmes are costly. By building partnerships with fisheries authorities, maritime agencies, customs administrations, and other custodians of administrative data, statistical offices can compile Ocean Accounts that support evidence-based ocean management and contribute to SDG 14 monitoring and reporting.

5. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

FOOTNOTES

1. ¶1 United Nations, 2014, *System of Environmental-Economic Accounting 2012: Central Framework*, Chapter VI, recognizing the importance of integrating data from diverse sources including administrative records for environmental-economic accounts.
2. ¶2 Wallgren, A. and B. Wallgren, 2014, *Register-based Statistics: Administrative Data for Statistical Purposes*, 2nd edition, Wiley, Ch. 1.
3. ¶3 Food and Agriculture Organization (FAO), 2020, *The State of World Fisheries and Aquaculture 2020*, Ch. 4 on fisheries governance and management frameworks.
4. ¶4 United Nations, 1982, *United Nations Convention on the Law of the Sea* (UNCLOS), Article 56 establishes sovereign rights of coastal States over living resources in the EEZ; Article 57 specifies the 200 nautical mile limit.

5. ¶5 United Nations and FAO, 2018, *System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries* (SEEA AFF), para. 3.164, distinguishing capture fisheries (ISIC 031) and aquaculture (ISIC 032).
6. ¶6 FAO, 1994 (updated), *Converting fish catches to live weight equivalent: conversion factors for 178 species*; FFA Vessel Day Scheme documentation on species-specific catch-per-vessel-day coefficients.
7. ¶7 OECD, 2006, *Using Market Mechanisms to Manage Fisheries: Smoothing the Path*, discusses ITQ systems and their data implications for resource valuation.
8. ¶8 SNA 2025, para. 20.14, on the treatment of idle fixed assets in balance sheets; FAO, 2003, *The Use of Vessel Monitoring Systems in Fisheries Management*, Section 4 on fleet register reconciliation.
9. ¶9 SEEA AFF, para. 3.166, defines aquaculture as farming of aquatic organisms with intervention in the rearing process and ownership of cultivated stock.
0. ¶10 SEEA AFF, para. 2.39, notes that residual flows from agriculture, forestry and fisheries activities can be incorporated as extensions to physical flow accounts.
1. ¶11 SEEA CF paras. 3.138–3.140 on residual flows and gross recording; Boyd et al. (2020), *Achieving sustainable aquaculture: Historical and current perspectives*, discussing IMTA nutrient accounting.
2. ¶12 UNCLOS Part VI (Continental Shelf) and Part XI (The Area) establish the framework for mineral resource exploitation in maritime zones.
3. ¶13 International Maritime Organization, 1996, *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972* (London Protocol).
4. ¶14 UNCLOS Article 246 specifies conditions for marine scientific research in the EEZ, requiring consent of the coastal State.
5. ¶15 SEEA CF paras. 5.19–5.22 on the accounting boundary for subsoil assets; ISA Exploitation Regulations (2023 draft); UNCLOS Part XI (The Area).
6. ¶16 United Nations, 2010, *International Merchandise Trade Statistics: Concepts and Definitions 2010*, provides standards for trade statistics based on customs data.
7. ¶17 SEEA AFF, para. 3.168, specifies that imports of fisheries commodities should be recorded in live weight equivalent for consistency in physical flow accounts; see also para. 3.165 on nominal catch in live weight equivalent.
8. ¶18 SEEA AFF, para. 3.153, on the structure of supply and use for fish products including domestic production, imports, intermediate use, consumption and exports; with import recording guidance at para. 3.168.
9. ¶19 SEEA AFF, para. 3.176-3.177, discusses the treatment of fish caught by foreign vessels in a country's EEZ and the distinction between residence of fishing vessel operator and location of catch.
0. ¶20 United Nations, 2015, *Transforming our World: The 2030 Agenda for Sustainable Development*, SDG Target 14.6 and Indicator 14.6.1 on combating IUU fishing.
1. ¶21 International Maritime Organization, SOLAS Convention Chapter V, Regulation 19, establishes AIS carriage requirements for vessels on international voyages.
2. ¶22 Global Fishing Watch, 2018, *Tracking the Global Footprint of Fisheries*, demonstrates large-scale analysis of fishing activity from AIS data.
3. ¶23 Kroodsma, D.A. et al., 2018, *Tracking the global footprint of fisheries*, Science 359(6378): 904-908, providing methods for inferring fishing behaviour from vessel tracks.
4. ¶24 FAO, 2015, *Voluntary Guidelines for Flag State Performance*, addresses monitoring and surveillance including VMS requirements for fishing vessels.
5. ¶25 United Nations Economic Commission for Europe (UNECE), 2011, *Using Administrative and Secondary Sources for Official Statistics: A Handbook of Principles and Practices*, provides comprehensive guidance on quality assessment.
6. ¶26 SNA 2025, paras. 6.51–6.55 on output at basic prices; SEEA AFF, Chapter 3 on monetary flow accounts.
7. ¶27 SEEA AFF, para. 3.162, notes that gross catch should in theory include IUU fishing but this is difficult in practice; para. 3.165 similarly notes that nominal catch should in principle include retained catch from IUU activity.
8. ¶28 FAO, 2002, *Sample-Based Fishery Surveys: A Technical Handbook*, FAO Fisheries Technical Paper No. 425, provides detailed guidance on catch assessment survey design for small-scale fisheries.
9. ¶29 SNA 2025, Chapter 15 (Supply and use tables), paras. 15.5 ff., describes data confrontation across sources including administrative data; see also the UNECE *Using Administrative and Secondary Sources for Official Statistics* (2011) for detailed bridging procedures.
0. ¶30 SNA 2025, Chapter 15 (Supply and use tables), paras. 15.36–15.42 on valuation of trade flows; IMTS 2010, Chapter 4 on valuation of merchandise trade.
1. ¶31 SEEA Central Framework, para. 1.58, notes that the accounting framework enables data confrontation and quality assessment across sources.
2. ¶32 SEEA AFF, para. 2.52, discusses consistency between physical flow accounts and asset accounts as a quality check mechanism.
3. ¶33 SEEA AFF, para. 3.13, emphasizes that the supply-and-use approach ensures internal consistency and coherence of data from different sources through confrontation and reconciliation.
4. ¶34 United Nations Fundamental Principles of Official Statistics, Principle 6, on confidentiality of individual data collected for statistical purposes.

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Citizen Science and Community-Based Monitoring

Provides guidance on incorporating citizen science and community-based monitoring data into ocean accounts.

Version 0.7.1 **Status** Draft **Stability** Emerging

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Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on incorporating citizen science and community-based monitoring data into ocean accounts, with particular attention to quality assurance for non-official data sources and compilation procedures for integrating volunteer-collected data with official statistics. Readers will gain an understanding of the types of marine citizen science programmes that can generate useful data for ocean accounting, the quality considerations that must be addressed when working with such data, approaches for integrating non-official data sources with official statistics, and concrete compilation procedures for processing citizen science observations into account-ready datasets. The guidance recognises that methods for incorporating citizen science data into official statistics are still developing, and standards in this area continue to evolve. Given this Emerging status, compilers should exercise appropriate caution when incorporating citizen science data into ocean accounts, clearly document the data sources and quality considerations, and be prepared to update approaches as methodological standards evolve.

Where relevant, this Circular identifies connections with traditional and indigenous knowledge systems, though the detailed treatment of these knowledge systems is provided in TG-3.6 Traditional Knowledge. Given the relevance of citizen science data to ecosystem condition monitoring, familiarity with ecosystem accounting concepts from TG-3.3 Economic Activity Relevant to the Ocean is recommended. The quality assurance framework applicable to all ocean accounting data, including citizen science contributions, is established in TG-0.7 Quality Assurance Principles. Key terms used in this Circular are defined in TG-0.6 Glossary of Key Terms. Indicators derived from citizen science monitoring programs may support the indicator frameworks described in TG-2.1 Aggregate Biophysical Indicators of Environmental State.

Citizen science data may contribute to multiple account types within the ocean accounting framework. TG-3.5 Social Accounts addresses the broader framework for social accounts, including community wellbeing and participatory assessment. TG-6.12 Marine Litter and Plastics Accounting specifically addresses beach litter surveys conducted by volunteer groups as a source for marine pollution accounts.

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¶1 **Framework Position**

¶2 TG-4.4 sits within Section 4 (Data Methods). It owns the treatment of volunteer-collected observations as a statistical source: programme typology, tier assignment, bias assessment and calibration against official data, FPIC and CARE governance for community-based monitoring, and the provenance and uncertainty that must travel with every citizen science estimate. It does not own the accounts those estimates feed. Ecosystem extent and condition accounts are **TG-3.1 Asset Accounts** Sections 3.5.1–3.5.2; marine litter stock accounts are **TG-6.12 Marine Litter and Plastics Accounting**.

1. Outcome

¶1 This Circular provides guidance on incorporating citizen science and community-based monitoring data into ocean accounts, with particular attention to quality assurance for non-official data sources and compilation procedures for integrating volunteer-collected data with official statistics. Readers will gain an understanding of the types of marine citizen science programmes that can generate useful data for ocean accounting, the quality considerations that must be addressed when working with such data, approaches for integrating non-official data sources with official statistics, and concrete compilation procedures for processing citizen science observations into account-ready datasets. The guidance recognises that methods for incorporating citizen science data into official statistics are still developing, and standards in this area continue to evolve. Given this Emerging status, compilers should exercise appropriate caution when incorporating citizen science data into ocean accounts, clearly document the data sources and quality considerations, and be prepared to update approaches as methodological standards evolve.

¶2 Where relevant, this Circular identifies connections with traditional and indigenous knowledge systems, though the detailed treatment of these knowledge systems is provided in **TG-3.6 Traditional Knowledge**. Given the relevance of citizen science data to ecosystem condition monitoring, familiarity with ecosystem accounting concepts from **TG-3.3 Economic Activity Relevant to the Ocean** is recommended. The quality assurance framework applicable to all ocean accounting data, including citizen science contributions, is established in **TG-0.7 Quality Assurance Principles**. Key terms used in this Circular are defined in **TG-0.6 Glossary of Key Terms**. Indicators derived from citizen science monitoring programs may support the indicator frameworks described in **TG-2.1 Aggregate Biophysical Indicators of Environmental State**.

¶3 Citizen science data may contribute to multiple account types within the ocean accounting framework. **TG-3.5 Social Accounts** addresses the broader framework for social accounts, including community wellbeing and participatory assessment. **TG-6.12 Marine Litter and Plastics Accounting** specifically addresses beach litter surveys conducted by volunteer groups as a source for marine pollution accounts.

2. Requirements

¶1 This Circular requires familiarity with:

- ¶2
  TG-0.1 General Introduction to Ocean Accounts – provides foundational understanding of Ocean Accounts components and the relationship between environmental and economic accounting frameworks.
- ¶3
  TG-0.7 Quality Assurance Principles – establishes the general quality framework applicable to ocean accounting data, including the quality dimensions and metadata standards that must be applied when assessing fitness for purpose of citizen science contributions.
- ¶4

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TG-3.1 Asset Accounts — for the ecosystem condition and extent accounting frameworks to which citizen science data on marine biodiversity and habitat condition can contribute, including the biophysical indicators and tiered measurement approaches referenced in this Circular.

3. Guidance Material

¶1 The *Framework for the Development of Environment Statistics* (FDES 2013) recognises that environment statistics draw upon diverse data sources, including "scientific research and special projects undertaken to fulfil domestic or international demand"[1]. In the marine context, citizen science programmes can provide observations on coastal conditions, marine species distributions, and environmental quality that may complement or extend official data collection in contexts where official monitoring networks have limited spatial or temporal coverage.

¶2 Integrating citizen science data into official statistical frameworks involves substantial methodological considerations. The *SEEA Ecosystem Accounting* (SEEA EA) emphasises that "appropriate review and validation of the data will be required, including, for example, consideration of the various measurement concepts and scopes that have been applied, to ensure that the data are suitable for the purposes of ecosystem accounting and that coherence across the accounts can be achieved"[2]. This principle applies with particular force to non-official data sources, where measurement methods may not conform to established statistical standards.

¶3 This section provides guidance on four key aspects of working with citizen science and community-based monitoring data: the types of programs that generate relevant data, the quality considerations that must be addressed, approaches for integration with official statistics, and compilation procedures for processing citizen science observations into account-ready datasets. For general principles of data quality applicable across all ocean accounting work, see **TG-0.7 Quality Assurance Principles**.

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3.1 Types of Citizen Science Programs

¶1 Marine citizen science covers a range of programmes in which volunteers participate in scientific data collection. These programmes vary in their structure, the types of data collected, and their potential relevance to ocean accounting. For the purposes of this guidance, citizen science programmes can be organised into several categories based on their primary focus and methodology.

¶2 Several established programmes in the Pacific region illustrate the range and maturity of marine citizen science, including the reef monitoring programmes described in Section 3.2. These programmes demonstrate that well-designed citizen science can produce data suitable for monitoring ecosystem condition variables relevant to ocean accounts.[3], [4], [5], [6], [7]

Biological monitoring programs

¶1 Many marine citizen science programmes document the presence, abundance, or condition of marine species. Table 3.1.1 below summarises the main types.

Program type	Description
Reef monitoring programs	Volunteers conduct standardized surveys of coral reef health, recording coral cover, bleaching events, and associated fauna. Programs such as Reef Check have developed standardized protocols that enable consistent data collection across sites and time periods[3].
Seabird and marine mammal counts	Coastal bird counts and marine mammal sightings programs engage volunteers in systematic observations that contribute to population monitoring. These programs often have long histories that provide valuable time series data[8].

Program type	Description
Fish identification and abundance surveys	Recreational divers and snorkelers contribute observations of fish species and abundance, particularly in areas of high recreational use such as marine parks [5] .
Intertidal zone surveys	Volunteers survey rocky shores, mudflats, and other intertidal habitats, documenting species assemblages and environmental conditions [9] .

¶2 These biological monitoring programmes may contribute to ecosystem condition accounts under the SEEA EA framework, particularly for variables relating to species diversity and population status. The *Technical Guidance on Biophysical Modelling for SEEA Ecosystem Accounting* notes that "in situ monitoring and accuracy assessments of ecosystem services maps" are needed, and that "standardized approaches for in situ monitoring of ecosystem services is even less well established than modelling approaches" [10] , [11] .

Environmental quality monitoring

¶1 Citizen science programmes also collect data on environmental conditions that may be relevant to ocean accounts. Table 3.1.2 below summarises the main environmental quality monitoring types.

Program type	Description
Water quality monitoring	Community groups collect samples and measurements of parameters such as temperature, salinity, turbidity, and nutrient levels. The FDES notes that "field-monitoring stations, especially those monitoring concentrations of pollutants in the environmental media, are usually located in 'hot spot' areas with high levels of pollution" [12] , suggesting that citizen science monitoring may help fill spatial gaps in official networks.
Marine debris surveys	Beach cleanup programs systematically document the quantity and types of marine debris, providing data on pollution pressures on coastal ecosystems [13] . Such data may be relevant to indicators discussed in **TG-2.1 Aggregate Biophysical Indicators of Environmental State** and directly support marine litter accounts in **TG-6.12 Marine Litter and Plastics Accounting**.
Phytoplankton and harmful algal bloom monitoring	Volunteers collect water samples to monitor for harmful algal blooms that can affect human health and fisheries [14] .

Observational reporting

¶1 Less structured citizen science approaches rely on opportunistic observations:

- ¶2 **Species sighting platforms** – Online platforms and mobile applications enable members of the public to report sightings of marine species, contributing to distribution records and phenological data [15] .
- ¶3 **Environmental incident reporting** – Community members report pollution events, strandings, and other environmental incidents that may not be captured by official monitoring [16] .

Community-based monitoring

¶1 Ongoing engagement by local communities in environmental observation, often reflecting long-term community interest in local resources and potentially incorporating traditional knowledge and practices. Community-based monitoring differs from the above categories in data ownership structures and consent obligations. Section 3.4 sets out the operational distinctions.

Mapping to SEEA EA account types

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¶1 The table below cross-references each citizen science program category against the principal SEEA EA account types and the maximum tier at which contribution is currently considered feasible. Entries marked with a dagger (†) are contested or jurisdiction-dependent.

¶2 *Table 3.1.1: Citizen Science Program Categories Mapped to SEEA EA Account Types*

CS Program Category	Ecosystem Extent	Ecosystem Condition	Ecosystem Services Flows	Material Flows
Biological monitoring	Tier 2 (habitat patch)	Tier 3	Tier 2	n/a
Environmental quality	Tier 1 †	Tier 2	Tier 1 †	Tier 2 (pollution)
Observational reporting	Tier 1 †	Tier 2	Tier 1	n/a
Community-based monitoring	Tier 2	Tier 3	Tier 2	Tier 2

¶3 **Notes:** "n/a" indicates the combination is not currently feasible. Extent contributions from observational/environmental quality programs are contested (†) because species sighting platforms do not constitute systematic habitat surveys. Community-based monitoring can reach Tier 3 for condition only where sustained protocol-adherent programs exist with overlapping official validation data.

3.2 Data Quality Considerations

¶1 The UN NQAF quality dimensions and overarching framework are in **TG-0.7 Quality Assurance Principles** and **TG-4.5 Research Data Section 3.3.1**. Citizen-science-specific quality risks are summarised in Table 3.2.1[17].

¶2 *Table 3.2.1: Citizen science quality risks*

Source	Description
Observer variability	Volunteers vary in experience and identification skill; training and certification reduce but do not eliminate this[18].
Sampling bias	Observations cluster in accessible locations and favourable conditions, producing non-random spatial and temporal coverage[19].
Measurement protocols	Variations in how volunteers interpret and apply standardised instructions introduce measurement error[20].

¶3 Generic validation methods for non-official sources (expert verification, comparison with official monitoring, internal consistency screening, photographic evidence) are in **TG-4.5 Section 3.3.1**[21]. Step-by-step citizen-science application is in Section 3.5 (Steps 7–8).

¶4 Uncertainty characterisation must document known biases, precision estimates (from replicate observations or reference-data comparison), and completeness (spatial/temporal coverage and gaps)[22], [23]. The Section 3.5 worked example illustrates uncertainty propagation through a Tier 2 compilation.

3.3 Integration with Official Statistics

¶1 Integrating citizen science data with official statistics requires clear methodological protocols that maintain the integrity of official data whilst drawing on the contribution of citizen science.

Tiered integration approaches

¶1 Drawing on the tiered approach to data quality described in the *Technical Guidance on Biophysical Modelling* (paras. 53-55), which distinguishes tiers by modelling complexity and

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data availability, this Circular proposes an analogous tiered framework for citizen science data integration. This tiering follows the graduated capacity framework described in **TG-0.7 Quality Assurance Principles**.

- ¶2 **Tier 1** approaches use citizen science data for awareness-raising, education, and analysis of broad patterns, without integration into official accounts [24].
- ¶3 **Tier 2** approaches use citizen science data to supplement official data where coverage is limited, with appropriate uncertainty characterisation and metadata [25].
- ¶4 **Tier 3** approaches involve formal calibration of citizen science data against official monitoring, with the data meeting the country's own official statistics quality standards for direct integration [26].

¶5 The appropriate tier depends on the application, the quality of the citizen science data, and the availability of official data. Most current applications of citizen science data in environmental accounting operate at Tier 1 or Tier 2 levels.

¶6 Table 3.3.1 summarises the characteristics, quality requirements, and typical applications of each tier.

¶7 *Table 3.3.1: Citizen Science Data Quality Tiers for Ocean Accounts*

Tier	Role in Accounts	Quality Requirements
Tier 1: Awareness	Gap identification, hypothesis generation	Minimal validation
Tier 2: Supplementary	Fill data gaps with caveats	Moderate validation, uncertainty documented
Tier 3: Formal	Direct account input	Meets national official statistics quality standards; calibrated against overlapping official data; no unaccounted systematic bias; uncertainty documented — see checklist below

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Tier assignment decision checklist

¶1 The following checklist guides tier assignment for a citizen science dataset. Mixed-tier assignment within a single dataset is explicitly permitted — for example, calibrated data from overlapping sites may qualify as Tier 3 whilst data from non-overlapping sites remain Tier 2. In account tables, each subset must be labelled with its assigned tier and associated uncertainty.

¶2 **Tier 1 — Minimum criteria:**

- ¶3 ☐ Data have undergone initial screening per Section 3.5 Step 3
- ¶4 ☐ Spatial and temporal coverage are documented in metadata
- ¶5 ☐ Data are not presented as direct account estimates

¶6 **Tier 2 — Additional criteria (all Tier 1 criteria plus):**

- ¶7 ☐ Bias sources (spatial, temporal, observer) have been assessed and documented (Section 3.5 Steps 4–5)
- ¶8 ☐ Uncertainty has been quantified and attached to any summary statistics
- ¶9 ☐ Data have undergone at least one form of validation (expert review, internal consistency checks, or comparison with official data where available)
- ¶10 ☐ Known limitations are disclosed in account metadata

¶11 **Tier 3 — Additional criteria (all Tier 2 criteria plus):**

- ¶12 ☐ Calibration has been conducted against overlapping official monitoring data (Section 3.5 Step 7)
- ¶13 ☐ The citizen science data meet the country's official statistics quality standards as applied to other data sources used in that account compilation — the applicable quality standard is

country-specific and should be documented

- ¶14 ☐ Residual uncertainty after calibration has been estimated and documented
- ¶15 ☐ No systematic bias remains that has not been accounted for and reported

¶16 Compilers exercise professional judgement in determining whether calibration evidence is sufficient for the intended account use. Some citizen science programs are contextual or trend-oriented and will appropriately remain at Tier 1 or Tier 2 regardless of calibration effort. If sufficient calibration evidence cannot be assembled, the data should be assigned Tier 2, not Tier 3.

¶17 **Program continuity and trend-capable tier assignment:** Where citizen science data are to be used for trend detection or multi-year condition assessment, tier assignment must also consider program continuity. As a guide, trend-capable assignment at Tier 2 or Tier 3 requires at least two independent accounting periods of data collected under consistent protocols. Calibration relationships derived from a single season or year should be applied to other periods only where there is documented evidence of protocol, volunteer pool, and survey effort stability across years. Where program continuity is uncertain — a common situation for SIDS programs with discontinuous funding — compilers should restrict use of the data to within-period reporting and flag the program continuity limitation in account metadata.

Metadata and provenance

¶1 When incorporating citizen science data, metadata should document:

- ¶2 The citizen science program and its protocols
- ¶3 Training and quality assurance procedures applied
- ¶4 Any validation or calibration conducted
- ¶5 Known limitations and biases
- ¶6 The relationship between citizen science data and any official data used in the same accounts

¶7 FAIR principles and domain-specific metadata standards (ISO 19115, Darwin Core, SDMX) applicable to all ocean accounting data sources, including citizen science, are described in **TG-4.5 Integrating Research Data into Official Statistics Section 3.4** and **TG-4.6 Data Harmonisation and Interoperability Section 3.1**. Citizen science datasets should be clearly distinguished from official data sources in account tables, using separate columns, footnotes, and uncertainty ranges, so that users can assess fitness for purpose. The quality-tier labelling scheme described in Section 3.3 of this Circular implements that requirement.

3.4 Community-Based Monitoring

¶1 Community-based monitoring is a distinct form of participatory data collection that involves ongoing engagement by local communities in environmental observation. In contrast to project-based citizen science, community-based monitoring often reflects long-term community interest in local resources and may incorporate traditional knowledge and practices.

Coastal community monitoring

¶1 In many coastal contexts, fishing communities, coastal residents, and marine resource user groups conduct informal or semi-formal monitoring of local conditions. This monitoring may encompass:

- ¶2 Observations of fish abundance and species composition
- ¶3 Documentation of changes in coastal habitats
- ¶4 Recording of environmental conditions relevant to fishing and other livelihoods
- ¶5 Monitoring of resource access and use

¶6 The Taskforce on Nature-related Financial Disclosures (TNFD) recommendations recognise the importance of engagement with "Indigenous Peoples, Local Communities and affected stakehold-

ers" in assessment of nature-related issues [27]. Whilst the TNFD framework addresses corporate disclosure rather than official statistics, the underlying principle — that local communities hold detailed knowledge of their environments — applies equally to ocean accounting.

¶7 Several Pacific Island community-based monitoring programs illustrate the potential for contributing to ocean accounts. In Fiji, the Locally-Managed Marine Area (LMMA) Network coordinates community-based monitoring of coral reef and coastal fisheries across more than 400 communities, using standardized protocols adapted to local capacity and generating long-term time series data on reef fish abundance and coral cover [28]. In American Samoa, village-based fisheries monitoring programs have documented changes in coastal fish stocks using methods combining traditional fisher knowledge with structured survey protocols [29]. In Palau, community monitoring of giant clam populations has provided data used in both fisheries management and ecosystem condition assessment [30]. These programmes demonstrate that sustained community engagement can yield data of sufficient quality and consistency to support accounting applications, particularly at Tier 2 level.

Compilation steps requiring modification for community-based monitoring

¶1 ⓘ **Community-Based Monitoring: Compilation Modifications**

¶2 The compilation procedure in Section 3.5 applies to community-based monitoring datasets, but the following steps require modification:

- ¶3 **Step 2 (Data acquisition):** Data held by communities may not be lodged with a program coordinator. Compilers must negotiate access directly with community governance bodies before requesting data. Standard data-sharing agreements used for government-to-government data exchange are generally not appropriate. A co-designed data access agreement that recognises community data ownership is required.
- ¶4 **Before any data use:** FPIC documentation is required before community-based monitoring data are incorporated into accounts — not merely before publication. See the FPIC checklist below.
- ¶5 **Step 10 (Metadata):** Data sovereignty obligations may restrict what metadata can be published. Communities retain the right to determine the level of spatial and programmatic detail that appears in public account documentation. Metadata fields that would reveal sensitive resource locations or culturally restricted information must be withheld or generalised on community instruction.
- ¶6 **Tier classification and publication:** Communities have the right to restrict the tier at which their data are classified or to prevent publication of specific account series. Where a community exercises this right, the compiler should document the restriction in internal records and present the affected series as "Data held — publication restricted" in public account tables.

¶7 See **TG-3.6 Traditional Knowledge** for the full protocol governing traditional knowledge integration.

FPIC documentation checklist

¶1 The following checklist specifies the minimum documentation a national statistics office must retain to demonstrate that FPIC was obtained before community-based monitoring data were incorporated into official accounts:

- ¶2 ☐ **Consent record format:** Written consent on record in a format agreed with the community (written, witnessed oral record, or community council resolution as appropriate to local governance norms). Retention period: not less than the publication life of the account series plus 10 years.
- ¶3 ☐ **Named signatories:** Consent document identifies the community governance body and individual(s) authorised to provide consent on the community's behalf, with reference to their governance role.
- ¶4 ☐ **Scope of consent:** Consent explicitly covers: (a) which data series are covered; (b) permitted uses (internal quality control, published accounts, supplementary material); (c) tier classification; (d) geographic scope of publication; and (e) duration of consent.
- ¶5 ☐ **Withdrawal process:** Consent document or covering agreement specifies the process for withdrawal of consent, including: notice period, method of notification, and process for retrospective amendment of published accounts where withdrawal occurs after publication.

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- ¶6 **Stronger national law:** Where national law (including Indigenous data sovereignty legislation) provides stronger protections than the Nagoya Protocol or UNDRIP minimum standards, the national law standard applies and must be documented.

¶7 Cross-reference: **TG-3.6 Traditional Knowledge** for the full traditional knowledge protocol.

Retrospective data governance for historical datasets

¶1 Many account compilation exercises draw on historical citizen science or community-based monitoring records collected before modern FPIC and data sovereignty standards existed. Compilers applying the above FPIC standards to historical datasets should apply the following procedure according to the applicable scenario:

¶2 **(a) Waiver of consent:** Where data are fully anonymised or aggregated to a level that prevents identification of individual community members or of specific community lands, and where collection was lawful at the time of collection, an institutional ethics review may authorise continued use.

¶3 **(b) Community-level authorisation:** Where data relate to Indigenous community lands, resources, or cultural heritage — regardless of whether individual consent was obtained at the time of collection — engagement with the current community governance body is required before data are incorporated into accounts. Community-level authorisation replaces the requirement for individual historical consent.

¶4 **(c) Use-limitation:** Where neither waiver nor community-level authorisation is achievable (for example, where governance structures have dissolved or community representatives cannot be identified), the data may be retained for internal quality control but must not appear in published accounts. [31]

¶5 In all three scenarios, document the consent status and data classification in the metadata record before use. Use-limitation series must be flagged as unavailable for public release.

CARE principles and data system design

¶1 The CARE principles (Collective Benefit, Authority to Control, Responsibility, Ethics) provide a framework for Indigenous data governance that complements FAIR principles. [32] Where ocean accounts draw on community-based monitoring, CARE constraints must be embedded in data system design before data collection begins:

- ¶2 **Collective Benefit:** Account outputs must be interpretable and accessible to source communities, not solely to NSO end-users. Data systems should produce community-facing reports in formats agreed with communities, not only statistical tables for national publication.
- ¶3 **Authority to Control:** Data systems must implement tiered access controls that can restrict or revoke access on community instruction, with provenance metadata linking each data series to the community of origin. A community must be able to instruct the NSO to remove or restrict a data series without requiring the community to justify the instruction.
- ¶4 **Responsibility:** Co-management arrangements between NSOs and communities are required. Data extraction without reciprocal benefit to the community, including capacity building and access to account outputs, is inconsistent with CARE alignment.
- ¶5 **Ethics:** Community decisions to restrict publication of culturally sensitive indicators take precedence over standard statistical dissemination obligations. Where a conflict arises between CARE obligations and statutory publication requirements, legal advice should be sought before publication proceeds.

¶6 CARE complements but does not replace FAIR principles. Data systems should satisfy both frameworks simultaneously where possible. Cross-reference: **TG-3.6 Traditional Knowledge**.

Data classification framework

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¶1 The following table specifies default access classification levels for ocean account data series involving citizen science or community-based monitoring data. Compilers must record the classification basis as a required metadata field for each data series.

¶2 *Table 3.4.1: Default Data Access Classification by Account Type*

Account Type	Default Classification	Basis	Notes
Ecosystem extent — remote sensing or aggregated survey	Open	Statistical dissemination obligation	No enterprise-level data; no sensitive species locations
Ecosystem condition — aggregated citizen science	Open with spatial generalisation	Statistical dissemination obligation	Apply spatial sensitivity protocol (Section 3.5 Step 2) for sensitive species
Ecosystem services flow — commercial (fisheries, aquaculture)	Restricted at enterprise level; open at aggregate account level	Statutory confidentiality (enterprise records)	Aggregate totals may be published; cell suppression required where fewer than 3 enterprises
Material flow — waste, pollution	Open	Statistical dissemination obligation	Check for commercially sensitive supplier data
Community-based monitoring data under FPIC agreement	Consent-conditional	Indigenous data sovereignty / FPIC scope	Access level determined by consent scope; document consent record reference

¶3 Classification basis must be documented in account metadata. Where classification is consent-conditional, the metadata record must reference the FPIC documentation (consent record identifier and date).

Integration with traditional knowledge

¶1 Community-based monitoring often draws upon, or is informed by, traditional ecological knowledge. The relationship between community-based monitoring and traditional knowledge systems requires respectful engagement with knowledge holders. Detailed guidance on working with traditional knowledge is provided in **TG-3.6 Traditional Knowledge**.

¶2 Engagement with traditional knowledge requires FPIC, respect for intellectual property and cultural protocols, proper attribution in accounts metadata, and reciprocal benefit to communities — see **TG-3.6 Traditional Knowledge** for the full protocol.[33], [34], [35], [36]

¶3 The TNFD recommendations include guidance on engagement of Indigenous Peoples, Local Communities and affected stakeholders, emphasising that organisations should "describe the Indigenous Peoples, Local Communities and affected stakeholders engaged in the assessment and management of nature-related dependencies, impacts, risks and opportunities, how they were identified, and a confirmation that this description has been agreed with those engaged"[37].

3.5 Compilation Procedures

¶1 This section provides practical guidance on the procedures for compiling citizen science data into ocean accounts, addressing data acquisition, processing, quality control, and integration steps.

Data acquisition and screening

¶1 The first stage of compilation involves acquiring citizen science data and conducting initial screening for quality issues:

¶2 **Step 1: Identify relevant programs** — Survey available citizen science and community-based monitoring programs operating in the accounting area. For marine contexts, priority programs typically include:

- ¶3 Beach litter surveys (e.g., Ocean Conservancy International Coastal Cleanup, OSPAR Beach Litter Monitoring)
- ¶4 Reef monitoring programs (e.g., Reef Check, CoralWatch)
- ¶5 Marine species sighting platforms (e.g., iNaturalist, eBird for seabirds)
- ¶6 Water quality monitoring networks (community-based programs)

¶7 **Step 2: Request data and documentation** — Contact program coordinators to request:

- ¶8 Raw observational data (species counts, condition scores, litter counts, water quality measurements)
- ¶9 Program protocols and standard operating procedures
- ¶10 Training materials and observer qualifications
- ¶11 Quality control procedures applied by the program
- ¶12 Metadata on survey locations, dates, and conditions

¶13 For community-based monitoring datasets, data access negotiation must follow the community-based monitoring compilation modifications described in Section 3.4 before data are requested.

¶14 **Spatial data sensitivity protocol:** When acquiring species occurrence data, apply the GBIF Best Practices for Generalising Sensitive Species Occurrence Data [38] sensitivity classification before publication. Four sensitivity categories apply, with corresponding coordinate generalisation standards:

Sensitivity Category	Description	Coordinate Generalisation
Category 1 — Extreme	Species at imminent extinction risk; commercially targeted at national scale	~1° decimal degrees
Category 2 — High	Threatened species; significant cultural/commercial sensitivity	0.1° decimal degrees
Category 3 — Medium	Near-threatened; moderate exploitation risk	0.01° decimal degrees
Category 4 — Low	No identified sensitivity	0.001° decimal degrees (or full precision)

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¶15 Coordinate generalisation — retaining spatially valid but imprecise data — is preferred over randomisation, which introduces false coordinates that cannot be corrected downstream. Metadata for each generalised series must record: stored coordinate precision, published coordinate precision, coordinate uncertainty radius (metres), sensitivity category, sensitivity reason, and review date.

¶16 **Conflict of interest assessment:** Before accepting a citizen science dataset, record whether any data-collecting organisation has a material financial interest in account outcomes — for example, regulatory compliance status, grant eligibility, or market certification that depends on account values. Data series from providers with a material financial interest must be flagged for independent cross-validation before assignment above Tier 1. The independence assessment must be documented in account metadata. Where independent cross-validation is not feasible, conflicted data series should be restricted to supplementary or sensitivity analysis use. [39]

¶17 **Step 3: Conduct initial screening** — Apply automated checks to flag obvious errors:

- ¶18 Values outside physically plausible ranges (e.g., negative counts, impossible measurements)
- ¶19 Locations outside the survey area or on land (for marine observations)
- ¶20 Dates outside the survey period or in the future
- ¶21 Duplicate records

¶22 Remove flagged records or query program coordinators for clarification. Document the number and proportion of records removed at this stage.

Bias assessment and correction

¶1 **Step 4: Assess spatial bias** — Map the distribution of citizen science observations and compare with the desired coverage:

- ¶2 Calculate the density of observations per unit area
- ¶3 Identify areas with high and low coverage
- ¶4 Compare coverage with population density, road networks, and accessibility indicators to identify biases

¶5 For reef monitoring as an example, observations may be heavily concentrated near dive shops and tourist areas. Document this spatial bias in metadata and, where necessary, stratify the dataset to avoid over-weighting accessible sites.

¶6 **Step 5: Assess temporal bias** — Analyse the temporal distribution of observations:

- ¶7 Plot observations by month, season, and year
- ¶8 Identify periods with high and low coverage
- ¶9 Compare with weather patterns and program schedules

¶10 Beach litter surveys, for instance, may be concentrated during organised cleanup events, missing inter-event accumulation. Document temporal bias and consider time-stratified sampling for trend estimation.

¶11 **Fallback temporal bias procedure for programs without sentinel sites:** Where a program does not have sentinel or reference sites available for cross-validation (for example, retrospective analysis of historical datasets or volunteer programs with no resource for sentinel deployment), apply the following fallback procedure:

1. ¶12 Analyse time-series autocorrelation in the citizen science dataset to identify event-driven observation spikes that indicate temporal clustering.
2. ¶13 Compare the temporal distribution of observations against publicly available environmental proxy data (for example, satellite-derived sea surface temperature, wind speed records, or rainfall indices) to identify weather-driven observation gaps.
3. ¶14 Document the findings of the autocorrelation and proxy comparison analyses in metadata.

¶15 Where temporal bias cannot be adequately characterised or corrected using this fallback procedure, the data should be restricted to Tier 1 or Tier 2, with a metadata note stating that temporal coverage is insufficient for Tier 3 calibration.

¶16 **Step 6: Apply bias corrections where justified** — For some applications, statistical corrections for known biases may be appropriate:

- ¶17 Distance from access point corrections for spatial bias
- ¶18 Weather condition corrections for temporal bias
- ¶19 Occupancy modelling for detection probability (for species sightings data only where replicated detection/non-detection data are available at sites visited on multiple occasions — see caution below)

¶20 **Occupancy modelling decision criterion:** Occupancy modelling is warranted only where the dataset includes replicated detection/non-detection records at sites visited on at least two independent occasions. Where this condition is not met, effort standardisation (dividing observation counts by survey effort, e.g., observer-hours or transect length) is the preferred approach. Occupancy modelling requires specialist statistical support and should not be attempted without relevant expertise. The `unmarked` R package[40] provides accessible implementation guidance for qualified practitioners.

¶21 Apply corrections conservatively and document methods. Where correction is not feasible, restrict use of the data to applications where the bias does not compromise fitness for purpose (e.g.,

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use spatially biased data only for trend monitoring at sampled sites, not for total stock estimation).

Validation and calibration

¶1 **Step 7: Cross-validate with official data** — Where citizen science and official monitoring overlap in space and time:

- ¶2 Extract paired observations from both sources
- ¶3 Calculate correlation coefficients and regression relationships
- ¶4 Assess systematic biases (e.g., consistent under- or over-estimation)
- ¶5 Estimate measurement error variances

¶6 For Tier 3 integration, calibration functions can be derived from these comparisons. For example, if citizen science beach litter counts are consistently 80% of professional survey counts (due to incomplete area coverage), a calibration factor of 1.25 can be applied with documented uncertainty.

¶7 Citizen science data submitted for Tier 3 integration should be assessed with the same expectations of scientific rigour — including sample size adequacy and regression model selection — as any other scientific data source used in compilation. The same professional judgement applied to other data sources governs the adequacy of calibration evidence. Prescriptive minimum thresholds are not specified because the appropriate standard varies across citizen science program types and national statistical quality frameworks. Some citizen science programs are contextual in nature or suitable only for trend analysis, and will appropriately remain at Tier 1 or Tier 2 even where calibration data exist. Compilers should document the basis for this determination. Where calibration evidence is insufficient for the intended account use, the data should default to Tier 2.

¶8 **Step 8: Expert review of flagged observations** — For observations that fail consistency checks but may be valid:

- ¶9 Compile sets of unusual observations (e.g., rare species, extreme values)
- ¶10 Request expert review from taxonomists or subject matter specialists
- ¶11 Verify observations with photographic evidence where available
- ¶12 Accept, reject, or flag as uncertain based on expert judgment

¶13 Document the number of observations reviewed and the proportion accepted, rejected, or flagged.

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Dataset preparation and integration

¶1 **Step 9: Aggregate to accounting units** — Transform point observations to the spatial and temporal units used in accounts:

- ¶2 For ecosystem condition accounts: aggregate observations to Basic Spatial Units (BSUs) or Ecosystem Accounting Areas (EAAs)
- ¶3 For time series accounts: aggregate to annual or sub-annual periods
- ¶4 Calculate summary statistics (mean, median, standard deviation) for each unit
- ¶5 Estimate uncertainty (standard errors, confidence intervals)

¶6 For example, citizen science reef condition observations would be aggregated to reef ecosystem polygons, with mean coral cover and associated confidence intervals calculated for each polygon.

¶7 **Note on spatial coverage and interpolation:** Citizen science observations that fall outside the boundaries of an accounting area cannot be used to characterise that accounting area. Where spatial interpolation is applied to extend observations within an accounting area, it should be treated with the same rigour applied to any other scientific data source: if the resulting uncertainty is too high, the unit should be flagged as "insufficient data" rather than assigned an estimate. Whether interpolation is appropriate also depends on data type and the spatial resolution required to

meaningfully characterise the accounting unit — interpolation from distant observations is inappropriate where high spatial resolution is required, regardless of whether uncertainty bounds can be calculated.

¶8 **Note on uncertainty in combined estimates:** When account totals combine official monitoring estimates and citizen science estimates, three sources of additional uncertainty warrant specific attention: (a) double-counting risk where datasets overlap spatially — compilers must verify that the same observations are not contributing to both official and citizen science subtotals; (b) calibration uncertainty, which is a systematic component correlated across all citizen science observations from a given program and must not be treated as random error; and (c) temporal propagation uncertainty, which accumulates when citizen science estimates are used to extend time series beyond the calibration period. For formal propagation methods, see the SEEA EA uncertainty annex[41].

¶9 **Step 10: Compile metadata and provenance** — For each citizen science dataset integrated into accounts, compile metadata including:

- ¶10 Programme name and coordinating organisation
- ¶11 Survey methods and protocols
- ¶12 Observer training and qualifications
- ¶13 Quality control procedures applied
- ¶14 Known biases and limitations
- ¶15 Validation and calibration procedures
- ¶16 Tier classification (Tier 1, 2, or 3)
- ¶17 Period of data collection
- ¶18 Number of observations and spatial coverage
- ¶19 Data classification basis (see Table 3.4.1)
- ¶20 Conflict of interest assessment outcome
- ¶21 For community-based monitoring: FPIC documentation reference and consent scope

¶22 This metadata should accompany the accounts as supplementary documentation.

¶23 **Step 11: Deliver citizen science estimates separately identified** — Never merge a citizen science estimate into an official series without a marker. Deliver:

- ¶24 The citizen science estimate as its own series, not blended into the official one
- ¶25 The data source and quality tier against each value
- ¶26 An uncertainty range for every citizen science value

¶27 For example, coral cover is delivered as two labelled series — "Coral cover (official monitoring)" and "Coral cover (citizen science, Tier 2)" — each with its confidence interval, so that the compiling circular can decide whether to present them as separate account columns, combine them, or use one to validate the other.

Worked example: Beach litter data compilation

¶1 A concrete worked example illustrates the compilation procedure. A statistical office compiling marine litter accounts (see **TG-6.12 Marine Litter and Plastics Accounting**) receives beach litter survey data from the Ocean Conservancy International Coastal Cleanup program for 85 beach sites surveyed over a three-year period. The compilation steps are:

¶2 **Step 1-2:** Acquire data including litter counts by material category, beach lengths surveyed, and survey dates. Obtain program protocols specifying survey methods. Conflict of interest assessment confirms the International Coastal Cleanup program has no material financial interest in account outcomes (non-governmental, no regulatory or grant linkage to account values).

¶3 **Step 3:** Screen data, identifying and removing 8 records with impossible dates and 3 records with beach lengths exceeding known beach dimensions (0.97% of records removed).

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¶4 **Step 4:** Map survey sites. Survey coverage concentrates in urban coastal areas (72% of surveys within 20km of cities > 50,000 population). Document spatial bias, and restrict use of data to "beach litter density at surveyed sites" rather than extrapolating to all coastlines.

¶5 **Step 5:** Plot temporal distribution. Observations concentrate on cleanup event dates (September International Coastal Cleanup Day = 58% of observations). Supplement with quarterly surveys at 12 sentinel sites to capture inter-event periods.

¶6 **Step 6:** No bias correction applied. Instead, stratify reporting by urban/remote and event/non-event categories.

¶7 **Step 7:** Compare 12 sentinel sites with professional monitoring, finding citizen science counts average 85% of professional counts (95% CI: 78-92%). Derive calibration factor of 1.18 (=1/0.85) for Tier 3 use, with uncertainty range of 1.09-1.28. Calibration evidence assessed as adequate for the intended account application (litter density estimates at monitored sites). The professional judgement basis for this determination is documented in the methodology note.

¶8 **Step 8:** Expert review not required for litter counts (straightforward enumeration), but material categorisation reviewed by 2 marine debris specialists for 10% of surveys, with 94% agreement.

¶9 **Step 9:** Aggregate to coastal administrative units (districts), calculating mean litter density (items per meter of beach) and total estimated stock (items) with confidence intervals reflecting sampling error and calibration uncertainty. Calibration uncertainty is treated as a systematic component (correlated across all citizen science observations) and is combined separately from random sampling error. No spatial interpolation is applied to districts without citizen science coverage. These districts are flagged as "insufficient data."

¶10 **Step 10:** Compile metadata documenting International Coastal Cleanup protocols, volunteer training (brief on-site instruction), known biases (urban concentration, event concentration), validation results (85% of professional counts), conflict of interest assessment (none), and Tier 2/3 classification (Tier 3 for calibrated data at overlapping sites, Tier 2 for data at non-overlapping sites).

¶11 **Step 11:** Deliver to **TG-6.12 Marine Litter and Plastics Accounting** three separately identified estimates:

- ¶12 Beach litter stock (official monitoring): 450,000 items (95% CI: 410,000-490,000) [12 sites]
- ¶13 Beach litter stock (citizen science, Tier 2, calibrated): 1,850,000 items (95% CI: 1,630,000-2,070,000) [73 non-overlapping sites]
- ¶14 Combined total (official + citizen science non-overlapping sites): 2,300,000 items (95% CI: 2,077,000-2,523,000, computed by summing variances as if the estimates were independent, which understates the interval because the calibration factor is derived from the official sentinel-site counts: SE_combined = sqrt(20,400^2 + 112,200^2) ~= 114,000)

¶15 This worked example demonstrates the practical steps and decision points in citizen science data compilation. Key principles illustrated include: transparent documentation of data processing decisions, restriction of data use to applications appropriate for the quality tier, derivation of calibration factors from overlap with official data, and clear communication of uncertainty.

3.6 Decision Use Cases for Citizen Science Data

¶1 The following use cases illustrate the tier assignments and quality requirements set out in Section 3.3. This section describes decision contexts where citizen science data can support ocean accounting and related policy analysis, illustrating how the compilation procedures described in Section 3.5 apply in practice.

Gap-filling for data-sparse coastal areas

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¶1 Many coastal nations, particularly Small Island Developing States (SIDS), have limited resources for establishing official monitoring networks with wide spatial coverage. Citizen science can provide observations in areas that would otherwise have no data:

¶2 **Use case:** A Pacific SIDS conducts official reef monitoring at 8 sites, providing high-quality data but covering only 5% of reef area. Reef Check volunteer surveys add 45 sites, increasing coverage to 35% of reef area. Whilst the volunteer data are less precise (Tier 2), they enable spatial stratification of condition estimates and identification of priority areas for management intervention. The combined dataset (official + citizen science) supports ecosystem condition accounts that would not be feasible with official data alone.

¶3 **Decision support:** Marine spatial planning authorities use the expanded dataset to identify degraded reef areas requiring protection and relatively intact areas suitable for tourism zoning. Without citizen science data, planning would proceed on the basis of limited site coverage or coarse remote sensing proxies.

Supplementing temporal resolution for trend detection

¶1 Official monitoring programs often operate on multi-year cycles due to resource constraints. Citizen science can provide higher-frequency observations:

¶2 **Use case:** A national coastal water quality program samples 30 estuaries biennially. A community-based monitoring network samples 15 of these estuaries monthly. The citizen science data capture seasonal variation and enable detection of short-term pollution events that would be missed by biennial sampling. When calibrated against the official biennial data (Tier 3 approach), the citizen science time series provide improved trend detection for nitrogen concentrations and turbidity.

¶3 **Decision support:** Watershed managers use the high-frequency citizen science data to identify seasonal pollution patterns linked to agricultural runoff timing. These patterns support targeted interventions. The biennial official data alone would not reveal these temporal patterns.

Beach litter monitoring for marine pollution accounts

¶1 Beach litter surveys are one of the most established applications of citizen science in marine environmental monitoring, with direct relevance to SDG 14.1 (marine pollution) and marine litter accounts (see **TG-6.12 Marine Litter and Plastics Accounting**):

¶2 **Use case:** A coastal nation compiles marine litter accounts drawing on beach litter survey data from the International Coastal Cleanup and regional monitoring programs. Annual cleanup events engage 5,000-8,000 volunteers surveying 200-300 beach sites. Data are standardised using Ocean Conservancy protocols, enabling material categorisation and source attribution (land-based vs. sea-based litter).

¶3 **Decision support:** The marine litter accounts combine citizen science survey data with waste management statistics. They reveal that single-use plastics from coastal tourism comprise 42% of beach litter by item count. This attribution supports targeted policy interventions including bans on specific single-use items and tourism operator education programmes. The spatial distribution of citizen science observations identifies pollution hotspots requiring enhanced cleanup and enforcement.

¶4 This decision context is particularly relevant for SIDS where beach tourism is economically important and beach aesthetics affect visitor satisfaction. Citizen science provides cost-effective, large-scale monitoring that would be prohibitively expensive to conduct through official programmes alone.

Reef condition reporting for ecosystem accounts

¶1 Coral reef condition is a priority indicator for many Pacific and Caribbean nations. Citizen science reef monitoring programs provide data for ecosystem condition accounts:

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¶2 **Use case:** Reef Check volunteer diver surveys complement official scientific monitoring, providing observations from 60 reef sites compared to 15 official sites. Volunteers record coral cover, bleaching incidence, and fish abundance using standardised underwater survey forms. Data undergo expert validation (photographic verification of coral identifications) and calibration against professional surveys at 10 overlapping sites.

¶3 **Decision support:** The expanded spatial coverage enables ecosystem condition accounts stratified by reef type (fringing, barrier, atoll) and management status (protected vs. unprotected). Trend analysis reveals that condition is declining faster in unprotected areas, supporting expansion of marine protected area networks. The citizen science data provide the spatial coverage necessary for meaningful stratification that would not be possible with official monitoring alone.

> ¶4 ⓘ **Compiling Ordinal Citizen Science Data**
>
> ¶5 Reef condition programs such as Reef Check and CoralWatch produce ordinal or semi-quantitative scores (e.g., bleaching categories 1–5, or coral cover estimated visually in 5% bands) rather than continuous measurements. Arithmetic means of ordinal scores are statistically inappropriate. Compilers working with these data types should apply the following conventions:
>
> - ¶6 **Summary statistics:** Use median and interquartile range (IQR) rather than mean and standard deviation. Present frequency distributions (proportion of observations in each category) alongside median and IQR.
> - ¶7 **Trend expression:** Express trends as the change in proportion of observations falling in each category between periods (e.g., "the proportion of surveys recording bleaching at category 3 or above increased from 18% to 34%"). Rank-based trend tests (Kendall's tau) are appropriate for ordinal time series.
> - ¶8 **Uncertainty representation:** Report the proportion-in-category with a binomial confidence interval for each category. Do not combine ordinal category estimates into a single composite index without documented justification and reference to the SEEA EA guidance on discrete condition variable aggregation [42].
> - ¶9 **Delivered form:** Deliver ordinal condition data as a frequency distribution rather than a single point estimate, flagged as ordinal so the compiling circular does not treat it as a continuous variable.

Estuarine and coastal water quality citizen science

¶1 Estuaries and coastal waterways are ecologically significant transition zones where freshwater and marine systems interact. Citizen science water quality monitoring programs operating in these environments can contribute to ocean accounts but involve institutional and statistical considerations not present in open-marine contexts:

¶2 **Use case:** A national statistics office compiling ocean accounts for a river delta system receives nutrient and turbidity monitoring data from a community water quality network operating across 22 catchment sub-basins flowing into a coastal lagoon. The network has monitored monthly for six years. Official water quality monitoring by the environment agency covers only 4 of the 22 sub-basins. The citizen science data are calibrated against official measurements at overlapping stations (Tier 3 for calibrated stations; Tier 2 for uncalibrated sub-basins) and used to estimate nitrogen loading from the catchment to the coastal lagoon.

¶3 **Decision support:** The nutrient flow accounts combine official and citizen science data. They enable attribution of nitrogen loading by sub-basin and seasonal pattern. Agricultural sub-basins with elevated wet-season nutrient pulses are identified as priority intervention areas. The accounts contribute to the freshwater-marine interaction accounts described in **TG-6.13 Freshwater-Marine Interaction Accounting**.

¶4 **Institutional interface:** Estuarine citizen science programs typically sit at the boundary between freshwater and marine statistics mandates. Compilers should:

- ¶5 Clarify institutional responsibility for estuarine accounts with both freshwater and marine statistics units before compilation begins, to avoid double-counting or gaps at the freshwater-marine boundary.
- ¶6 Apply consistent spatial attribution rules: observations collected at or above the defined tidal limit should be classified as freshwater observations, observations below the tidal limit as

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marine observations, and observations at tidal limit monitoring stations as estuarine with dual-system attribution.

- ¶7 Ensure that nutrient flow estimates from citizen science programs are reconciled with any overlapping official estimates in freshwater flow accounts before inclusion in coastal nutrient flow accounts, to avoid double-counting the same nutrient loads.

¶8 These use cases illustrate that citizen science data serve distinct purposes in ocean accounting: gap-filling where official data are sparse, temporal supplementation where official data are infrequent, cost-effective large-scale monitoring for distributed pressures like beach litter, spatial expansion for ecosystem condition assessment, and catchment-to-coast nutrient flow estimation in estuarine systems. In each case, appropriate quality assurance (bias assessment, calibration, validation) and transparent metadata documentation ensure that the data are fit for purpose for the intended decision context.

3.7 Emerging Practices and Future Development

¶1 The field of citizen science and community-based monitoring is changing quickly, with advances in technology, methodology, and institutional frameworks. Statistical offices and accounting practitioners should track emerging developments that may expand the potential for citizen science contributions to ocean accounts.

Technology developments

¶1 Mobile applications, low-cost sensors, and image recognition technologies are making it easier for volunteers to collect and submit observations, while also enabling new forms of quality control [43]. Environmental DNA (eDNA) sampling, where volunteers collect water samples for laboratory analysis, represents a particularly promising development for marine biodiversity monitoring [44].

¶2 **eDNA data and the tier framework:** eDNA data derived from volunteer-collected samples are currently restricted to Tier 1 until all three of the following conditions are met:

¶3 (a) The sampling program has a documented chain-of-custody from sample collection to laboratory analysis, including sample preservation, shipping, and receipt records.

¶4 (b) The analytical laboratory holds ISO 17025 accreditation relevant to the analytical methods applied, or has benchmarked its methods against an ISO 17025-accredited laboratory with documented results.

¶5 (c) The eDNA-derived variable (for example, species presence/absence, relative abundance index, or diversity metric) has been mapped to a specific SEEA EA biophysical variable with documented conversion uncertainty, including the uncertainty contribution from reference database coverage.

¶6 Statistical offices should monitor the development of eDNA standards by ISO/TC 147/SC 5 (Water quality — Biological methods subcommittee), which is developing international standards for eDNA methods that may provide the basis for future Tier 2 or Tier 3 qualification. [45]

Methodological advances

¶1 Research is advancing on statistical methods for combining citizen science data with official monitoring data, accounting for known biases and uncertainty [46]. These methods, sometimes termed "data fusion" or "integrated modelling," may enable more rigorous integration of citizen science data into official accounts over time. Integrated species distribution models, which combine structured survey data with opportunistic citizen science observations within a single statistical framework, have shown particular promise for marine applications. Recent work on occupancy models that account for imperfect detection in volunteer surveys is enabling more reliable estimation of species occurrence and abundance trends from citizen science datasets [47]. As these

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statistical methods mature and become more widely adopted, the potential for Tier 3 integration of citizen science data is likely to increase.

Institutional developments

¶1 Some national statistical offices are beginning to explore frameworks for incorporating citizen science and other non-traditional data sources into official statistics [48]. As these frameworks mature, clearer guidance on integration approaches is likely to emerge.

¶2 The SEEA EA *Technical Guidance on Biophysical Modelling* notes that "data quality frameworks developed by statistical agencies currently do not include standards for modelled data. These frameworks should be expanded to encompass the specific quality issues that arise from modelled data" [49]. The same observation applies to citizen science data — existing quality frameworks were developed for traditional data sources and may need adaptation for the specific characteristics of volunteer-collected data.

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¶2 **Reviewers:** [To be confirmed]

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Integrating Research Data into Official Statistics

Provides guidance on bridging the gap between scientific research data and official statistics for the compilation of ocean accounts.

Version 0.7.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on bridging the gap between scientific research data and official statistics for the compilation of ocean accounts. Ocean accounting requires diverse data sources that extend beyond traditional statistical surveys and administrative records to include oceanographic observations, biodiversity monitoring, ecosystem assessments, and other forms of research data generated by universities, research institutions, and international scientific programmes. This Circular addresses the systematic integration of research data into statistical production, maintaining the quality standards expected of official statistics whilst drawing on the distinct capabilities of scientific research organisations.

By implementing the guidance in this Circular, practitioners will be able to identify research data sources relevant to ocean accounting applications, assess their fitness for statistical purposes using quality frameworks adapted from the United Nations National Quality Assurance Framework (UN NQAF), establish institutional partnerships with research organisations, and compile ocean accounts that combine traditional statistical sources with research data in a transparent and methodologically sound manner. The specific applications addressed include the use of oceanographic research data for ecosystem condition accounts (see TG-3.1 Asset Accounts Section 3.5.2), stock assessment data for fisheries accounts (see TG-6.7 Fisheries Stock Assessment), and biodiversity monitoring data for extent accounts (see TG-3.1 Asset Accounts Section 3.5.1).

The quality assessment dimensions presented here build on the overarching quality framework established in TG-0.7 Quality Assurance, whilst the data harmonisation techniques needed to reconcile research data with other sources are detailed in TG-4.6 Data Harmonisation. Key terms used in this Circular are defined in TG-0.6 Glossary.

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ABOUT THIS CIRCULAR

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¶1 **Framework Position**

¶2 TG-4.5 sits within Section 4 (Data Methods). It owns the assessment and preparation of research-sourced data for statistical use: fitness-for-purpose against the UN NQAF quality dimensions, metadata alignment and provenance, uncertainty quantification, spatial and temporal reconciliation including the choice of interpolation method, institutional arrangements with research providers, and the revision policy that governs retrospectively corrected datasets. It does not own the accounts the prepared variables enter — **TG-3.1 Asset Accounts** for extent and condition, **TG-6.7 Fisheries Accounting: Integrating Stock Assessment** for fisheries assets — nor the indicators derived from them, which are **TG-2.1 Aggregate Biophysical Indicators of Environmental State**.

1. Outcome

¶1 This Circular provides guidance on bridging the gap between scientific research data and official statistics for the compilation of ocean accounts. Ocean accounting requires diverse data sources that extend beyond traditional statistical surveys and administrative records to include oceanographic observations, biodiversity monitoring, ecosystem assessments, and other forms of research data generated by universities, research institutions, and international scientific programmes. This Circular addresses the systematic integration of research data into statistical production, maintaining the quality standards expected of official statistics whilst drawing on the distinct capabilities of scientific research organisations.

¶2 By implementing the guidance in this Circular, practitioners will be able to identify research data sources relevant to ocean accounting applications, assess their fitness for statistical purposes using quality frameworks adapted from the United Nations National Quality Assurance Framework (UN NQAF), establish institutional partnerships with research organisations, and compile ocean accounts that combine traditional statistical sources with research data in a transparent and methodologically sound manner. The specific applications addressed include the use of oceanographic research data for ecosystem condition accounts (see **TG-3.1 Asset Accounts** Section 3.5.2), stock assessment data for fisheries accounts (see **TG-6.7 Fisheries Stock Assessment**), and biodiversity monitoring data for extent accounts (see **TG-3.1 Asset Accounts** Section 3.5.1).

¶3 The quality assessment dimensions presented here build on the overarching quality framework established in **TG-0.7 Quality Assurance**, whilst the data harmonisation techniques needed to reconcile research data with other sources are detailed in **TG-4.6 Data Harmonisation**. Key terms used in this Circular are defined in **TG-0.6 Glossary**.

2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** — provides foundational understanding of ocean accounts components and the relationship between environmental and economic accounting frameworks, including the conceptual basis for integrating diverse data sources into a coherent accounting system.
- ¶3 **TG-0.7 Quality Assurance** — establishes the overarching quality framework applicable to ocean accounting data, including the quality dimensions and assessment procedures that this Circular applies specifically to research data sources.

3. Guidance Material

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¶1 The compilation of ocean accounts frequently requires data from scientific research programmes that were not originally designed for statistical purposes. Research data can fill gaps in ocean observation and ecosystem monitoring that traditional statistical sources cannot address. Integrating such data into official statistics requires careful attention to quality assessment, metadata documentation, and institutional coordination. This Circular sets out a systematic approach to that integration.

¶2 The quality considerations discussed here should be understood within the broader quality assurance framework described in **TG-0.7 Quality Assurance**. For guidance on reconciling data from multiple sources with different classifications and spatial boundaries, see **TG-4.6 Data Harmonisation**.

3.1 Decision Use Cases for Research Data

¶1 Research data integration supports specific decision-making applications in ocean accounting. This section identifies the primary use cases where research data sources provide essential inputs that traditional statistical sources cannot supply.

3.1.1 Integration modes and governance accountability

¶1 Before identifying specific use cases, practitioners should classify each prospective integration of research data into one of three modes, as each mode triggers different governance requirements within the NSO. This classification is material to the NSO's legal and audit accountability, since substituting an official source with research data may require formal endorsement from the national statistical authority rather than a technical decision by the compiling unit.

¶2 **Mode A — Gap-filling.** No official statistical source exists for the required variable. Research data are the only feasible input. Examples include subsurface dissolved oxygen profiles in pelagic waters, eDNA-based species occurrence in remote habitats, and acoustic biomass estimates for non-commercial species. Governance: technical judgement by the compiling unit, documented in account metadata under the standard quality-assessment workflow set out in Section 3.5.

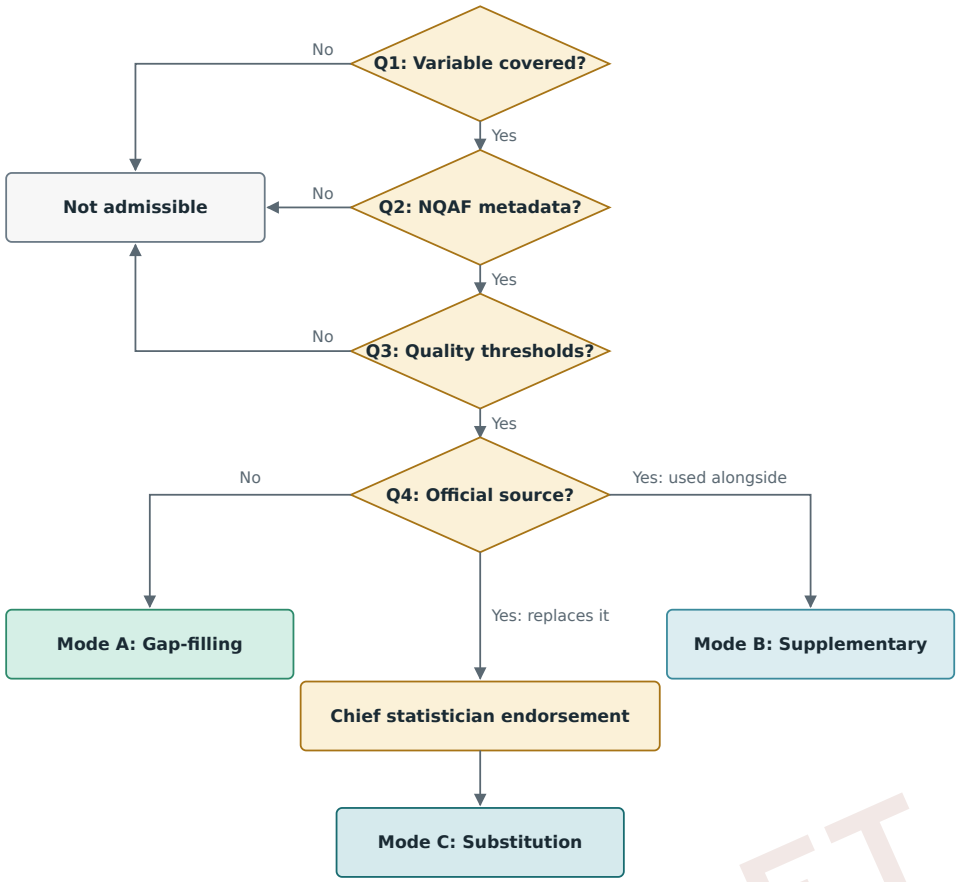
¶3 **Mode B — Supplementary use.** An official source exists but research data are used in parallel as a secondary validation source, a cross-check, or a higher-resolution overlay. Examples include using satellite chlorophyll products alongside ship-based water-quality monitoring, or using research stock assessments to validate administrative catch records. Governance: technical judgement by the compiling unit, with a coherence test required under Section 3.5.3 Step 3.3.

¶4 **Mode C — Primary substitution.** An official source exists but is replaced by research data judged of higher quality. Examples include replacing a discontinued shipboard nutrient monitoring programme with an autonomous Argo-derived product, or substituting an obsolete remote-sensing land-cover product with a research-grade national mapping. Governance: requires chief statistician (or equivalent national statistical authority) endorsement, plus a documented UN NQAF Level A institutional-framework compliance check, before the substituted source can be published in an official account. The substitution decision and its endorsement must be recorded in the account compilation metadata.

¶5 The mode applicable to a given source should be determined by the compiling NSO when applying the Section 3.5 procedure.

¶6 Figure 4.5.1 summarises the screening path: three sequential admissibility gates (Q1–Q3) check variable coverage, metadata completeness, and quality-threshold compliance; mode routing gate (Q4) then classifies the admissible source as Mode A (gap-filling), Mode B (supplementary), or Mode C (primary substitution — chief statistician endorsement required before publication in official accounts).

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Figure 4.5.1 Research-data admissibility gates Q1–Q4 and integration modes A–C.

3.1.2 Ecosystem condition accounts

¶1 Ecosystem condition accounts require measurements of biophysical and chemical variables that characterise the state of marine ecosystems [1]. For ocean environments, many of these measurements are only available through oceanographic research programmes:

¶2 **Oceanographic surveys** provide temperature, salinity, dissolved oxygen, nutrient concentrations, and pH measurements throughout the water column. The Global Ocean Observing System (GOOS) coordinates international efforts to standardise observation methods and improve data sharing [2]. For condition accounts in pelagic waters (see **TG-6.5 Pelagic and Open Ocean Accounting**), research vessel surveys and autonomous profiling floats (such as the Argo network) are the primary sources for subsurface condition data.

¶3 **Acoustic surveys** estimate biomass of schooling pelagic fish and benthic invertebrates using scientific echosounders. Regional fisheries management organisations (RFMOs) often conduct acoustic surveys to assess stock condition, providing data that can be integrated into ecosystem condition accounts where fish biomass serves as a condition indicator [3].

¶4 **Water quality monitoring** by environmental research agencies tracks pollution levels, turbidity, and harmful algal blooms. For coastal condition accounts, research monitoring of nitrogen and phosphorus loading provides essential data on eutrophication pressure.

¶5 The SEEA Ecosystem Accounting framework identifies specific condition characteristics that typically require research data inputs, including biotic characteristics (species diversity, biomass, community composition), abiotic characteristics (water temperature, pH, salinity), and functional characteristics (primary productivity, nutrient cycling) [4].

3.1.3 Fisheries stock assessment

¶1 Stock assessment for commercial and subsistence fisheries depends heavily on scientific research data [5]:

¶2 **Catch-at-age data** from research vessel surveys provide independent estimates of population abundance and age structure, complementing catch data reported by commercial vessels. For highly migratory species such as tuna, international research programmes coordinated through RFMOs are often the only source of systematic catch-at-age information across the species' range.

¶3 **Tagging programmes** using electronic tags, acoustic telemetry, and genetic markers reveal migration patterns, population structure, and survival rates. Close-kin mark-recapture methods using genetic analysis allow estimation of absolute abundance for high-value species such as southern bluefin tuna, where traditional survey methods are impractical [6].

¶4 **Life history parameters** including growth rates, natural mortality, and fecundity are typically derived from research laboratory studies and field sampling programmes rather than routine statistical collection.

¶5 National Statistical Offices (NSOs) compiling fisheries accounts rely on stock assessments produced by fisheries research institutes to estimate the physical and monetary value of aquatic resources, as described in **TG-3.1 Asset Accounts**.

¶6 **Data-rich versus data-poor stock assessments.** NSOs must distinguish between data-rich and data-poor stock assessment methods. Data-rich methods (e.g., age-structured Virtual Population Analysis, integrated statistical catch-at-age models) combine catch-at-age, abundance indices, and life-history parameters to produce biomass estimates with characterisable confidence intervals. Data-poor methods (e.g., Length-Based Spawning Potential Ratio (LBSPR), Catch-Maximum Sustainable Yield (CMSY), Depletion-Based Stock Reduction Analysis (DB-SRA)) rely on far fewer inputs and produce estimates with much wider, often order-of-magnitude, uncertainty ranges [7]. The quality tier reported alongside fisheries asset accounts (Tier 1, 2, or 3 in SEEA EA terminology) must reflect the underlying assessment method: data-rich age-structured assessments typically support Tier 3 reporting, whilst data-poor length-based or catch-only methods should generally be reported as Tier 1, with the methodological caveats made explicit in the account release notes. Publishing a fisheries asset account derived from a data-poor assessment without communicating that limitation can mislead policy audiences about the precision of the stock estimate.

3.1.4 Biodiversity and extent mapping

¶1 Research programmes provide essential data for ecosystem extent accounts and biodiversity indicators:

¶2 **Benthic habitat mapping** using multibeam echosounder surveys, remotely operated vehicles (ROVs), and drop cameras classifies seabed substrates and identifies ecosystem types such as cold-water coral reefs, sponge beds, and seagrass meadows. National hydrographic offices and marine research institutes are typically the custodians of these data.

¶3 **Species occurrence records** from biodiversity surveys, museum collections, and citizen science programmes are aggregated in global repositories such as the Ocean Biodiversity Information System (OBIS) and the Global Biodiversity Information Facility (GBIF) [8]. For ecosystem extent accounts based on the IUCN Global Ecosystem Typology, these occurrence data support delineation of ecosystem functional groups.

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¶4 **Coral reef monitoring** through the Global Coral Reef Monitoring Network and regional programmes such as the Coral Triangle Initiative provides systematic assessments of coral cover, bleaching events, and reef condition that underpin extent and condition accounts for coral reef ecosystems (see **TG-6.1 Coral Reef Ecosystem Accounting**).

¶5 The Framework for the Development of Environment Statistics (FDES) notes that "scientific research data can be used to address data gaps" in environmental statistics, particularly for parameters that require specialised measurement techniques [9].

3.2 Types of Research Data

¶1 Research data relevant to ocean accounting come from a range of sources, each with distinct characteristics, collection methodologies, and quality considerations. These distinctions determine which data sources are appropriate and how their fitness for accounting purposes is assessed.

3.2.1 Oceanographic observation data

¶1 Oceanographic observation systems generate continuous or periodic measurements of physical, chemical, and biological ocean parameters [10]. These include temperature, salinity, currents, dissolved oxygen, nutrient concentrations, and chlorophyll levels. Major international programmes such as the Global Ocean Observing System (GOOS), the Argo float network, and regional ocean observing systems (e.g., the Integrated Marine Observing System in Australia) provide standardised data streams that can support ecosystem condition accounts [11]. The Intergovernmental Oceanographic Commission (IOC) of UNESCO coordinates international efforts to improve ocean observation capacity and data sharing [12].

¶2 Such data are typically collected using instrumented platforms including research vessels, moored buoys, autonomous underwater vehicles, satellite remote sensing, and profiling floats. The primary advantages include (1) systematic temporal coverage enabling trend analysis, (2) standardised measurement protocols developed through international scientific consensus, and (3) growing open access through global data repositories. However, spatial coverage can be uneven, with data density varying widely between coastal and open ocean areas, and between developed and developing country waters [13].

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¶3 Among the most directly relevant oceanographic variables for ecosystem condition accounts are the Essential Ocean Variables (EOVs) defined by GOOS. The EOV framework organises ocean observations into physics, biogeochemistry, and biology/ecosystems domains [14]. For ecosystem condition accounts, priority EOVs include sea surface temperature, dissolved oxygen, inorganic carbon, ocean colour (as a proxy for phytoplankton biomass), and marine habitat properties. For ecosystem extent accounts, relevant EOVs include hard coral cover, seagrass cover, mangrove cover, and macroalgal canopy cover. Practitioners should consult the current GOOS EOV specification sheets, which document readiness levels, observation requirements, and data product availability for each variable, to determine which EOVs are feasible data sources for their national accounting context.

3.2.2 Biodiversity survey data

¶1 Biodiversity surveys document species occurrence, abundance, and distribution through structured sampling programmes [15]. For marine environments, these include fish stock assessments, invertebrate surveys, marine mammal and seabird censuses, coral reef monitoring, and seagrass mapping exercises. Such data support ecosystem extent accounts (mapping ecosystem types), ecosystem condition accounts (assessing biodiversity indicators), and ecosystem services accounts (quantifying provisioning services such as fisheries).

¶2 Biodiversity data are collected through diverse methodologies including visual census, acoustic surveys, environmental DNA (eDNA) sampling, and citizen science programmes [16]. The Global Biodiversity Information Facility (GBIF) aggregates species occurrence records from research

institutions worldwide and provides standardised access through its data portal [17]. Regional initiatives such as the Ocean Biodiversity Information System (OBIS) focus specifically on marine biodiversity data [18].

¶3 Biodiversity surveys often follow sampling designs optimised for scientific research questions rather than complete spatial coverage. Such designs can bias sampling towards accessible locations or areas of particular scientific interest, a bias that must be addressed when the data are used for area-based ecosystem accounts [19].

3.2.3 Ecosystem monitoring programmes

¶1 Long-term ecosystem monitoring programmes track changes in ecosystem structure, function, and condition over time. Examples relevant to ocean accounting include coral reef monitoring networks (e.g., the Global Coral Reef Monitoring Network), mangrove forest assessments, seagrass habitat mapping, and kelp forest monitoring programmes [20]. These programmes typically combine remote sensing data with ground-truthing surveys to map ecosystem extent and assess condition indicators.

¶2 The SEEA Ecosystem Accounting framework recommends using a tiered approach for ecosystem monitoring, with Tier 1 using globally available default data, Tier 2 using regionally appropriate data, and Tier 3 using nationally collected data with full spatial and temporal coverage [21]. Research monitoring programmes often provide the foundation for Tier 2 and Tier 3 approaches, particularly for marine ecosystems where routine statistical collection is limited.

3.2.4 Remote sensing and Earth observation data

¶1 Satellite-based Earth observation provides systematic, repeated coverage of ocean and coastal areas at scales relevant to national accounting [22]. Key parameters measurable from space include sea surface temperature, ocean colour (indicative of chlorophyll and primary productivity), sea level, surface currents, coastal land cover change, and wetland extent. The European Union's Copernicus Marine Service and NASA's Ocean Biology Processing Group provide validated ocean data products derived from multiple satellite sensors [23].

¶2 Remote sensing data are valuable for their temporal frequency (enabling detection of change) and their spatial reach (enabling complete national coverage). Limitations include cloud cover interference, the inability to observe below the sea surface, and the requirement for ground-truthing to validate derived products. The SEEA Technical Guidance on Biophysical Modelling notes that remote sensing offers "enormous opportunities to disseminate data with very short time-lags and high-frequency" [24].

¶3 The major satellite platforms relevant to ocean accounting (Sentinel-2, Landsat, MODIS, and Sentinel-1 SAR) span spatial resolutions from 10 metres to 1 kilometre, with revisit times from daily (MODIS) to 16 days (Landsat). For full guidance on sensor characteristics and selection, see **TG-4.1 Remote Sensing and Geospatial Data**. [25]

¶4 **Atmospheric correction validation in coastal and optically complex waters.** Standard atmospheric correction algorithms used for open-ocean ("Case 1") waters, including DARK_PIXEL, SeaDAS default, and the Case-2 Regional CoastColour processor (C2RCC), are known to perform poorly in turbid, shallow, sediment-laden, or chlorophyll-rich coastal ("Case 2") waters. The systematic biases this introduces propagate directly into derived products such as chlorophyll-a, suspended sediment, and turbidity, which are the principal remote sensing inputs to coastal condition accounts. For NSOs in tropical and developing country contexts, where Case 2 waters dominate the coastal zone, in situ validation of satellite-derived products is mandatory before use in official accounts. Practitioners should (i) confirm that the product is derived from a Case 2-capable processor and consult the Copernicus Marine Service product quality factsheet for the specific product version, (ii) verify validation status against EUMETSAT/ACRI atmospheric correction validation protocols, and (iii) where feasible, perform a matchup analysis against in situ radiometric measure-

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ments from the AERONET Ocean Color network (AERONET-OC) or a comparable national field campaign. Uncorrected or unvalidated products should not be published as the basis of official condition statistics for coastal waters.

3.2.5 Scientific research publications and datasets

¶1 Peer-reviewed scientific publications are a source of coefficients, conversion factors, and methodological parameters for ecosystem service modelling [26]. For example, estimates of carbon sequestration rates in mangroves, nutrient retention by seagrass meadows, or coastal protection values from coral reefs are frequently derived from published research rather than direct national measurement. Whilst individual studies may be site-specific, synthesis studies and meta-analyses can provide generalised values applicable across similar ecosystem types.

¶2 Many funders and publishers now require research datasets underlying publications to be deposited in open repositories as a condition of publication or funding. The Framework for the Development of Environment Statistics (FDES) notes that scientific research data "are usually available at no or low cost" and "can be used to address data gaps" [27]. However, the FDES also cautions that such data "often use terms and definitions that differ from those used in statistics", may have "limited scope", and are "often available on a one-time basis only" [28].

¶3 **Coefficient selection protocol where multiple published estimates exist.** It is common, especially for developing country ocean accounts compiling blue carbon, nutrient retention, or coastal protection coefficients, to encounter multiple published estimates for the same parameter that span an order of magnitude or more. Mangrove soil carbon sequestration estimates, for example, span roughly 0.5 to 15 Mg C ha^{-1} yr^{-1} in the published literature, with central tendency varying by biogeography, stand age, and methodology. Where multiple estimates exist, NSOs should follow this four-step coefficient selection protocol:

1. ¶4 **Prefer systematic reviews and meta-analyses over individual studies.** Where a published systematic review or meta-analysis exists for the parameter of interest, use its central estimate as the default value rather than averaging across individual studies. Meta-analyses adjust for study quality and weight estimates by sample size.
2. ¶5 **Where multiple meta-analyses exist, document the range and select the most geographically and ecologically appropriate value.** Geographic and ecological matching (e.g., tropical vs. temperate mangroves, or high-rainfall vs. arid coastal settings) should be explicit and justified in writing. A simple arithmetic mean of meta-analyses with different geographic scopes is not recommended.
3. ¶6 **Apply a sensitivity analysis across the plausible range.** Re-compute the affected account aggregate using at least the lower and upper bounds of the range of credible estimates, and report the resulting account values as a sensitivity envelope alongside the central estimate. This propagates coefficient uncertainty into the account.
4. ¶7 **Document the selection rationale in account metadata.** The selected coefficient, its source, the alternatives considered and rejected, the geographic-matching justification, and the sensitivity envelope must be recorded in the account compilation metadata to support audit and replication.

¶8 Where SEEA EA biome-specific default values are available, these should be used as the baseline starting point for the protocol and any departure justified.

3.3 Quality Assessment Frameworks

¶1 Research data must be assessed for fitness for statistical purposes before incorporation into ocean accounts. The quality dimensions applied to research data differ in emphasis from those applied to survey data, reflecting the distinct characteristics of scientific data production.
For the overarching quality framework applicable to all ocean accounting data, see **TG-0.7 Quality Assurance**.

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3.3.1 Dimensions of data quality

¶1 The UN NQAF quality dimensions (relevance, accuracy, reliability, timeliness, accessibility, coherence, comparability) and their general definitions are in **TG-0.7 Quality Assurance Principles**[29]. Applied to research data, relevance turns on spatial/temporal/variable alignment with the account structure. Accuracy turns on sampling design, methodology validation, and error propagation in derived products, with SEEA EA Technical Guidance on Biophysical Modelling for modelled outputs[30]. Coherence turns on mapping research classifications to statistical standards (see **TG-4.6 Data Harmonisation**). Comparability turns on methodology breaks and documented bridging factors[31]. Accessibility turns on licensing, format compatibility, documented access protocols, and FAIR principles (Section 3.4.1).

¶2 **Minimum acceptability thresholds.** Identifying the relevant dimensions is necessary but not sufficient: NSOs require a decision rule for when a research dataset can be admitted to an official account. Table 3.3.1 specifies, for each UN NQAF dimension, the conditions under which a data source is (a) acceptable without qualification, (b) acceptable with documented caveats, or (c) not acceptable for use in official accounts. The thresholds are anchored to international standards where these exist (e.g., the IOC/GOOS ±0.2 mg/L accuracy precedent for dissolved oxygen) and otherwise expressed as documentation requirements that allow defensible compilation. The ±0.2 mg/L figure is used here as an exemplar of how a published international standard can be carried directly into the integration decision. Equivalent dimension-specific thresholds should be substituted where they exist for other variables.

¶3 *Table 3.3.1: Minimum acceptability thresholds by UN NQAF quality dimension*

Dimension	Acceptable without qualification	Acceptable with documented caveats	Not acceptable
Relevance[32]	Spatial coverage, temporal resolution, and measured variables directly match account requirement	Partial match; transformation or scaling required and documented	Variable is conceptually misaligned with the account; no defensible transformation
Accuracy[33]	Validated against an international standard (e.g., IOC/GOOS ±0.2 mg/L for DO); error budget published	Accuracy estimate available but not against a recognised standard; uncertainty disclosed in account release	No accuracy assessment available and no alternative validation feasible
Reliability	Documented sampling design, repeated comparable surveys, published precision	Single-event survey with documented methods; precision inferred from method	Methods undocumented; no precision basis
Coherence	Classification crosswalk to SEEA/IUCN GET exists; co-located comparison available	Mapping requires interpretive judgement; documented and reviewed	Categories not mappable to statistical classifications
Comparability	Stable methodology across full time series; no breaks	Documented methodological change with bridging factors applied	Undocumented method change creating an unresolvable break
Accessibility[34]	Open licence, persistent identifier, machine-readable format	Restricted licence with documented terms; access via MoU	No defined access path; licence prohibits statistical use
Timeliness	Update schedule compatible with the accounting cycle	Lag exceeds accounting cycle by no more than one period; documented	Lag exceeds two accounting periods with no commitment to update

¶4 *Note on Mode C (primary substitution) entries:* Where the integration mode is Mode C under Section 3.1.1 (i.e., a research dataset replaces an existing official source), all threshold assessments

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in Table 3.3.1 remain applicable, but the overall admission decision additionally requires chief-statistician (or equivalent national statistical authority) endorsement before the source can be published in an official account. Mode C sources that pass all Table 3.3.1 thresholds but lack this endorsement may not be published.

¶5 A data source rated "Not acceptable" on any compilation-blocking dimension (accuracy, coherence, or accessibility) cannot be admitted to an official account without remediation. Sources rated "Acceptable with caveats" may be admitted provided the caveats are recorded in account metadata and surfaced in the account release.

3.3.2 Reproducibility, replicability, and scientific rigour

¶1 **Reproducibility**, obtaining consistent results using the same data and methods [35], is essential for updatable ocean accounts. **Replicability**, obtaining consistent results when new data are collected using the same methods [36], provides confidence that coefficients derived in one context can be applied in another. The SEEA Technical Guidance on Biophysical Modelling emphasises that "transparency of approaches is essential". [37]

¶2 **Three-level reproducibility standard for integration.** To convert reproducibility from an aspirational requirement into an auditable gate, NSOs should apply the following three-level standard when assessing research data:

- ¶3 **Level 1 — Minimum acceptable for integration of empirical (non-model) data.** Methods are fully described in a peer-reviewed publication or equivalent technical report. Raw inputs and processing code need not be publicly archived, but the methods must be sufficient to allow a competent practitioner to reproduce the analysis given the inputs.
- ¶4 **Level 2 — Preferred standard, and the minimum required for any model-based output (e.g., biophysical model results, modelled ecosystem service values, statistically interpolated condition indices).** Processing code and processed data are archived in a public repository (e.g., Zenodo, GitHub) with documented inputs and a usable readme. Cited datasets carry persistent identifiers.
- ¶5 **Level 3 — Highest standard.** All of Level 2, plus archived raw inputs and a containerised or fully scripted processing environment (e.g., Docker, Singularity, or a versioned conda environment) that enables byte-exact reproduction of outputs.

¶6 Legacy empirical datasets that pre-date open-data mandates may be integrated under Level 1, provided their methods are documented in peer-reviewed publications. Outputs of biophysical or statistical models must meet at least Level 2 before being admitted to an official account. This is the level at which audit exposure is highest, as the result depends on assumptions and code rather than direct measurement.

3.3.3 Uncertainty quantification

¶1 Research data are characterised by various sources of uncertainty that must be documented and, where possible, quantified. Uncertainty can arise from sampling variability, measurement error, model parameter uncertainty, and structural model uncertainty. The SEEA Technical Guidance on Biophysical Modelling notes that "uncertainty matrices, which outline possible sources of uncertainty for each model" provide a basic approach to uncertainty documentation [38].

¶2 For ecosystem accounts derived from biophysical models, "outputs should be seen as best estimates, rather than absolute values" unless detailed parameterisation and validation has been conducted [39]. Statistical agencies should communicate uncertainty alongside point estimates, enabling users to assess fitness for their specific purposes. The tiered approach recommended in SEEA EA supports this, with lower tiers acknowledged to have greater uncertainty but serving valuable purposes for awareness-raising and broad trend analysis [40].

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¶3 The UN NQAF recommends that "statistical agencies should publish information on the quality of the statistics they compile and disseminate" and that "quality information should include measures of accuracy" [41]. For research data integrated into ocean accounts, this translates to publishing confidence intervals, standard errors, or qualitative uncertainty assessments alongside the data values used in the accounts.

¶4 **Combining uncertainty components — methods note.** Where an account value carries multiple uncertainty components (typically measurement uncertainty, spatial interpolation uncertainty, and model parameter uncertainty), the components must be combined into a single published uncertainty using a method that is both transparent and methodologically defensible. NSOs should apply the following:

- ¶5 **Quadrature combination (root sum of squares)** for uncertainty components that are statistically independent and uncorrelated. If $u_1, u_2, \ldots, u_n$ are the independent component uncertainties (expressed as standard uncertainties), the combined uncertainty is $u_c = \sqrt{u_1^2 + u_2^2 + \cdots + u_n^2}$. This is the method specified by the Joint Committee for Guides in Metrology (JCGM 100:2008 — Guide to the Expression of Uncertainty in Measurement, "GUM"), the international standard for measurement uncertainty propagation, and should be the default for ocean accounts.
- ¶6 **Arithmetic addition** ($u_c = u_1 + u_2 + \cdots + u_n$) as a conservative upper bound where the correlation structure between components is unknown or where components are believed to be positively correlated. This approach overstates uncertainty for independent components and should be clearly identified as a conservative bound when used.

¶7 **Structural model uncertainty** (also called scenario uncertainty or model-form uncertainty) arises when the mathematical structure of a model may be wrong, independently of whether its parameter values are correct. As structural uncertainty has no standard probabilistic form, it cannot be combined in quadrature with measurement or parameter uncertainties. It must instead be reported as a separate qualitative statement or as a scenario-based range (e.g., low/central/high scenario outputs from alternative model structures). This separate reporting requirement applies whenever biophysical model outputs are used as primary inputs to ocean accounts. IPCC AR6 Working Group I uncertainty guidance and JCGM 100:2008 Annex notes on model-form uncertainty provide relevant precedent. The chosen combination method, the components combined, and the assumed correlation structure must be documented alongside the account release. Where uncertainty components have been combined arithmetically because correlation structure is unknown, future work to characterise the correlation structure and move to a GUM-aligned quadrature combination should be flagged in the account quality report.

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3.4 Metadata Standards

¶1 Complete metadata documentation is essential for integrating research data into statistical systems. Metadata enable data discovery, support quality assessment, and provide the documentation required for reproducible compilation of accounts.

3.4.1 FAIR principles for research data

¶1 The FAIR Guiding Principles (Findable, Accessible, Interoperable, Reusable) provide the overarching data management framework that underpins research-data integration [42]. Full definitions and practical requirements for each principle are provided in **TG-4.6 Data Harmonisation and Interoperability** Section 3.3. NSOs should prioritise research data sources that adhere to FAIR principles and advocate for FAIR practices when negotiating data sharing arrangements with research organisations, since non-FAIR research datasets impose additional metadata remediation work at Phase 2 of the compilation procedure (Section 3.5.2). [43]

3.4.2 Domain-specific metadata standards

¶1 Several domain-specific metadata standards are relevant for ocean accounting, including ISO 19115 (geospatial metadata), Darwin Core (biodiversity occurrence), CF Conventions (gridded oceanographic data in NetCDF), SDMX (statistical data and metadata exchange), and the IHO S-100 Universal Hydrographic Data Model [44]. Practitioners drawing on biodiversity survey data, spatially-referenced ocean observations, or hydrographic products should adopt the relevant standard at the point of ingest so that metadata records remain interoperable with national and international statistical systems. For full treatment of these standards, the SDMX adoption pathway, and the harmonisation workflow that connects them, see **TG-4.6 Data harmonisation**.

3.4.3 Data provenance documentation

¶1 Provenance documentation tracks the history of a dataset through its processing chain, so that users can understand how data have been transformed from raw observations to derived products [45]. For research data used in ocean accounting, provenance should document:

- ¶2 Original data sources and collection methods
- ¶3 Processing steps and algorithms applied
- ¶4 Software and version numbers used
- ¶5 Personnel responsible for processing
- ¶6 Dates of processing steps
- ¶7 Quality control procedures applied

¶8 The SEEA Technical Guidance on Biophysical Modelling recommends maintaining "a data provenance system" that "improves users' ability to understand the fitness for purpose of data sets" [46].

3.5 Compilation Procedure

¶1 This section outlines a systematic procedure for assessing, acquiring, and integrating research data into ocean accounting programmes. The procedure consists of four phases: research data assessment, metadata alignment, quality assurance, and account integration.

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3.5.1 Phase 1: Research data assessment

¶1 The first phase involves identifying candidate research data sources and conducting a preliminary fitness assessment:

¶2 **Step 1.1: Identify data requirements** — Determine which components of the ocean accounts require research data inputs. This assessment should be guided by the account structure and the availability of alternative data sources. For example, if ecosystem condition accounts for pelagic waters are planned (see **TG-6.5 Pelagic and Open Ocean Accounting**), identify which condition variables (dissolved oxygen, chlorophyll-a, sea surface temperature) are available from research programmes versus traditional statistical sources.

¶3 **Step 1.2: Survey available research data** — Conduct a systematic survey of research data sources within the accounting domain. This survey should cover:

- ¶4 National research institutions (marine laboratories, oceanographic institutes, fisheries research centres)
- ¶5 International research programmes (GOOS, Argo, regional ocean observing systems)
- ¶6 Global data repositories (OBIS, GBIF, Copernicus Marine Service)
- ¶7 Published scientific literature and associated datasets

¶8 **Step 1.3: Apply integration checklist** — For each candidate data source, complete the integration checklist presented in Table 3.5.1. This checklist draws together the quality, metadata, and institutional considerations discussed in Sections 3.3 and 3.4. Each criterion is designated as either *mandatory* (must be met or formally waived before progression to Phase 2) or *conditional* (may remain open during Phase 2 or 3, subject to a documented resolution path).

¶9 *Table 3.5.1: Research Data Integration Checklist*

Integration Criterion	Status	Assessment Questions	Documentation Required
Spatial coverage	Mandatory	Does it cover the accounting area?	Geographic metadata (bounding box, coordinate system)
Temporal alignment	Mandatory	Does it match accounting periods?	Date/time stamps, temporal resolution
Methodological consistency	Mandatory	Are methods comparable to official statistics?	Methods documentation, peer-reviewed publications
Institutional access	Mandatory	Can the NSO access/use the data?	Data sharing agreement, licensing terms
Quality assurance	Conditional	What QA procedures were applied?	Quality reports, validation studies
Classification alignment	Conditional	Are categories mappable to SEEA/ISIC?	Classification concordance or crosswalk
Metadata completeness	Conditional	Are ISO 19115/FAIR metadata available?	Metadata catalogue entry
Reproducibility	Conditional	Can results be reproduced from documented inputs?	Code repository, processing documentation

¶10 **Phase 1 gate.** A data source may proceed to Phase 2 only if all *mandatory* criteria are met or formally waived. A waiver may be issued only by a named authority within the NSO (typically the head of the responsible statistical unit, or, for Mode C primary substitutions under Section 3.1.1, the chief statistician). The waiver, its scope, its expiry, and the remediation pathway must be recorded in the account compilation file. Conditional criteria that remain open at the gate must be assigned a target resolution date within Phase 2 or Phase 3. Failure to resolve a conditional criterion within Phase 3 escalates it to a mandatory issue at the Phase 4 release decision.

3.5.2 Phase 2: Metadata alignment

¶1 Once candidate data sources have been identified, the second phase addresses metadata harmonisation:

¶2 **Step 2.1: Extract existing metadata** – Retrieve available metadata from the research data source. This may exist in ISO 19115 format (for geospatial data), Darwin Core format (for biodiversity observations), or NetCDF-CF format (for oceanographic model outputs).

¶3 **Step 2.2: Assess metadata completeness against a two-tier standard** – Compare existing metadata against the requirements for statistical use. NSOs should apply a two-tier metadata standard.

¶4 *Statistical minimum (required to proceed to Phase 3 quality assurance).* The dataset must have documented:

- ¶5 Temporal extent (reference period and, where relevant, temporal resolution and update frequency)
- ¶6 Spatial coverage (geographic extent and coordinate reference system)
- ¶7 Measurement method (instrument, protocol, or modelling approach)
- ¶8 Uncertainty estimate (quantitative where available, or qualitative otherwise)
- ¶9 Access terms (licence, citation requirements, restrictions)

¶10 Where formal metadata records (e.g., ISO 19115, Darwin Core) are absent, as is common for high-quality legacy datasets and many older oceanographic programmes, the statistical minimum may be satisfied using metadata extracted from a peer-reviewed publication that documents the dataset. The compiling NSO must record the source of each minimum element, including the publication citation and section reference where applicable.

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¶11 *Full standard (long-term target for repeated and high-profile sources).* The dataset is described by a fully-populated ISO 19115 record (for geospatial data) or Darwin Core record (for biodiversity data), including all of the elements identified by the UN NQAF Level D essential metadata list: identification (title, abstract, keywords), temporal extent (reference period, temporal resolution, update frequency), spatial extent (geographic coverage, coordinate reference system), data quality (accuracy, completeness, consistency), lineage (data sources, processing steps), distribution (access constraints, usage licences), and contact information (data custodian, responsible party)[47].

¶12 A dataset meeting the statistical minimum may progress to Phase 3 whilst work to reach the full standard is undertaken in parallel.

¶13 **Step 2.3: Fill metadata gaps** — Where research data lack statistical metadata elements, work with the data provider to document missing information. Priority gaps include: correspondence to statistical classifications (e.g., mapping research ecosystem types to IUCN GET categories), uncertainty quantification (confidence intervals, accuracy assessments), and update schedules (will data be available on a recurring basis to support time series accounts?).

¶14 **Step 2.4: Document provenance** — Create or enhance provenance documentation following the framework in Section 3.4.3. For research data that have undergone multiple processing steps (e.g., satellite imagery processed to ocean colour products, acoustic survey data processed to biomass estimates), the provenance chain must be fully documented to support reproducibility.

3.5.3 Phase 3: Quality assurance

¶1 The third phase applies the quality assessment framework from Section 3.3:

¶2 **Step 3.1: Assess relevance** (as defined in Section 3.3.1) — Verify that the research data address the specific accounting requirements identified in Phase 1, considering both conceptual fit (do the measured variables correspond to the accounting concepts?) and practical fit (are the data sufficiently timely, granular, and complete?).

¶3 **Step 3.2: Evaluate accuracy** (as defined in Section 3.3.1) — Assess accuracy using available validation studies, inter-comparison exercises, or ground-truthing campaigns. For satellite-derived products, consult published accuracy assessments. For modelled outputs, assess model skill metrics against independent observations.

¶4 **Step 3.3: Test coherence** (as defined in Section 3.3.1) — Verify that research data can be combined with other account data sources. Coherence testing should identify discrepancies in spatial boundaries, temporal reference periods, or measurement units that require harmonisation (see **TG-4.6 Data Harmonisation**).

¶5 Where co-located independent monitoring is available (e.g., research station data co-located with an environmental protection agency monitoring station), coherence is tested by direct comparison of measurements at common locations and times. Where co-located data are unavailable, which is the typical situation for pelagic, open-ocean, and deep-shelf accounts, the following fallback coherence testing hierarchy applies. At least one fallback test must be completed and documented:

1. ¶6 **Temporal climatology test.** Compare research data values to climatological norms from global ocean databases (e.g., NOAA World Ocean Atlas, Copernicus Marine Service reanalyses) for the matching season, depth, and biogeographic region. Values falling outside the 5th-95th percentile range of the climatology should be reviewed for outlier status and either corrected, flagged, or accepted with documented justification.
2. ¶7 **Cross-variable coherence test.** Verify that correlated variables observed in the same dataset exhibit expected relationships (e.g., dissolved oxygen and temperature follow expected solubility relationships, and chlorophyll-a and nitrate exhibit expected biogeochemical coupling). Departures from expected relationships indicate either real ecosystem signal or measurement issue and must be examined.

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3. ¶8 **Literature-based plausibility check.** Compare summary statistics (mean, range, seasonal cycle) to published ranges for equivalent ecosystem types in the peer-reviewed literature. Values outside the published range should be reviewed for plausibility.

¶9 These fallback tests are not substitutes for direct co-location where it is feasible, but they ensure that the coherence check does not silently fail in the open-ocean and deep-water contexts where research data are most essential.

¶10 **Step 3.4: Check comparability** (as defined in Section 3.3.1) — Document any methodological changes that create breaks in time-series comparability, and verify consistent methods across geographic domains.

¶11 **Step 3.5: Quantify uncertainty** — Where feasible, quantify the uncertainty associated with research data values. This may take the form of standard errors (for survey-based estimates), confidence intervals (for modelled values), or qualitative uncertainty categories (high/medium/low confidence). Uncertainty estimates should be documented in metadata and, where appropriate, published alongside account values. Where multiple uncertainty components must be combined into a single published figure, follow the methods note in Section 3.3.3.

3.5.4 Phase 4: Delivery to the account

¶1 The final phase puts the quality-assured research data into the form the account expects, and hands it over:

¶2 **Step 4.1: Apply classification concordances** — Where research data use different classifications from statistical standards, apply the concordances or crosswalks developed in Phase 2. For example, if research biodiversity data use scientific taxonomic names but the account structure requires aggregation to functional groups, apply the taxonomic-to-functional-group mapping.

¶3 **Step 4.2: Reconcile spatial and temporal boundaries** — Align research data to the spatial and temporal structure of the accounts. This may require spatial aggregation (from fine-resolution survey points to accounting spatial units), temporal aggregation (from monthly observations to annual accounting periods), or gap-filling (interpolating missing values).

¶4 *Spatial interpolation method selection.* The choice of spatial interpolation method must be justified by the density and spatial distribution of the source data, not selected by default. Table 3.5.4 specifies the recommended method as a function of station density and spatial pattern. The choice and its justification must be recorded in the account compilation file.

¶5 *Table 3.5.4: Recommended spatial interpolation method by station density and distribution*

Station density / distribution	Recommended method	Notes
Dense (>30 stations over the accounting area) with approximately random or stratified spatial distribution	Ordinary kriging (or universal kriging where trend is present)	Variogram should be fitted and inspected; cross-validation mandatory
Moderate density (10–30 stations) with clustered or coastal-biased distribution	Inverse distance weighting (IDW) with documented search radius	Sensitive to clustering; report edge-effect zones as higher-uncertainty
Sparse coverage (<10 stations) or strongly heterogeneous environment	Thiessen (Voronoi) polygon assignment, or assignment by ecosystem stratum mean	Resulting account values must be flagged as Tier 1 (broad indicative) under SEEA EA tiering
Sparse and gridded reference data available	Regression-based methods (e.g., regression-kriging) using auxiliary covariates (bathymetry, SST)	Requires documented covariate justification

¶6 *Cross-validation is mandatory* whichever interpolation method is selected. Leave-one-out cross-validation should produce a root-mean-square error no greater than the tolerance threshold, defined as the published measurement uncertainty of the source data multiplied by 1.5 (i.e., tolerance

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threshold = baseline RMSE × 1.5, a multiplicative allowance of 50% above the measurement uncertainty). Values exceeding this threshold indicate that interpolation uncertainty dominates and that the interpolated product must either be downgraded in tier, supplemented with additional stations, or replaced with a coarser spatial aggregation.

¶7 **Step 4.3: Document data sources** — Record the use of research data in the account compilation metadata. Documentation should identify: the research data source (with citation and persistent identifier), the account components that use the research data, the processing steps applied, and the quality assessment results. This documentation supports transparency and reproducibility.

¶8 **Step 4.4: Establish update procedures** — Where research data will be used on a recurring basis for time series accounts, establish procedures for data updates. Coordinate with research data providers to understand their publication schedule and arrange for regular data transfers. Monitor for methodological changes that may affect comparability across accounting periods.

¶9 *Back-revision policy for retroactively corrected research data.* Research datasets are frequently revised: stock assessments are updated as new cohorts enter the record, satellite data products undergo reprocessing, and bathymetric and hydrographic surveys are revised as better data become available. A retrospective revision to historical research data can propagate through multiple accounting periods of a time series account, creating apparent trends that are artefacts of data revision rather than real ecosystem change. NSOs must adopt a back-revision policy with the following elements:

- ¶10 **Monitoring.** NSOs should subscribe to dataset versioning notices from research data providers and incorporate a versioning check into the standing data transfer protocol (Section 3.7.4).
- ¶11 **Materiality threshold.** A retrospective revision triggers formal revision of previously published accounts where it produces a change of more than 5% in any key account indicator for any covered accounting period, or where it materially changes the direction of a published trend. Below the materiality threshold, the revision is recorded in the next account release without republication of historical accounts.
- ¶12 **Version identification.** Every account release must identify the specific version (DOI or equivalent persistent identifier) of each research dataset used. This allows users to trace account values to specific dataset versions and supports reconstruction of historical account values.
- ¶13 **Metadata revision history.** The account compilation metadata must include a revision history listing the date, dataset, version change, materiality assessment, and the action taken (republished, recorded in next release, or no action).

¶14 This policy aligns with SEEA EA guidance on revision policy in statistical frameworks and with UN NQAF Level B revision policy requirements.

3.6 Worked Example: Delivering Oceanographic Survey Data to a Condition Account

¶1 This worked example demonstrates the application of the compilation procedure to a realistic scenario: a National Statistical Office seeking to compile ecosystem condition accounts for coastal shelf waters using dissolved oxygen data from a national oceanographic research programme.

¶2 **Setting:** A coastal nation with 150,000 km² of exclusive economic zone (EEZ) shelf waters (depths <200m) seeks to compile annual condition accounts for the Marine Shelf (M1) ecosystem type following the IUCN Global Ecosystem Typology. One of the selected condition variables is dissolved oxygen concentration, which serves as an indicator of ecosystem health and hypoxia risk. The NSO has identified the National Oceanographic Research Institute (NORI) as a potential data provider.

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> *Note on illustrative scope. This worked example uses a single condition variable (dissolved oxygen) and a linear-rescaling condition index purely for pedagogical clarity. SEEA EA Table 5.3 envisages multi-variable condition indices that combine abiotic chemical, abiotic physical, biotic compositional, structural, and functional characteristics, and a production-grade Marine Shelf (M1) condition account would aggregate dissolved oxygen with at least temperature, chlorophyll-a, and a biotic indicator. The minimum-threshold value used below (2.0 mg/L) is the OSPAR acute-toxicity level for oxygen deficiency; the OSPAR Ecological Quality Objective itself is an area-specific assessment level of 4–6 mg/L.[48] The reference value (8.0 mg/L) is illustrative, taken from the 6–8 mg/L range for a well-mixed shelf in Step 1.1; it is not an OSPAR value. National standards (e.g., EU Water Framework Directive good ecological status thresholds, regional sea convention values) may differ and should be used where authoritative locally.*

¶3 **Phase 1: Research data assessment**

¶4 *Step 1.1: Identify data requirements* — The condition account requires dissolved oxygen measurements representative of the shelf ecosystem. Following SEEA EA guidance, the reference condition is defined as the dissolved oxygen level corresponding to a healthy, well-mixed shelf ecosystem (typically 6-8 mg/L). The account structure requires annual average values aggregated to ecosystem asset spatial units. Applying the Section 3.1.1 integration-mode typology, the NSO classifies this as Mode A (gap-filling): no official statistical source for subsurface dissolved oxygen exists in this jurisdiction.

¶5 *Step 1.2: Survey available data* — NORI conducts quarterly oceanographic surveys at 45 fixed stations distributed across the shelf. Each station is sampled at 5 depth intervals (surface, 25m, 50m, 75m, 100m). Dissolved oxygen is measured using calibrated Winkler titration (precision ±0.1 mg/L). The programme has operated continuously since 2010 with consistent methodology. Data are archived in NORI's institutional repository.

¶6 *Step 1.3: Apply integration checklist* — Applying Table 3.5.1 with mandatory/conditional designations:

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Criterion	Status	Assessment Result	Documentation
Spatial coverage	Mandatory	45 stations cover 150,000 km² shelf area; spatial interpolation required	Station coordinates in WGS84
Temporal alignment	Mandatory	Quarterly surveys provide seasonal coverage; annual averaging feasible	Survey dates documented per cruise
Methodological consistency	Mandatory	Winkler titration is standard oceanographic method	NORI Standard Operating Procedures manual
Institutional access	Mandatory	NORI willing to share data; MoU required	Draft MoU provided by NORI legal office
Quality assurance	Conditional	Inter-laboratory bias <0.15 mg/L vs. IOC/GOOS ±0.2 mg/L standard	QA reports 2012-2020
Classification alignment	Conditional	Dissolved oxygen is a standard SEEA EA condition variable	SEEA EA Table 5.3
Metadata completeness	Conditional	Station metadata exist; cruise-level metadata incomplete	ISO 19115 records for stations
Reproducibility	Conditional	Raw titration data archived; processing code not version-controlled	NORI agrees to deposit in GitHub

¶7 **Phase 1 gate finding:** All four mandatory criteria are met (subject to MoU finalisation, which the NSO head of environmental statistics waives for a 90-day remediation window). Conditional crite-

ria are open but on a documented resolution path. The source proceeds to Phase 2.

¶8 **Phase 2: Metadata alignment**

¶9 *Step 2.1: Extract existing metadata* — NORI provides station-level metadata in CSV format including: station ID, latitude, longitude, depth, seafloor substrate type, and sampling history. Dissolved oxygen data are provided in a separate CSV with fields: station ID, cruise ID, date, depth, dissolved oxygen (mg/L), temperature (°C), salinity (PSU).

¶10 *Step 2.2: Assess metadata completeness against the two-tier standard (Section 3.5.2)* — Existing metadata are evaluated against the *statistical minimum*: temporal extent (partially documented, with gaps in cruise-level dates), spatial coverage and CRS (CRS implicit, must be made explicit), measurement method (documented), uncertainty estimate (available from QA reports), access terms (under MoU). The dataset meets the statistical minimum once CRS is explicitly documented and cruise dates are filled in. The full ISO 19115 standard is set as a 12-month target.

¶11 *Step 2.3: Fill metadata gaps* — NSO and NORI jointly develop enhanced metadata including:

- ¶12 Temporal coverage: Date range for each quarterly cruise added to cruise metadata table
- ¶13 Spatial reference: Coordinate reference system explicitly documented as WGS84 (EPSG:4326)
- ¶14 Quality flags: NORI applies automated QC checks (range test, climatology test, spike test) following GOOS recommendations and adds QC flags to data file (1=good, 2=probably good, 3=probably bad, 4=bad)
- ¶15 Provenance: Processing workflow documented: raw titration volume → dissolved oxygen calculation using modified Winkler equation → temperature and salinity correction → final value in mg/L

¶16 *Step 2.4: Document provenance* — Provenance record created:

> *Dissolved oxygen values are measured using Winkler titration following the GOOS BioEco Panel recommendations. Seawater samples are collected using Niskin bottles mounted on a CTD rosette. Titration is performed shipboard within 6 hours of collection. Raw titration volumes are converted to dissolved oxygen concentration using the modified Winkler equation with temperature and salinity corrections applied. Processing code (Python) is version-controlled at* `https://github.com/NORI/oceanography/DO-processing` *[fictional URL] (Reproducibility Level 2 per Section 3.3.2). Quality control follows GOOS Real-Time Quality Control procedures (GOOS, 2021).*

¶17 **Phase 3: Quality assurance**

¶18 *Step 3.1: Assess relevance* — The dissolved oxygen data directly address the condition account requirement for chemical state characteristics. Quarterly temporal resolution provides adequate seasonal coverage for annual aggregation. Spatial coverage (45 stations across 150,000 km²) is sparser than ideal but sufficient for broad-scale condition assessment given the relatively homogeneous shelf environment.

¶19 *Step 3.2: Evaluate accuracy* — NORI's QA reports indicate inter-laboratory comparison results within ±0.15 mg/L of reference standards, satisfying the IOC/GOOS ±0.2 mg/L accuracy threshold referenced in Table 3.3.1. Sampling precision (replicate measurements at same station) averages ±0.08 mg/L. The accuracy dimension is rated "Acceptable without qualification".

¶20 *Step 3.3: Test coherence* — NSO compares dissolved oxygen data against coastal water quality monitoring data from the environmental protection agency at 12 co-located stations. Average difference is 0.12 mg/L (within measurement uncertainty), confirming coherence. For shelf-edge stations where no co-located independent monitoring exists, the NSO additionally applies the tempo-

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ral climatology test against NOAA World Ocean Atlas seasonal climatology: all 45 stations' annual means fall within the 5th–95th percentile range of climatological values for the matching region and depth. This confirms the absence of systematic bias.

¶21 *Step 3.4: Check comparability* — NORI methodology has remained unchanged since programme inception (2010). All data are directly comparable over time. Spatial comparability verified by consistent station locations and sampling protocols.

¶22 *Step 3.5: Quantify uncertainty* — Based on QA assessment, dissolved oxygen values carry measurement uncertainty of ±0.15 mg/L (combining measurement precision and inter-laboratory comparison). This is combined in quadrature with spatial interpolation uncertainty (Step 4.2 cross-validation) per the JCGM 100:2008 (GUM) procedure described in Section 3.3.3. Combined uncertainty $u_c = \sqrt{(0.15)^2 + u_{spatial}^2}$ varies by asset unit depending on distance to the nearest station.

¶23 **Phase 4: Delivery to the account**

¶24 *Step 4.1: Apply classification concordances* — No classification mapping is required, as dissolved oxygen is used directly.

¶25 *Step 4.2: Reconcile spatial and temporal boundaries* — The accounting area is divided into 500 ecosystem asset spatial units (300 km² each) based on seabed substrate type. Applying the Table 3.5.4 method-selection rubric: with 45 stations over 150,000 km² in an approximately stratified spatial distribution, the rubric points to ordinary kriging. However, because variogram fitting at this station density is unstable, the NSO uses inverse distance weighting with a 90 km search radius (about 1.5 times the mean station spacing of about 58 km) as a pragmatic alternative and documents the reasoning. Mandatory leave-one-out cross-validation yields RMSE = 0.22 mg/L, within the 50% tolerance over the measurement uncertainty (0.15 × 1.5 = 0.225 mg/L), so the interpolated product is accepted. Quarterly values are averaged to produce annual mean dissolved oxygen per asset unit.

> ¶26 ⓘ **Corrected 24 September 2026**
> ¶27 The search radius was 30 km, shorter than the mean station spacing of about 58 km (150,000 km² over 45 stations), so about a third of the asset units, and most stations held out in the cross-validation, would have had no station within it; it is now 90 km. The cross-validation figure is illustrative and unchanged.

¶28 *Step 4.3: Document data sources* — Account compilation metadata records:

> *Dissolved oxygen condition data sourced from National Oceanographic Research Institute Quarterly Shelf Survey (NORI-QSS), 2015–2020, dataset version 2021.1 (DOI: 10.xxxx/nori-qss-2021.1) [fictional]. Data access via MoU between NSO and NORI dated 2021-03-15. Data processing conducted by NSO Environmental Accounts Unit using scripts deposited at* `https://github.com/NSO/ocean-accounts/condition-processing` *[fictional URL]. Integration mode: A (gap-filling). Spatial interpolation: inverse distance weighting, 90 km search radius (justified per Table 3.5.4, cross-validation RMSE 0.22 mg/L). Temporal aggregation: arithmetic mean of quarterly values. Uncertainty combined in quadrature per JCGM 100:2008: ±0.15 mg/L measurement plus variable spatial interpolation uncertainty.*

¶29 *Step 4.4: Establish update procedures* — NSO and NORI agree that NORI will provide annual data extracts by 31 March each year (covering the previous calendar year). NSO will re-run spatial interpolation and update condition accounts by 30 June. NORI will notify NSO of any methodological changes at least 6 months prior to implementation. Under the back-revision policy applied here, NORI dataset versioning notices are subscribed to. Any retrospective revision producing >5%

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change in the asset-unit condition index for any previously published year triggers re-publication of affected accounts. Each account release identifies the NORI dataset DOI.

¶30 **Variable delivered (example for one asset unit):**

Accounting year	Dissolved oxygen (mg/L)	Uncertainty	Reference value	Tier
2015	6.8	±0.35 mg/L	8.0 mg/L	2
2016	6.5	±0.33 mg/L	8.0 mg/L	2
2017	5.9	±0.38 mg/L	8.0 mg/L	2
2018	6.2	±0.36 mg/L	8.0 mg/L	2
2019	5.7	±0.40 mg/L	8.0 mg/L	2
2020	5.4	±0.42 mg/L	8.0 mg/L	2

¶31 *Note:* Uncertainty varies across years, as some monitoring stations had intermittent data gaps in later years. The gaps increased spatial interpolation distance and, with it, the combined-in-quadrature uncertainty for this asset unit. The reference value against which the variable will be rescaled is delivered with it (see **TG-4.8 Physical Condition Measurement** Section 3.1 on reference condition), so that the rescaling is reproducible.

¶32 **Outcome:** The NSO has established a quality-assured, documented dissolved oxygen series for each of the 500 asset units, with uncertainty and reference values attached. The series declines over 2015-2020. Rescaling it to a condition indicator and entering it in the ecosystem condition account is **TG-3.1 Asset Accounts** Section 3.5.2; aggregating across variables into a condition index is **TG-2.1 Aggregate Biophysical Indicators of Environmental State**. The provenance record above is what makes both reproducible.

3.7 Institutional Arrangements

¶1 Effective integration of research data into official statistics requires institutional arrangements that bridge the different cultures, incentives, and practices of statistical offices and research organisations.

3.7.1 Roles of National Statistical Offices

¶1 The SEEA Technical Recommendations identify several roles that NSOs can play in ecosystem accounting that are relevant to research data integration. Table 3.7.1 below summarises these roles. [49]

Role	Description
Data organisation	NSOs have expertise in collecting and organising data from diverse sources, building coherent pictures from varied inputs.
Standards stewardship	NSOs establish and maintain definitions, concepts, and classifications, addressing the multiple definitions common in research contexts.
Data integration	NSOs integrate data from various sources within national and international statistical frameworks.
Quality frameworks	NSOs apply data quality frameworks enabling consistent assessment and accreditation of information sources.
National coverage	NSOs create national pictures, applying techniques for scaling information to national level.
Authority	NSOs present an authoritative voice through application of standard measurement approaches and quality frameworks.

¶2 Whilst NSOs may not have deep expertise in marine science, they bring essential capabilities for transforming research data into official statistics [50] .

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3.7.2 Roles of research institutions

¶1 Research institutions contribute domain expertise, data collection infrastructure, and methodological innovation. The SEEA Technical Recommendations note that "agencies that lead work on geographic and spatial data — particularly the mapping of environmental data and the use of remote sensing information — including for spatial and temporal modelling of ecosystem services" play important roles [51]. For ocean accounting, relevant research institutions include:

- ¶2 Universities with marine science programmes
- ¶3 National oceanographic and hydrographic agencies
- ¶4 Fisheries research institutes
- ¶5 Environmental monitoring agencies
- ¶6 International research programmes (e.g., IOC, ICES)

¶7 These institutions are often the primary custodians of ocean observation data, biodiversity records, and ecosystem assessments needed for ocean accounts.

3.7.3 Establishing partnerships

¶1 The Global Statistical Geospatial Framework (GSGF) provides general guidance on collaboration between statistical offices and geospatial agencies [52], but agreements with research institutions need to address dimensions that NSO-geospatial agency templates (such as the UN-GGIM MoU template) do not cover [53]. Research institutions operating under university or grant-funded regimes have data governance requirements (publication embargo periods, intellectual property ownership, attribution under Creative Commons or funder mandates) that differ materially from those of national mapping agencies. NSOs negotiating data sharing arrangements with research partners should therefore use a purpose-built research data sharing agreement rather than carrying over the UN-GGIM template unchanged. The OECD Principles and Guidelines for Access to Research Data from Public Funding (2007) provide the governing international framework.

¶2 *Research data sharing agreement checklist.* A research data sharing agreement should address the following at minimum:

- ¶3 **Intellectual property ownership.** Identify the rights holders of the data (institution, individual researcher, funder, or joint), confirm that the NSO has the rights necessary to ingest, transform, and republish the data in statistical products, and record any conditions imposed by funders (e.g., European Research Council, NIH, Wellcome, NSF).
- ¶4 **Publication embargo periods.** Where the research team needs to publish primary findings before the data are released, specify the embargo duration. The maximum acceptable embargo for ocean-accounting purposes is 6 months from the end of the data collection period, consistent with the annual account publication cycle: data collected by 31 December must be available to the NSO by 30 June of the following year to meet standard account publication deadlines (see Step 4.4). Shorter embargoes should be sought wherever possible. Embargoes beyond 6 months are not compatible with the annual publication cycle of official accounts and should not be accepted. Where a research partner requires a longer embargo as a condition of data sharing, this should be escalated to the chief statistician as an exceptional governance case. Note that many major international funder mandates (e.g., Horizon Europe, NSF) require data availability within 12 months of collection. This funder deadline does not override the NSO's 6-month operational requirement.
- ¶5 **Attribution requirements.** Specify the citation form required by the data provider (data DOI plus accompanying publication) and confirm that the NSO will discharge these in account release documentation.
- ¶6 **Data lifecycle.** Address versioning (how new versions will be announced and made available), deprecation (how withdrawn versions will be handled), and the back-revision interaction (Section 3.5.4 Step 4.4).

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- ¶7 **Confidentiality of pre-publication data.** Where the NSO is provided access to pre-publication data, specify the handling regime (named individuals, secured storage, no onward sharing) and the point at which the data may be released into the NSO's normal compilation environment.

¶8 **Communities of practice.** Regular engagement through working groups or committees maintains relationships and addresses emerging issues. The SEEA Technical Recommendations emphasise that "appropriate institutional arrangements and resourcing to support ongoing engagement and communication are also required" [54].

¶9 **Capacity building.** Joint training and skill-sharing activities build mutual understanding between statistical and research communities. Research personnel may need orientation on statistical concepts and quality frameworks, whilst statistical personnel may need training on oceanographic data and methods.

¶10 Several countries provide practical models for NSO-research institution partnerships in ocean accounting. In Australia, the ABS compiles environmental-economic accounts in partnership with DCCEEW, drawing on scientific data inputs from CSIRO and IMOS.[55] In the Netherlands, Statistics Netherlands (CBS) has worked with Wageningen University and NIOZ to compile experimental natural capital accounts for the North Sea using research-derived biophysical models and real-time sensor networks.[55] Successful partnerships require sustained engagement over multiple accounting cycles, clear allocation of responsibilities, and mutual recognition of complementary capabilities.

3.7.4 Data transfer protocols

¶1 The SEEA Technical Note on Air Emission Accounts recommends establishing "data transfer protocols" given that "data may be acquired from a number of institutions or agencies" [56]. Such protocols should address:

- ¶2 Data formats and transmission methods
- ¶3 Timing and frequency of data provision
- ¶4 Procedures for handling system changes and upgrades
- ¶5 Metadata to be provided with each data transfer
- ¶6 Dataset versioning notices (to support the Section 3.5.4 back-revision policy)
- ¶7 Feedback mechanisms for data quality issues

¶8 Reliable protocols prevent disruption to statistical production when research systems are upgraded or personnel change.

3.7.5 Guidance for low-capacity and SIDS contexts

¶1 The institutional arrangements set out in Sections 3.7.1–3.7.4 assume that one or more national research institutions exist with which the NSO can establish a formal partnership. For many small island developing states (SIDS), least developed countries, and other contexts where national research capacity is still developing, ocean accounts must be compiled using data sourced entirely from international repositories and global research programmes. This is the dominant scenario for a substantial part of the GOAP target audience. The absence of a domestic research institution partner should not be treated as a barrier to compiling ocean accounts.

¶2 The following adapted procedure applies where no national research institution partner exists:

- ¶3 **Use pre-validated global data products as research data inputs without a national MoU.** Acceptable sources include the Copernicus Marine Service (validated ocean colour, sea surface temperature, sea level, and biogeochemistry products), GOOS Argo (subsurface temperature, salinity, dissolved oxygen), and OBIS / GBIF (biodiversity occurrence). These products are issued under open licences that permit statistical use without bespoke agreements. The product DOI or persistent identifier serves the role that the MoU would otherwise play in establishing access provenance.

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- ¶4 **Base quality assurance on the product's published quality reports.** In place of a bespoke Section 3.5.3 quality assessment, the NSO may rely on the product quality factsheet, validation report, or technical note published by the data provider, provided this is referenced in the account compilation metadata together with the product version. The Section 3.5.3 Step 3.3 fallback coherence tests still apply.
- ¶5 **Engage regional bodies as institutional partners in lieu of national research institutes.** Examples include the Secretariat of the Pacific Regional Environment Programme (SPREP) and the Pacific Community (SPC) for the Pacific Islands, the Indian Ocean Global Ocean Observing System (IOGOOS), the Caribbean Community Climate Change Centre (5Cs), and the Intergovernmental Oceanographic Commission Sub-Commission for Africa and the Adjacent Island States (IOCAFRICA). Regional bodies can provide brokered access to data, technical support, and a community of practice that substitutes for a national institutional partner.
- ¶6 **Simplified metadata and provenance documentation.** Pre-validated global products carry mature metadata, and the NSO's documentation obligation is reduced to citing the product, version, access date, and the elements of the product's quality report relied upon in the account.

¶7 NSOs operating in low-capacity contexts should not be deterred by the formal arrangements set out earlier in Section 3.7: those arrangements describe the upper end of the institutional spectrum, whilst this sub-section describes the lower end at which ocean accounting is equally feasible.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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forecast data in NetCDF; SDMX 3.0 (Statistical Data and Metadata Exchange); and the IHO S-100 Universal Hydrographic Data Model (covering bathymetry S-102, surface currents S-111, and water level S-104). See TG-4.6 Data harmonisation for the full treatment, classification crosswalks, and SDMX adoption pathway.

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4. ¶54 SEEA Technical Recommendations, para. 1.57. "Given the need for involving many areas of expertise, an important aspect of implementation is the allocation of resources to co-ordination, data sharing and communication."
5. ¶55 SEEA Technical Recommendations, paras. 1.55-1.62 on institutional arrangements for ecosystem accounting, including examples of multi-agency collaboration models.
6. ¶56 SEEA Technical Note: Air Emission Accounts, para. 81. "Given that data may be acquired from a number of institutions or agencies, it is important to establish data transfer protocols."

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Data Harmonisation and Interoperability

Helps practitioners harmonise and integrate ocean accounting data from diverse sources.

Version 0.7.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

After completing this Circular, practitioners will be able to harmonise and integrate ocean accounting data from diverse sources, formats, and domains, applying interoperability standards that address the technical and methodological challenges of multi-source data integration. Data harmonisation underpins three decision contexts for ocean accounting: cross-agency data sharing within national statistical systems, international comparability of ocean accounts across jurisdictions, and dissemination of ocean accounting data to external users through standardised exchange platforms.

Cross-agency data sharing: Ocean accounts draw upon data from national statistical offices (economic statistics), environmental agencies (ecosystem monitoring), hydrographic organisations (bathymetry), fisheries management authorities (catch and effort data), and maritime administrations (vessel tracking). Without harmonised classifications, coordinate reference systems, and exchange formats, each bilateral data transfer requires bespoke transformation procedures. The standards described in this Circular enable agencies to establish common data integration protocols that reduce transaction costs and improve data quality through systematic quality checks.

International comparability: Countries implementing ocean accounts require comparable indicators for benchmarking, knowledge exchange, and coordination of regional ocean governance. The SDMX framework provides the international standard for exchanging statistical data, enabling ocean accounting indicators to be disseminated through the same infrastructure as national accounts, environmental-economic accounts, and SDG indicators. Alignment with geospatial standards from the Open Geospatial Consortium and International Hydrographic Organization ensures that spatial data components of ocean accounts can similarly be exchanged across jurisdictions.

Standardised dissemination: Publication of ocean accounting data through SDMX-compliant data repositories enables automated discovery and retrieval by policy analysts, researchers, and decision-support systems. Classification concordances ensure that data collected under national frameworks can be mapped to international reference classifications, so that national detail is preserved and the data remain reusable.

This Circular covers the principal international standards for statistical data exchange, including (1) the Statistical Data and Metadata Exchange (SDMX) framework, (2) geospatial interoperability standards from the Open Geospatial Consortium (OGC) and International Hydrographic Organization (IHO), and (3) classification concordance mechanisms that enable mapping between different classification systems. By applying the principles and protocols described here, compilers can establish data integration workflows that raise data quality and reduce manual processing.

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1. Outcome

¶1 After completing this Circular, practitioners will be able to harmonise and integrate ocean accounting data from diverse sources, formats, and domains, applying interoperability standards that address the technical and methodological challenges of multi-source data integration. Data harmonisation underpins three decision contexts for ocean accounting: cross-agency data sharing within national statistical systems, international comparability of ocean accounts across jurisdictions, and dissemination of ocean accounting data to external users through standardised exchange platforms.

¶2 **Cross-agency data sharing**: Ocean accounts draw upon data from national statistical offices (economic statistics), environmental agencies (ecosystem monitoring), hydrographic organisations (bathymetry), fisheries management authorities (catch and effort data), and maritime administrations (vessel tracking). Without harmonised classifications, coordinate reference systems, and exchange formats, each bilateral data transfer requires bespoke transformation procedures. The standards described in this Circular enable agencies to establish common data integration protocols that reduce transaction costs and improve data quality through systematic quality checks.

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2. Requirements

¶1 **Essential prerequisites:**

- ¶2 **TG-0.1 General Introduction to Ocean Accounts**: conceptual framework and key components of Ocean Accounts.

¶3 **Helpful background:**

- ¶4 **TG-0.7 Quality Assurance Principles**: quality dimensions and assessment frameworks, particularly coherence and comparability.

¶5 **Framework Position**

¶6 This Circular addresses data harmonisation and interoperability across the accounting domains. Harmonisation ensures consistent measurement across edges linking economic flows to environmental stocks and ecosystem services to economic activity. In the Ocean Accounts Framework (TG-0.1 Figure 0.1.2):

Edge	Direction	Description
E3	FG1 ↔ SG1	Monetary flows between assets and economic sectors
E9	SG3 → FG1	Ecosystem services to economy (SEEA)

3. Guidance Material

¶1 Ocean accounts draw upon a diverse range of sources: fisheries catch statistics from national statistical offices, bathymetric surveys from hydrographic agencies, satellite observations from earth observation programmes, ecosystem condition assessments from environmental monitoring networks, and economic statistics from national accounts. Each of these data streams has evolved within its own institutional context, employing different standards, classifications, formats, and temporal and spatial reference systems. Ocean accounting must harmonise these disparate data streams into a coherent accounting framework whilst preserving data quality and provenance. For guidance on spatial delineation of accounting units, see **TG-2.12 Spatial Data Frameworks** Sections 3.2 and 3.3. For temporal considerations, see **TG-2.12 Spatial Data Frameworks** Section 3.4.

¶2 This section examines four interrelated dimensions of data harmonisation and interoperability: data standards that define common structures and semantics, exchange formats that enable machine-readable data transmission, interoperability protocols that support automated data discovery and retrieval, and classification concordances that enable translation between different coding systems. Together, these elements form the technical infrastructure for integrated ocean accounting.

¶3 Figure 4.6.1 shows how economic data (SDMX), geospatial and marine data (OGC/IHO S-100), and classification concordances feed an integration layer that produces coherent ocean accounts[1].

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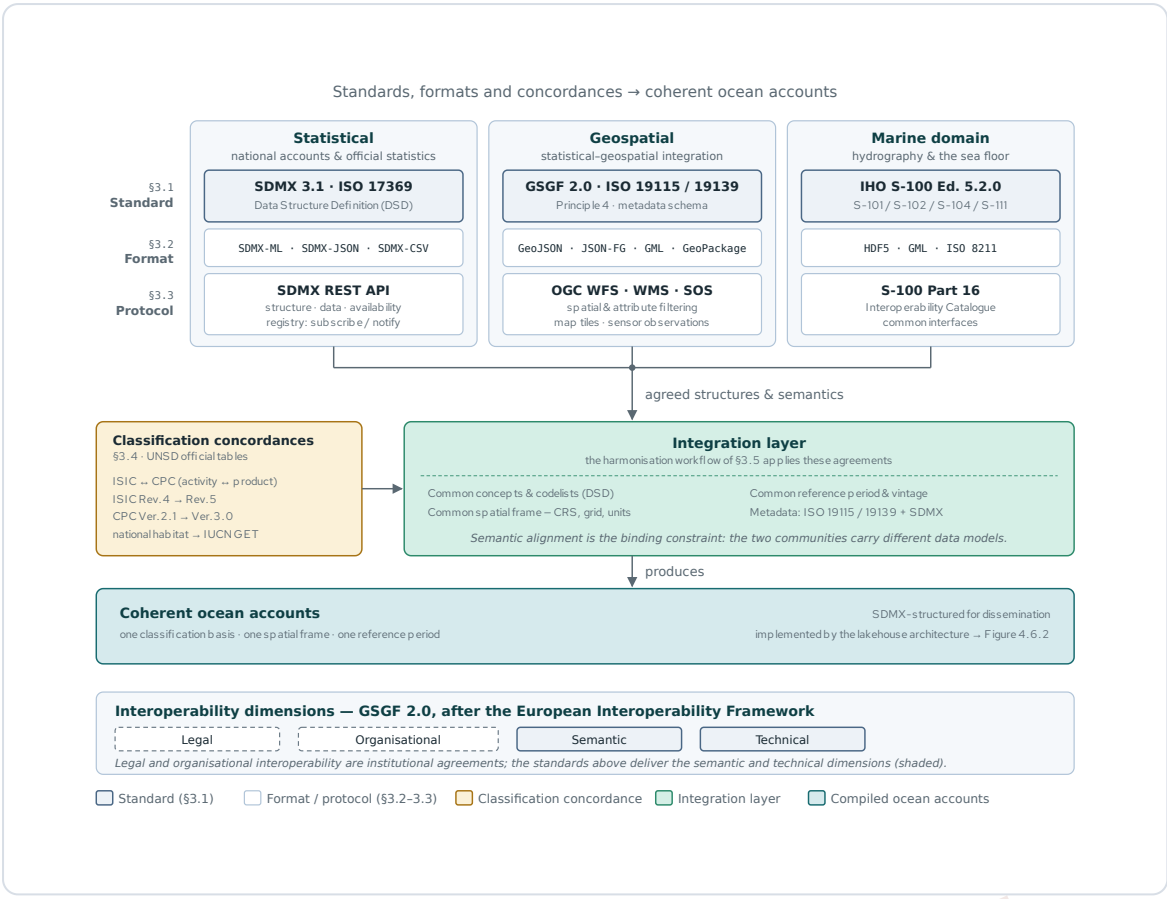


Figure 4.6.1 Statistical, geospatial and marine standards, with classification concordances, converge on an integration layer that yields ocean accounts on one classification, spatial and temporal basis. Colour marks role, not family. The system that runs this integration is Figure 4.6.2.

Source: TG-4.6 §3.1 (data standards, Tables 3.1.1–3.1.2), §3.2 (exchange formats), §3.3 (interoperability protocols) and §3.4 (classification concordances); SDMX 3.1 information model (May 2025), ISO 17369; GSGF v2.0 (UN-GGIM / UNSC 2025); ISO 19115 / ISO/TS 19139; IHO S-100 Edition 5.2.0 (June 2024) and the S-101 / S-102 / S-104 / S-111 product specifications (December 2024); UNSD ISIC Rev.4–Rev.5 and CPC Ver.2.1–Ver.3.0 correspondence tables; IUCN Global Ecosystem Typology.

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3.1 Data Standards

¶1 Data standards provide the foundational agreements on how data should be structured, described, and interpreted. For ocean accounting, three families of standards are particularly important: statistical data standards, geospatial data standards, and marine domain-specific standards. The application of these standards supports the quality dimensions described in **TG-0.7 Quality Assurance Principles**, particularly coherence and comparability.

Statistical Data and Metadata Exchange (SDMX)

¶1 The **Statistical Data and Metadata Exchange (SDMX)** initiative provides the international standard for exchanging statistical data and metadata [2]. Developed by the seven sponsor organisations (BIS, ECB, Eurostat, IMF, OECD, United Nations, and World Bank), SDMX has been designated as an ISO International Standard (ISO 17369) [3]. The SDMX 3.1 version, released in May 2025, introduces enhanced support for geospatial data, microdata, and improved data structure definitions [4].

¶2 SDMX is built around an **information model** that defines the structural metadata needed to describe statistical data [5]. At its core is the **Data Structure Definition (DSD)**, which specifies the dimensions, attributes, and measures that characterise a particular data collection. For ocean accounting, DSDs would define the structure of fisheries statistics, marine economic activity data, and

environmental flow accounts. The structure of physical flow accounts is described in **TG-2.6 Ocean Economy Investment**.

¶3 The SDMX framework supports three process patterns for data exchange[6]:

1. ¶4 **Bilateral exchange** — counterparties agree on specific formats and processes
2. ¶5 **Gateway exchange** — multiple organisations agree on a common exchange format
3. ¶6 **Data-sharing exchange** — open standards enable any organisation to access and use data

¶7 For ocean accounting, the data-sharing model is particularly relevant as it enables national statistical offices, environmental agencies, and research institutions to publish data in standard formats that can be automatically discovered and integrated.

¶8 SDMX provides three transmission formats (SDMX-ML, SDMX-JSON, SDMX-CSV)[7], detailed in Section 3.2 below. The CSV format is particularly accessible to non-specialist users whilst remaining losslessly convertible to the other formats[8]. SDMX registry services provide "visibility into the data and metadata existing within the community, and support the access and use of this data and metadata by providing a set of triggers for automated processing"[9]. A registry-based architecture enables ocean accounting compilers to discover available data sources, retrieve structural metadata, and automate data collection workflows.

Geospatial Standards

¶1 The **Global Statistical Geospatial Framework (GSGF)**, version 2.0 released by UN-GGIM and the Statistical Commission in 2025, provides the overarching framework for integrating statistical and geospatial information[10]. The GSGF defines five principles, of which Principle 4 on "Statistical and geospatial interoperability" is directly relevant to ocean accounting data integration[11].

¶2 Data interoperability, as defined in the GSGF, refers to "the ability of different systems, organizations, and applications to exchange, interpret, and use data in a coordinated manner"[12]. The framework identifies four interoperability dimensions derived from the European Interoperability Framework (EIF)[13]. Table 3.1.1 below summarises these dimensions.

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Dimension	Description
Legal interoperability	Enabling organisations under different legal frameworks to share data.
Organisational interoperability	Aligning business processes and responsibilities.
Semantic interoperability	Exchanging data through common terminology and formats.
Technical interoperability	Linking systems through standard interfaces and formats.

¶3 For ocean accounting, semantic interoperability is particularly challenging as statistical and geospatial communities have "evolved their own general data models, metadata capabilities, architectures, and data infrastructures, creating differences in fundamental terminology over time"[14].

¶4 The **Open Geospatial Consortium (OGC)** provides the principal geospatial interoperability standards relevant to ocean accounting[15]. Table 3.1.2 below summarises those standards.

Standard	Description
Web Feature Service (WFS)	For vector data exchange, applicable to administrative boundaries, marine protected area polygons, and ecosystem extent units.
Web Map Service (WMS)	For raster map images and tiles, useful for bathymetric visualisation and land cover products.
Geography Markup Language (GML)	The XML encoding standard for geospatial features.

¶5 Two additional ISO standards are essential for geospatial metadata management. **ISO 19115** (*Geographic information — Metadata*) provides the standard schema for describing geographic datasets and services, defining the metadata elements needed for data discovery, evaluation, and

use [16]. Its XML implementation, **ISO/TS 19139**, specifies the encoding format in which ISO 19115 metadata should be stored and exchanged, enabling machine-readable metadata interchange between systems [17]. Together, these standards ensure that geospatial data used in ocean accounts carry sufficient provenance and quality information for informed integration.

¶6 The GSGF recommends that organisations "host appropriate technical infrastructures which support the use of the relevant standards where systems and services are linked through standard interfaces, services, and data formats" [18].

Marine Domain Standards: IHO S-100

¶1 The **International Hydrographic Organization (IHO) S-100** standard provides the Universal Hydrographic Data Model for marine geospatial data [19]. S-100 Edition 5.2.0, adopted in June 2024, builds upon the earlier Edition 5.1.0 (October 2023) and establishes "a contemporary hydrographic geospatial data standard that can support a wide variety of hydrographic-related digital data sources, and is fully aligned with mainstream international geospatial standards, in particular the ISO 19100 series" [20]. In December 2024, IHO Member States approved operational editions of key S-100-based Product Specifications, including S-101 (Electronic Navigational Charts), S-102 (Bathymetric Surface), S-104 (Water Level Information), and S-111 (Surface Currents) [21].

¶2 S-100 is designed to support applications "that go beyond the scope of traditional hydrography – for example, high-density bathymetry, seafloor classification, marine GIS" [22]. The standard comprises multiple parts covering conceptual schema, feature catalogues, spatial schemas, metadata, portrayal, and encoding formats including ISO 8211, GML, and HDF5 [23].

¶3 Part 16 of S-100 specifically addresses the **Interoperability Catalogue Model**, which "enables interoperability between disparate technologies through the use of common interfaces" [24]. For ocean accounts that integrate hydrographic data (bathymetry, tides, currents) with ecosystem and economic data, S-100 provides the interoperability framework for the marine domain component.

3.2 Exchange Formats

¶1 Standardised exchange formats enable data to be transmitted between systems in machine-readable form. The choice of format affects both the technical ease of data integration and the preservation of semantic content.

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SDMX Transmission Formats

¶1 The three SDMX transmission formats introduced in Section 3.1 serve distinct use cases [25]:

- ¶2 **SDMX-ML** (XML-based) provides the most complete expression of the SDMX information model. The Structure Specific Data format is "the sole XML format for data exchange" following the deprecation of legacy formats in SDMX 3.0 [26]. Appropriate for formal data exchanges where complete metadata preservation is required.
- ¶3 **SDMX-JSON** is "well-suited to web-based applications and modern programming environments" [27] and is increasingly preferred for API-based data access.
- ¶4 **SDMX-CSV** provides a "simple columnar format" that offers accessibility for practitioners without specialised tools whilst still enabling conversion to other SDMX formats "without loss" [28]. CSV may serve as a practical intermediate format for data validation and review.

Geospatial Formats

¶1 For geospatial ocean accounting data, several format standards are relevant:

¶2 **GeoJSON** and **JSON-FG** (OGC Features and Geometries JSON) provide JSON-based formats for geographic features that are "well-suited to web mapping applications" [29]. These formats are appropriate for ecosystem extent boundaries, marine protected area polygons, and other vector features.

¶3 **GML** (Geography Markup Language) provides the full XML encoding for geographic information conforming to ISO 19136 [30]. GML is required for formal data exchange in contexts where complete geometry representation and coordinate reference system information must be preserved.

¶4 **HDF5** (Hierarchical Data Format version 5) is adopted by IHO S-100 for gridded and imagery data [31]. HDF5 is appropriate for bathymetric grids, ocean temperature fields, and other multi-dimensional environmental data.

¶5 **GeoPackage** provides an SQLite-based container format that can store both vector and raster data. GeoPackage is increasingly used for distributing compiled geospatial datasets.

3.3 Interoperability Protocols

¶1 Interoperability protocols define how systems communicate to discover, query, and retrieve data. Effective protocols enable automation of data collection workflows. Automation reduces manual processing and improves timeliness.

SDMX RESTful Web Services

¶1 SDMX defines a **RESTful web services API** for querying data and structural metadata [32]. The API enables:

- ¶2 Structure queries — retrieving Data Structure Definitions, codelists, concept schemes
- ¶3 Data queries — retrieving data observations filtered by dimension values
- ¶4 Availability queries — discovering what data exists for given parameters

¶5 The RESTful API design means queries are expressed through URL patterns, enabling integration with standard web tools. For example, a query for fisheries catch data might specify the dataflow, reference area, time period, and species codes through URL parameters.

¶6 The SDMX registry architecture supports "automated processing" through subscription and notification services [33]. Compilers can subscribe to data updates and receive notifications when new data becomes available, enabling near-real-time data integration workflows.

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OGC Web Services

¶1 The OGC web services introduced in Section 3.1 (Table 3.1.2) function as interoperability protocols: WFS supports spatial and attribute filtering for retrieval of ecosystem assets within specified bounds, whilst WMS supports rendered map visualisation of spatial context. The **Sensor Observation Service (SOS)** complements these by providing access to sensor data and observations [34], relevant for integrating ocean monitoring data (water quality, temperature, wave height) into ocean accounts.

¶2 The GSGF emphasises that technical infrastructure should support "standard interfaces, services, and data formats, including metadata standards" [18]. Implementation of OGC services enables ocean accounting systems to integrate with national spatial data infrastructures.

FAIR Data Principles

¶1 The **FAIR Principles** (Findability, Accessibility, Interoperability, Reusability) provide guiding principles for scientific data management that are increasingly applied to statistical data [35]. The GSGF explicitly incorporates FAIR principles, noting that the Interoperability principle "emphasises metadata" and that "(meta)data should be ready to be exchanged, interpreted and combined in a (semi)automated way" [36].

¶2 For ocean accounting, FAIR principles translate to practical requirements summarised in Table 3.3.1 below.

Principle	Practical requirement
Findability	Data should be registered in searchable catalogues with persistent identifiers.

Principle	Practical requirement
Accessibility	Data should be retrievable through standard protocols with clear access conditions.
Interoperability	Data should use standard formats, vocabularies, and include qualified references to other data.
Reusability	Data should have clear provenance and appropriate licenses.

¶3 The FAIR principles align with quality dimensions in **TG-0.7 Quality Assurance Principles** and should guide the design of ocean accounting data management systems.

3.4 Classification Concordances

¶1 Classification concordances (also called crosswalks or mapping tables) enable translation between different classification systems. For ocean accounting, concordances are essential for:

- ¶2 Linking economic activity data (ISIC) with product data (CPC)
- ¶3 Mapping national ecosystem classifications to international reference classifications
- ¶4 Converting between historical and current classification versions
- ¶5 Integrating data collected under different classification frameworks

¶6 The classification systems relevant to ocean accounting are described in **TG-0.2 Overview of Relevant Statistical Standards**.

Activity and Product Classifications

¶1 The relationship between **ISIC** (activity classification) and **CPC** (product classification) is fundamental to economic statistics. As the CPC documentation explains, "each subclass of the CPC consists of goods or services that are generally produced in a specific class or classes of the ISIC" [37]. The CPC documentation includes explicit correspondences to ISIC, enabling ocean accounting compilers to link product flows with producing industries.

¶2 The CPC serves as a "central" classification providing "a framework for international comparison and promotes harmonization of various types of statistics related to goods and services" [38]. The classification was "developed primarily to enhance harmonization among various fields of economic and related statistics and to strengthen the role of national accounts as an instrument for the coordination of economic statistics" [39].

¶3 With the endorsement of **ISIC Rev.5** and **CPC Ver.3.0** by the UN Statistical Commission in March 2024, compilers should note that the division-level structure for ocean-relevant activities has been maintained, though with increased detail at lower classification levels [40]. For ocean accounting, key concordance relationships include:

- ¶4 **ISIC Division 03 (Fishing and Aquaculture)** corresponds to **CPC Division 04 (Fish and Other Fishing Products)**
- ¶5 **ISIC Division 50 (Water Transport)** corresponds to relevant groups within **CPC Divisions 64-67 (Transport and Supporting Services)**, with specific correspondence at the group and class level documented in official UNSD concordance tables

¶6 The UNSD has developed official correspondence tables for the ISIC Rev.4-to-Rev.5 and CPC Ver.2.1-to-Ver.3.0 transitions [41]. These tables should be used when bridging data compiled under different classification versions. Compilers working with historical data collected under ISIC Rev.4 and CPC Ver.2.1 should apply these official correspondence tables rather than constructing ad hoc mappings, to ensure consistency and comparability across time.

¶7 Detailed guidance on ocean-relevant economic classifications is provided in **TG-0.2 Overview of Relevant Statistical Standards**.

Ecosystem Type Concordances

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¶1 The **IUCN Global Ecosystem Typology (GET)** provides the reference classification for ecosystem types in SEEA Ecosystem Accounting [42]. However, "countries may have their own national classification system of ecosystems (or ecological areas) that could be used for the extent accounts. In such cases, developing a bridge or concordance (often called a schema crosswalk in GIS) of this national classification system with the GET reference classification may facilitate comparability across countries" [43].

¶2 For marine ecosystems specifically, concordances may be required between:

- ¶3 National marine habitat classifications and GET Marine Realm types
- ¶4 EUNIS habitat classification and GET Ecosystem Functional Groups
- ¶5 National land cover classifications and GET transitional realm types (for coastal areas)

¶6 The SEEA Biophysical Modelling Guidelines note that the GET "represents a global typological framework that applies a process-based approach to ecosystem classification across the whole planet" [44]. The hierarchical structure (Realms, Biomes, Ecosystem Functional Groups) provides natural aggregation levels for concordance development.

¶7 Guidance on ecosystem classification for ocean accounts is provided in **TG-4.1 Remote Sensing and Geospatial Data** Section 3.2.4 and **TG-3.1 Asset Accounts**.

Concordance Development Process

¶1 Developing classification concordances involves:

1. ¶2 **Structural comparison** – examining the hierarchical structure and level of detail in each classification
2. ¶3 **Conceptual alignment** – identifying where definitions align or diverge
3. ¶4 **Mapping relationships** – defining one-to-one, one-to-many, or many-to-many relationships
4. ¶5 **Documentation** – recording mapping rationale and any approximations
5. ¶6 **Validation** – testing concordances with actual data

¶7 The UNFC (United Nations Framework Classification for Resources) provides an example of formalised concordance development: "mapping schemes have been developed showing the link between the UNFC2009 and the SPE and CRIRSCO classifications" for mineral and petroleum resources [45].

Temporal Concordances

¶1 Classification systems evolve over time through revision processes. ISIC has progressed through Revisions 3, 3.1, 4, and now 5. The CPC has progressed through Versions 1.0, 1.1, 2.0, 2.1, and now 3.0. The UN Statistics Division maintains official correspondence tables between versions to enable time series compilation across classification changes.

¶2 For ocean accounting, temporal concordances are required when:

- ¶3 Compiling time series that span classification revisions
- ¶4 Integrating historical data collected under previous classifications
- ¶5 Comparing international data collected under different version implementations

¶6 The ISIC documentation emphasises that "continuity, i.e., comparability between the revised and preceding versions of ISIC, has always been a major concern expressed by the Commission" [46]. The official ISIC Rev.4-to-Rev.5 correspondence table, developed between March and October 2024 following the endorsement of ISIC Rev.5 explanatory notes, should be consulted when compiling time series that bridge these classification versions [47]. Similarly, the CPC Ver.2.1-to-Ver.3.0 correspondence table is available through the UNSD classifications portal [48].

3.5 Data Harmonisation Workflow

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¶1 Implementing data harmonisation for ocean accounts requires a systematic workflow that transforms heterogeneous source data into consistent, integrated accounting tables. This section describes the compilation procedure and provides a worked example.

Compilation Procedure

¶1 The data harmonisation workflow consists of four sequential phases:

¶2 **Phase 1: Classify** — Assign source data to standardised classifications. For ocean accounting, this involves:

- ¶3 Mapping economic activity data to ISIC Rev.5 divisions and groups
- ¶4 Mapping product flows to CPC Ver.3.0 categories
- ¶5 Mapping ecosystem types to IUCN GET Ecosystem Functional Groups
- ¶6 Mapping spatial units to the national spatial framework and coordinate reference system

¶7 Classification mappings should be documented in concordance tables that record the source classification, target classification, mapping type (1:1, 1:many, many:1, many:many), and any assumptions or approximations.

¶8 **Phase 2: Map** — Transform source data values to common units and temporal reference periods. This includes:

- ¶9 Converting spatial coordinates to the accounting area's coordinate reference system (typically WGS84 for horizontal coordinates)
- ¶10 Aligning temporal references to accounting period start/end dates (calendar year, fiscal year)
- ¶11 Converting physical units to standard measurement units (e.g., tonnes for biomass, hectares for extent, cubic metres for water volumes)
- ¶12 Converting monetary values to constant prices using deflators where time series require comparability

¶13 Mapping transformations should preserve source values in metadata to enable quality checks and re-transformation if specifications change.

¶14 **Phase 3: Validate** — Check integrated data for consistency, completeness, and plausibility. Validation includes:

- ¶15 Range checks: values fall within plausible bounds (e.g., catch cannot exceed vessel capacity)
- ¶16 Balance checks: supply equals use in flow accounts
- ¶17 Spatial checks: geometries are valid, no gaps or overlaps in exhaustive spatial frameworks
- ¶18 Temporal checks: time series are continuous, no unexplained breaks
- ¶19 Cross-source confrontation: data from multiple sources describing the same phenomena are reconciled

¶20 Validation should generate exception reports that flag issues for resolution. The quality assurance framework in **TG-0.7 Quality Assurance Principles** provides detailed validation procedures.

¶21 **Phase 4: Integrate** — Compile validated data into accounting tables. Integration produces:

- ¶22 Asset accounts combining physical extent, condition indicators, and monetary valuations
- ¶23 Flow accounts recording extractions, emissions, and ecosystem service flows
- ¶24 Supply-use tables linking ocean economy production and consumption
- ¶25 Combined presentations integrating environmental, economic, and social dimensions (see **TG-3.8 Combined Presentations**)

¶26 *Table 3.5.1: Data harmonisation workflow phases*

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Phase	Inputs	Transformation	Outputs	Quality Checks
1. Classify	Source data with native classifications	Apply concordance tables	Data assigned to standard classifications	Classification coverage: all source items mapped
2. Map	Classified data in source units/CRS	Unit conversions, coordinate transformations, temporal alignment	Data in common units, CRS, accounting periods	Transformation validity: reversible where possible
3. Validate	Mapped data from multiple sources	Range, balance, spatial, temporal checks	Validated data with exception reports	Consistency: cross-source confrontation resolved
4. Integrate	Validated data	Compile into accounting tables	Asset, flow, activity accounts; combined presentations	Completeness: all required cells populated or flagged

Worked Example: Harmonising Fisheries Data Using SDMX

¶1 This synthetic example demonstrates the data harmonisation workflow for integrating fisheries catch data from multiple agencies into ocean accounts. The scenario: a national statistical office is compiling fisheries accounts and must integrate data from three sources with different reporting frameworks:

- ¶2 **Source A**: National fisheries agency — species-level catch data by fishing zone, reported quarterly in tonnes live weight
- ¶3 **Source B**: Port authority — landing declarations by vessel and port, reported monthly in various product forms (whole fish, fillets, processed)
- ¶4 **Source C**: Customs administration — seafood export data using national tariff codes, reported monthly in kilograms and monetary value (FOB)

¶5 **Phase 1: Classify**

¶6 The compiler establishes an SDMX Data Structure Definition (DSD) for fisheries flow accounts with the following dimensions:

- ¶7 **REF_AREA**: Fishing zone (territorial waters, EEZ zones by bathymetry, high seas)
- ¶8 **TIME_PERIOD**: Accounting period (annual, with quarterly detail available)
- ¶9 **SPECIES**: Fish species using FAO ASFIS codes
- ¶10 **ACTIVITY**: Producing industry using ISIC Rev.5 codes (Group 031: Marine fishing)
- ¶11 **PRODUCT**: Output product using CPC Ver.3.0 codes (Division 04: Fish and other fishing products)

¶12 For each source, the compiler develops classification mappings:

- ¶13 Source A reports species using national codes, and a concordance table maps these to FAO ASFIS codes (mostly 1:1)
- ¶14 Source B records product forms, and a concordance table maps these to CPC Ver.3.0 with conversion factors to derive live weight equivalent (1:many mapping: one product code may correspond to multiple CPC classes depending on processing level)
- ¶15 Source C uses HS 2022 tariff codes, and the official UNSD concordance table maps these to CPC Ver.3.0 (many:many mapping requiring allocation based on supplementary information)

¶16 **Phase 2: Map**

¶17 Unit conversions and temporal alignment:

- ¶18 Source A data are already in tonnes live weight, and temporal alignment aggregates quarterly data to annual totals for stock accounts whilst preserving quarterly detail for

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seasonal analysis

- ¶19 Source B landing weights require conversion to live weight equivalent using species-specific factors (e.g., fillets to whole fish factor 2.5 for snapper, 2.8 for tuna). Conversion factors documented in metadata
- ¶20 Source C export data in kilograms converted to tonnes product weight, and to live weight equivalent using the same species- and product-form factors as Source B, with monetary values (FOB) converted to national currency constant prices using fish price deflator

¶21 Spatial mapping:

- ¶22 Source A fishing zones map to ocean accounting spatial framework using GIS overlay of zone boundaries
- ¶23 Source B port locations geocoded using national address gazetteer, with landings attributed to fishing zones using vessel logbook data on fishing grounds (where available) or pro-rata allocation based on Source A zone proportions for species
- ¶24 Source C export port locations geocoded, with spatial attribution to production zones inferred from Source A and B integration

¶25 **Phase 3: Validate**

¶26 Validation checks applied:

- ¶27 **Range check**: No individual vessel catch exceeds vessel hold capacity (cross-reference with vessel register)
- ¶28 **Balance check**: Total catch (Source A) equals total landings (Source B) plus estimated at-sea discards, within tolerance threshold of 5%
- ¶29 **Cross-source confrontation**: Export volumes (Source C) reconciled with landing volumes (Source B) accounting for domestic consumption, processing losses, and stock changes

¶30 Discrepancies identified:

- ¶31 Source A reports 15,200 tonnes tuna catch in EEZ, whilst Source B records 14,100 tonnes landings. The difference is attributed to unreported landings (estimated 600 tonnes based on observer coverage) and at-sea discards (estimated 500 tonnes, 3.3% discard rate consistent with observer data)
- ¶32 Source C reports 8,200 tonnes tuna exports in product weight, or 9,100 tonnes live weight equivalent (the 900-tonne difference is weight removed in processing), which reconcile with Source B after accounting for 4,800 tonnes domestic consumption and 200 tonnes cold storage stock increase

¶33 Validation produces exception report documenting assumptions and highlighting areas requiring further investigation (unreported catch estimation method).

¶34 **Phase 4: Integrate**

¶35 Validated data compiled into SDMX-compliant fisheries flow account table with dimensions:

REF_AREA	TIME_PERIOD	SPECIES	ACTIVITY	PRODUCT	OBS_VALUE	UNIT
EEZ_ZONE_1	2024	YFT (Yellowfin tuna)	ISIC 031	CPC 04111	8,500	Tonnes
EEZ_ZONE_2	2024	YFT	ISIC 031	CPC 04111	6,700	Tonnes
TERRITORIAL	2024	SKJ (Skipjack)	ISIC 031	CPC 04112	3,200	Tonnes

¶36 The DSD includes attributes documenting data sources, estimation methods, and quality flags. The compiled data structure enables:

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- ¶37 Dissemination through SDMX registry for automated retrieval by analysts
- ¶38 Integration with economic accounts using ISIC and CPC concordances
- ¶39 Comparison with international fisheries statistics using FAO ASFIS species codes
- ¶40 Spatial analysis of catches by zone for marine spatial planning

¶41 The worked example demonstrates how SDMX Data Structure Definitions provide a standardised framework for harmonising heterogeneous source data. That framework supports systematic quality checks and produces interoperable outputs for ocean accounting.

3.6 Modular Data Architecture Patterns

¶1 The technical infrastructure supporting ocean account data harmonisation must accommodate diverse data sources, multiple processing workflows, and varied dissemination requirements. This section describes modular architecture patterns that enable national statistical offices and ocean accounting programmes to build scalable, maintainable data systems. The guidance draws on established practices in statistical data management and modern data engineering, adapted to the specific requirements of environmental-economic accounting.

Data lake versus data warehouse

¶1 Two architectural paradigms are relevant for ocean accounting data infrastructure: data lakes and data warehouses. Each serves a distinct purpose, and many implementations will employ both in combination.

¶2 A **data lake** stores data in its original format (raw satellite imagery, CSV files from monitoring stations, spreadsheets from fisheries agencies, GIS shapefiles) without imposing a predefined schema. The data lake preserves full provenance and enables re-processing when methodologies change. For ocean accounting, a data lake is appropriate for ingesting heterogeneous source data from the diverse agencies described in Section 3.1, including remote sensing products (**TG-4.1 Remote Sensing and Geospatial Data**), survey microdata (**TG-4.2 Survey Methods for Ocean Economic Activity**), administrative records (**TG-4.3 Administrative Data Sources**), and citizen science observations (**TG-4.4 Citizen Science**).

¶3 A **data warehouse** stores data in a structured, schema-enforced format optimised for analytical queries and reporting. The warehouse contains harmonised data that has passed through the classify-map-validate-integrate workflow described in Section 3.5. For ocean accounting, the data warehouse holds the compiled account tables in SDMX-compliant structures, ready for dissemination and analysis. The data warehouse enforces the classification concordances (Section 3.4) and accounting identities that ensure internal consistency.

¶4 The recommended pattern for ocean accounting is a **lakehouse architecture** that combines both approaches: source data are ingested into a data lake, processed through harmonisation pipelines, and loaded into a structured warehouse layer for dissemination. This pattern provides the flexibility to accommodate new data sources without redesigning the warehouse schema, whilst maintaining the rigour required for official statistical products. Figure 4.6.2 sets out the end-to-end lakehouse data architecture, in which heterogeneous source systems feed a data lake, a classify-map-validate-integrate harmonisation pipeline processes the lake's data into a schema-enforced warehouse, and the warehouse publishes through a tiered dissemination layer, with international standards and the metadata, quality and governance framework as cross-cutting rails.

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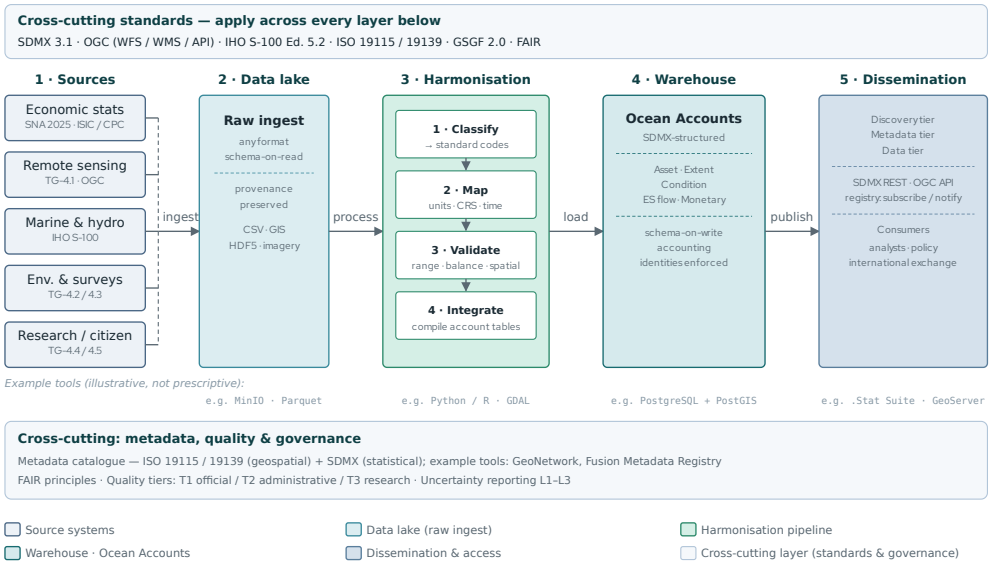


Figure 4.6.2 Lakehouse architecture moves ocean-account data from source systems through lake, warehouse, and dissemination layers under cross-cutting standards rails. Warehouse holds SDMX-structured Ocean Accounts. No adopted SEEA Ocean standard; GOAP TG is the interim framework.

Source: TG-4.6 draft §3.5 (data harmonisation workflow, Table 3.5.1) and §3.6 (modular data architecture patterns, Tables 3.6.1–3.6.2); SDMX 3.1 information model (May 2025); GSGF v2.0 (UN-GGIM / UNSC 2025); IHO S-100 Edition 5.2.0 (June 2024); ISO 19115 / 19139; SEEA CF (2012); SNA 2025.

¶5 *Table 3.6.1: Architecture pattern comparison for ocean accounts*

Characteristic	Data Lake	Data Warehouse	Lakehouse (Recommended)
Schema	Schema-on-read (flexible)	Schema-on-write (enforced)	Both: flexible ingest, enforced output
Data formats	Any (CSV, GIS, HDF5, imagery)	Structured (relational tables, SDMX)	Source formats preserved; output standardised
Processing	Batch and ad hoc	ETL pipelines	Harmonisation workflow (Section 3.5)
Users	Data engineers, researchers	Analysts, dissemination platforms	All stakeholders
Quality control	Minimal at ingest	Enforced at load	Validation at harmonisation stage
Suitable for	Raw data preservation, exploration	Official statistics, reporting	End-to-end ocean accounting

API design for data access

¶1 Application Programming Interfaces (APIs) enable automated data exchange between ocean accounting systems and external users. The API design should follow the SDMX RESTful web services specification (Section 3.3) for statistical data access, supplemented by OGC API standards for geospatial data. Key design principles include:

¶2 APIs should provide **three access tiers**: a discovery tier (what data are available, covering which areas and periods), a metadata tier (data structure definitions, classification codelists, quality reports), and a data tier (observation values with full dimensional context). This mirrors the SDMX

architecture of structure queries, availability queries, and data queries. Each tier should support standard HTTP methods and return responses in both SDMX-JSON and SDMX-CSV formats to accommodate different client capabilities.

¶3 **Versioning** is essential for APIs serving official statistics. Each API version should be maintained for a minimum of two years after a successor version is released, enabling downstream systems to migrate without disruption. Version identifiers should appear in the URL path (e.g., `/api/v2/data/ocean-accounts/...`) following REST conventions.

¶4 **Authentication and access control** should follow the data governance policies established by the national statistical office. Public-use indicators may be served without authentication, whilst microdata or geographically detailed data may require registration and licence acceptance, consistent with the FAIR principles described in Section 3.3.

Metadata standards

¶1 Complete metadata is essential for data discovery, evaluation, and reuse. Ocean accounting data should carry metadata conforming to two complementary standards:

¶2 **Geospatial metadata** follows ISO 19115 / ISO 19139 (introduced in Section 3.1). All geospatial data products used in ocean accounts (ecosystem extent maps, bathymetric grids, spatial unit boundaries) should carry ISO 19115-compliant metadata encoded in ISO 19139 XML, documenting the coordinate reference system, spatial resolution, temporal coverage, processing history, and quality assessment results.

¶3 **Statistical metadata** follows the SDMX information model (Section 3.1). All compiled ocean account tables should be accompanied by SDMX structural metadata defining the dimensions, attributes, and measures of each dataset. Reference metadata (quality reports, methodological descriptions) should follow the SDMX metadata structure definition format.

¶4 Where ocean accounting data combines geospatial and statistical components (as is typical), both metadata standards should be applied. The GSGF (Section 3.1) provides guidance on achieving interoperability between ISO 19115 and SDMX metadata, recommending that organisations maintain metadata catalogues that link geospatial and statistical metadata for the same underlying datasets.

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Open-source stack recommendations

¶1 National statistical offices and ocean accounting programmes with constrained budgets can implement the lakehouse architecture using open-source software. The following stack has been demonstrated in environmental-economic accounting contexts and aligns with the standards described in this Circular:

¶2 *Table 3.6.2: Open-source technology stack for ocean accounting data infrastructure*

Layer	Function	Recommended Tools	Standards Supported
Data lake storage	Raw data preservation	MinIO (S3-compatible), Apache Parquet	Any format
Geospatial processing	Spatial data harmonisation	GDAL/OGR, PostGIS, QGIS	OGC WFS/WMS, ISO 19115
Statistical processing	Data transformation and validation	Python (pandas), R	SDMX (via sdmx1 library)
Data warehouse	Structured storage and queries	PostgreSQL + PostGIS	SQL, spatial SQL
API layer	Data dissemination	.Stat Suite (SDMX), GeoServer (OGC)	SDMX REST, OGC API

Layer	Function	Recommended Tools	Standards Supported
Metadata catalogue	Data discovery	GeoNetwork (ISO 19115), Fusion Metadata Registry (SDMX)	ISO 19139, SDMX
Visualisation	Dashboard and reporting	Apache Superset, Observable Framework	Web standards

¶3 The SDMX community maintains the **.Stat Suite**, an open-source platform for SDMX data dissemination that is already used by several national statistical offices and international organisations. For geospatial data, **GeoServer** provides OGC-compliant web services. These tools can be deployed on standard server infrastructure or cloud platforms, with costs scaling according to data volume and user load.

3.7 Science-to-Accounts Translation Protocols

¶1 Ocean accounts depend on data from scientific research programmes (oceanographic surveys, ecological monitoring, biodiversity assessments, and fisheries stock assessments) that are produced for scientific purposes and must be translated into the structured formats required by accounting frameworks. This section provides protocols for converting research datasets into account-ready inputs, managing uncertainty, and establishing quality tiers that reflect the maturity and reliability of different data sources.

Converting research datasets

¶1 Scientific datasets differ from administrative and statistical data in several respects that affect their suitability for ocean accounts. Research data may cover irregular spatial domains (transects, sampling stations) rather than exhaustive spatial frameworks, may use non-standard temporal reference periods (field seasons, project durations) rather than accounting years, and may employ bespoke classification schemes in place of international standard classifications. The conversion protocol addresses each of these differences systematically.

¶2 **Spatial harmonisation**: Research data collected at point locations (monitoring stations, sampling sites) must be interpolated or modelled to produce estimates for the exhaustive spatial units used in ocean accounts. The biophysical modelling guidance in **TG-2.1 Aggregate Biophysical Indicators of Environmental State** describes interpolation and modelling techniques. Compilers should document the interpolation method, the spatial support (area over which each estimate applies), and the estimation uncertainty. Remote sensing data (**TG-4.1 Remote Sensing and Geospatial Data**) can provide spatially complete coverage to supplement point-based research data.

¶3 **Temporal alignment**: Research datasets with non-standard temporal coverage must be adjusted to accounting periods. Where research data cover a different period (e.g., a biological survey conducted from March to November), compilers should assess whether temporal adjustment is needed (for stocks that change slowly, the survey period may be a reasonable proxy for the annual average) or whether correction factors should be applied (for seasonally variable quantities such as biomass or water quality). The temporal alignment should be documented in metadata, including any assumptions about seasonal patterns.

¶4 **Classification mapping**: Research datasets often use scientific taxonomic or habitat classification schemes that differ from the standard classifications used in ocean accounts. Compilers should develop and maintain concordance tables mapping research classifications to accounting classifications (IUCN GET for ecosystem types, FAO ASFIS for species, ISIC/CPC for economic activities). The concordance development process described in Section 3.4 applies. Where research classifications provide finer detail than accounting classifications, the mapping is straightforward (aggregation). Where research classifications are coarser or use different conceptual categories, expert judgement is required and should be documented.

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¶5 *Table 3.7.1: Science-to-accounts conversion steps*

Step	Input	Transformation	Output	Documentation Required
1. Data assessment	Raw research dataset	Evaluate spatial, temporal, and thematic coverage	Gap analysis and fitness-for-purpose assessment	Assessment report with quality rating
2. Spatial harmonisation	Point/transect data	Interpolation, modelling, or aggregation to spatial units	Spatially complete estimates by accounting unit	Method, assumptions, uncertainty estimates
3. Temporal alignment	Survey-period data	Adjustment to accounting year	Annual estimates	Seasonal adjustment method, correction factors
4. Classification mapping	Scientific classifications	Apply concordance tables	Data classified to accounting standards	Concordance table with mapping rationale
5. Unit conversion	Research measurement units	Convert to accounting standard units	Data in standard units (tonnes, km², etc.)	Conversion factors and sources
6. Quality annotation	Converted dataset	Assign quality tier and metadata flags	Account-ready dataset with quality metadata	Quality tier justification

Uncertainty propagation

¶1 Scientific data carry measurement uncertainty that must be propagated through the accounting framework. Ocean accounts should report uncertainty for key aggregates, enabling users to assess the confidence they can place in derived indicators. Three levels of uncertainty reporting are recommended, in order of increasing sophistication:

¶2 **Level 1 — Qualitative assessment**: Each data input is assigned a qualitative uncertainty rating (low, medium, high) based on expert judgement of the data source, collection method, and processing steps. This minimum level is feasible for all ocean accounting programmes and should be documented in metadata for every compiled account.

¶3 **Level 2 — Confidence intervals**: Key aggregates (total ecosystem extent, total fish stock biomass, ocean economy GVA) are reported with confidence intervals derived from the uncertainty of input data. Where input uncertainties are characterised as standard errors or confidence intervals, propagation follows standard statistical methods (error propagation for sums, products, and ratios). This level requires quantitative uncertainty estimates for the major input datasets.

¶4 **Level 3 — Monte Carlo simulation**: For accounts involving complex non-linear transformations (such as ecosystem service valuation using benefit transfer, or carbon stock estimation using allometric equations), Monte Carlo simulation provides the most rigorous uncertainty propagation. Input distributions are sampled repeatedly, the accounting calculations are performed for each sample, and the resulting distribution of outputs characterises the aggregate uncertainty. This level requires specification of probability distributions for all major inputs and is appropriate for high-priority accounts where uncertainty is a policy concern.

¶5 *Table 3.7.2: Uncertainty reporting levels*

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Level	Method	Input Requirements	Output	Recommended For
1	Qualitative assessment	Expert judgement	Low/Medium/High rating per indicator	All accounts (minimum requirement)
2	Confidence intervals	Standard errors for key inputs	95% confidence intervals for aggregates	Priority indicators, headline dashboard
3	Monte Carlo simulation	Probability distributions for all inputs	Full uncertainty distributions	High-stakes policy indicators, valuation accounts

Quality tiers

¶1 Not all data used in ocean accounts meet the standards of official statistics. To accommodate data of varying provenance and reliability whilst maintaining transparency, ocean accounts should classify data inputs into three quality tiers:

¶2 **Tier 1 — Official statistics**: Data produced by national statistical offices or designated official statistics producers, compiled according to the UN Fundamental Principles of Official Statistics. Tier 1 data have been through established quality assurance processes and carry the authority of the national statistical system. Examples include national accounts aggregates, population census data, and fisheries catch statistics compiled by the national statistical office. The quality assurance framework in **TG-0.7 Quality Assurance Principles** describes the quality dimensions applicable to official statistics.

¶3 **Tier 2 — Provisional and administrative data**: Data from government agencies (environmental ministries, fisheries authorities, port authorities) that follow documented collection and processing procedures but have not been formally designated as official statistics. Tier 2 data may be subject to revision and may not meet all quality dimensions of official statistics. Examples include environmental monitoring data, vessel tracking records, and protected area registries. Administrative data guidance is provided in **TG-4.3 Administrative Data Sources**.

¶4 **Tier 3 — Experimental and research data**: Data from research programmes, citizen science initiatives, remote sensing products, and modelled estimates that have been peer-reviewed or validated but are not part of the official statistical system. Tier 3 data are often the only source available for ecosystem condition indicators, ecosystem service estimates, and blue carbon stocks. Research data guidance is provided in **TG-4.5 Research Data**, and citizen science guidance in **TG-4.4 Citizen Science**.

¶5 Combined presentations and dashboards should display the quality tier for each indicator, enabling users to distinguish between well-established indicators based on official statistics and emerging indicators based on experimental estimates. Over time, investment in data systems should aim to progressively elevate key indicators from Tier 3 to Tier 2 and from Tier 2 to Tier 1.

Peer review workflows

¶1 Research data entering the ocean accounts should undergo peer review appropriate to the quality tier. For Tier 3 data, the minimum requirement is that the underlying research has been published in a peer-reviewed journal or technical report, or has been reviewed by a technical advisory committee with relevant domain expertise. For Tier 2 data, the data collection methodology should be documented and reviewed by the national statistical office or an equivalent quality assurance body. For Tier 1 data, the full quality assurance framework of the national statistical system applies.

¶2 Where ocean accounting programmes commission new research or monitoring to fill data gaps, the research design should be reviewed before data collection begins (to ensure the outputs will be compatible with accounting requirements) and the results should be reviewed before incorporation into accounts. The review should assess fitness for purpose (does the data measure what the

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account requires?), methodological rigour (is the collection and processing method sound?), and reproducibility (could another team replicate the results?).

3.8 Time-Series Data Investment Guidance

¶1 Sustained monitoring and data collection are essential for compiling the time-series accounts that reveal trends in ocean health, economic activity, and social outcomes. This section provides guidance on identifying critical data gaps, evaluating the cost-benefit of sustained monitoring investments, and prioritising data collection to maximise the analytical value of ocean accounts.

Identifying critical gaps

¶1 A systematic gap analysis should be conducted as part of the initial compilation of ocean accounts, and updated periodically (at least every three years) as data systems evolve. The gap analysis should assess data availability against the full indicator set specified in the combined presentation dashboard (**TG-3.8 Combined Presentations**, Section 3.7) and the thematic account requirements of each relevant Circular.

¶2 For each indicator, the gap analysis should record: the current data source (if any), the quality tier (Section 3.7), the spatial and temporal coverage, the update frequency, the time lag between reference period and data availability, and the estimated cost of producing the indicator. Gaps should be classified into three categories:

¶3 **Complete gaps**: No data source exists for the indicator. Complete gaps are the most serious, as they prevent compilation of entire account components. Common complete gaps in ocean accounting include ecosystem condition indices for deep-sea ecosystems, monetary valuation of regulating services, and governance effectiveness indicators.

¶4 **Partial gaps**: Data exist but with insufficient spatial coverage (e.g., monitoring stations cover only a fraction of the coastline), temporal coverage (e.g., surveys conducted once rather than annually), or thematic detail (e.g., employment data available for the ocean economy as a whole but not disaggregated by industry). Partial gaps can often be addressed through statistical estimation or modelling, but sustained monitoring investment is needed for reliable time-series compilation.

¶5 **Quality gaps**: Data exist with adequate coverage but at an insufficient quality tier (e.g., Tier 3 experimental estimates where Tier 1 official statistics are needed for policy credibility). Quality gaps require investment in data collection methodology, quality assurance processes, or institutional capacity rather than new monitoring infrastructure.

¶6 *Table 3.8.1: Gap analysis template*

Indicator	Current Source	Quality Tier	Spatial Coverage	Temporal Coverage	Update Frequency	Gap Type	Prio
Ecosystem extent (coastal)	Satellite imagery	Tier 2	Full	2018-present	Annual	None	–
Ecosystem condition (coral)	Research surveys	Tier 3	30% of reefs	2020, 2023	Ad hoc	Partial (spatial + temporal)	High
Fish stock biomass	Stock assessment	Tier 2	Commercial species only	Annual	Annual	Partial (thematic)	Medi
Ocean economy GVA	National accounts	Tier 1	National	Annual	Annual	None	–
Ecosystem service valuation	None	–	–	–	–	Complete	High
Coastal community wellbeing	Census proxy	Tier 2	Full	Decennial	Decennial	Partial (temporal)	Medi

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Cost-benefit of sustained monitoring

¶1 Investment in sustained ocean monitoring should be evaluated against the analytical value it generates for ocean accounts and the policy decisions it enables. The cost-benefit assessment should consider both the direct costs of data collection (equipment, personnel, survey operations, data processing) and the indirect benefits (improved policy decisions, avoided environmental damage, international reporting compliance).

¶2 Three principles should guide the cost-benefit assessment. The first is marginal value: the value of an additional year of data increases non-linearly with the length of the existing time series. The first five years of a monitoring programme establish baseline conditions, years five to ten reveal short-term trends, and only after ten or more years can long-term trends be distinguished from natural variability. Discontinuing a monitoring programme after a few years therefore sacrifices most of the accumulated investment value. The second is the integration multiplier: data that serve multiple accounts and indicators have higher value per unit cost than data serving a single purpose. Ecosystem extent data, for example, feeds into extent accounts, condition accounts (as a pressure indicator), ecosystem service accounts (as a scaling factor), and governance accounts (as a baseline for protected area assessment). The third is substitutability: some data can only be collected through direct observation (e.g., deep-sea biodiversity surveys), whilst others can be estimated from proxies or models (e.g., wave energy potential from reanalysis products). Investment priority should favour non-substitutable observations.

¶3 *Table 3.8.2: Monitoring investment priority matrix*

Priority Level	Criteria	Examples	Recommended Action
Critical	Non-substitutable; serves multiple accounts; policy-mandated	Fish stock assessments, water quality monitoring, ecosystem extent mapping	Sustain and strengthen; protect from budget cuts
High	Serves multiple accounts; partial substitutes available	Coral reef condition surveys, coastal erosion monitoring, marine debris surveys	Establish sustained programme; explore cost-sharing
Medium	Serves single account; substitutes partially available	Deep-sea biodiversity, offshore air quality, recreational fishing effort	Periodic surveys (3-5 year cycle); supplement with modelling
Low	Substitutable through modelling or proxies	Wave climate, sea surface temperature, chlorophyll-a concentration	Rely on global products (satellite, reanalysis); validate periodically

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Priority investments

¶1 Based on the gap analysis and cost-benefit assessment, ocean accounting programmes should develop a prioritised data investment plan. The investment plan should be aligned with the national statistics development strategy and the broader ocean governance priorities. Priority investments for most countries implementing ocean accounts will typically include:

¶2 Establishing **annual ecosystem extent monitoring** using satellite remote sensing, which provides the foundational spatial data for extent accounts, condition assessments, and ecosystem service estimation. The relatively low marginal cost of processing freely available satellite imagery (Sentinel-2, Landsat) makes this a high-value investment. Guidance on remote sensing methods is provided in **TG-4.1 Remote Sensing and Geospatial Data**.

¶3 Strengthening **coastal water quality monitoring** networks to provide consistent, spatially representative measurements of nutrients, sediments, and pollutants. Water quality data serve the residual flow accounts (**TG-3.4**), ecosystem condition accounts, and the water-marine quality integration protocol described in **TG-3.8 Combined Presentations**, Section 3.8.

¶4 Developing **ocean economy satellite accounts** within the national accounts framework, enabling consistent measurement of ocean economy GVA, employment, and trade. This requires collaboration between the national statistical office and sectoral ministries to agree on the scope of ocean-related industries and compile thematic accounts following **TG-3.3 Economic Activity Relevant to the Ocean**.

¶5 Investing in **sub-national data disaggregation** to support provincial and municipal ocean accounting, as described in **TG-3.8 Combined Presentations**, Section 3.9. Many national datasets can be disaggregated to sub-national level at relatively low additional cost if the disaggregation requirement is built into data collection design from the outset.

Link to TG-4.7

¶1 The data investment priorities identified in this section should be integrated into the broader capacity development strategy described in **TG-4.7 National Data Coordination Architectures**. Sustained monitoring requires institutional capacity as well as financial investment: trained personnel, maintained equipment, quality assurance systems, and data management infrastructure. The capacity development Circular provides guidance on building and maintaining these institutional foundations, including workforce planning, training programmes, and partnerships with research institutions and international organisations. Data investment plans should be reviewed and updated alongside the capacity development strategy to ensure that monitoring ambitions are matched by implementation capacity.

4. Summary

¶1 Data harmonisation and interoperability underpin the integration of diverse data sources into coherent accounting frameworks. The main elements are:

- ¶2 **SDMX** provides the statistical data exchange standard, with DSDs defining data structures, transmission formats enabling machine-readable exchange, and registry services supporting data discovery
- ¶3 **Geospatial standards** from OGC and IHO S-100, supported by ISO 19115 metadata standards, enable integration of marine spatial data, with the GSGF providing the overarching framework for statistical-geospatial integration
- ¶4 **FAIR principles** guide data management to maximise findability, accessibility, interoperability, and reusability
- ¶5 **Classification concordances** enable translation between ISIC/CPC for economic data, between national and international ecosystem classifications, and across classification versions over time, with official UNSD correspondence tables available for the ISIC Rev.5 and CPC Ver.3.0 transitions
- ¶6 **Data harmonisation workflow** provides systematic procedures for classifying, mapping, validating, and integrating heterogeneous source data into ocean accounts

¶7 Implementation of these standards requires institutional investment in technical infrastructure, staff capacity building, and sustained collaboration across organisational boundaries. The GSGF notes that "both the statistical and geospatial communities operate their own general data models, metadata capabilities, architectures, and data infrastructures" and that bridging these requires "greater incorporation of geospatial processes, standards, and best practices in the statistical business processes and data management systems" [49].

¶8 For ocean accounting practitioners, a pragmatic approach involves:

1. ¶9 Adopting SDMX-CSV as an accessible intermediate format whilst building toward full SDMX-ML/JSON implementation

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2. ¶10 Ensuring geospatial data conforms to OGC standards and carries ISO 19115-compliant metadata to enable integration with national spatial data infrastructures
3. ¶11 Documenting all classification concordances used, including rationale and limitations, and using official UNSD correspondence tables for transitions between ISIC and CPC versions
4. ¶12 Implementing FAIR principles progressively, prioritising persistent identifiers and standardised metadata
5. ¶13 Establishing data harmonisation workflows with systematic quality checks at each phase

¶14 All ocean accounts benefit from harmonised data infrastructure. Asset accounts (**TG-3.1 Asset Accounts**) integrate physical and monetary data from diverse sources, requiring consistent classifications and units. Ocean economy investment accounts (**TG-2.6 Ocean Economy Investment**) depend on concordances between economic activity and product classifications. Combined presentations (**TG-3.8 Combined Presentations**) integrate environmental, economic, and social data, relying on interoperable formats and metadata standards. Data harmonisation and interoperability are therefore foundational to the ocean accounting framework.

¶15 Guidance on specific data integration challenges for individual account types is provided in the relevant thematic Circulars: **TG-4.1 Remote Sensing and Geospatial Data**, **TG-4.2 Survey Methods for Ocean Economic Activity**, **TG-4.3 Administrative Data Sources**, **TG-4.4 Citizen Science**, and **TG-4.5 Research Data**.

Implementation Considerations

¶1 For minimum institutional capacity, data infrastructure, and human skills requirements for implementing these data methods, see TG-0.8 Implementation Readiness Assessment.

5. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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National Data Coordination Architectures

Helps practitioners design and establish national data coordination architectures for ocean accounting, including the data-sharing arrangements.

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OUTCOME

After completing this Circular, practitioners will be able to design and establish national data coordination architectures for ocean accounting, including the data-sharing arrangements, technical working groups, and coordination mechanisms required to bring together diverse ocean data streams into coherent accounting frameworks. It addresses how national statistical offices (NSOs) and ocean-related agencies can collaborate effectively through formal data sharing agreements, joint technical committees, and shared data platforms to produce and maintain ocean accounts.

The scope of this Circular is deliberately focused on data-specific coordination: the memoranda of understanding (MOUs) that govern data exchange between agencies, the technical working groups that resolve methodological questions about data integration, and the platform architectures that enable shared access to accounting data. Broader questions of governance design are addressed elsewhere: how ocean accounts are embedded within national planning frameworks in TG-1.10 OA and National Planning Integration, and inter-ministerial coordination models and strategies for building domestic champions in TG-0.8 Implementation Readiness Assessment Section 3.5.

Ocean accounting is inherently multi-institutional. As the SEEA Ecosystem Accounting framework recognises, “given the high degree to which ecosystem accounting is cross-cutting and spatial in nature, implementation necessitates a highly collaborative approach and the active participation of representatives of many different agencies and disciplines”. The data coordination architectures described in this Circular provide the institutional infrastructure through which this collaboration is realised at the operational level.

This Circular complements TG-0.8 Implementation Readiness Assessment, which provides the broader context for evaluating a country’s institutional, data, and human capacity prerequisites for ocean accounting. Where TG-0.8 helps countries assess their readiness across all dimensions of implementation, the present Circular provides detailed operational guidance on establishing and managing the data coordination mechanisms that readiness assessment identifies as necessary.

The data harmonisation standards and interoperability protocols described in TG-4.6 Data Harmonisation and Interoperability provide the technical foundation on which the coordination architectures in this Circular are built. Whilst TG-4.6 addresses what standards and formats to use, TG-4.7 addresses how agencies organise themselves to apply those standards collaboratively.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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1. Outcome

¶1 After completing this Circular, practitioners will be able to design and establish national data coordination architectures for ocean accounting, including the data-sharing arrangements, technical working groups, and coordination mechanisms required to bring together diverse ocean data streams into coherent accounting frameworks. It addresses how national statistical offices (NSOs) and ocean-related agencies can collaborate effectively through formal data sharing agreements, joint technical committees, and shared data platforms to produce and maintain ocean accounts.

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2. Requirements

¶1 **Essential prerequisites:**

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** – for the conceptual framework and key components of Ocean Accounts, including the relationship between environmental and economic accounting frameworks that data coordination must bridge.
- ¶3 **TG-4.6 Data Harmonisation and Interoperability** – for the data standards, exchange formats, and interoperability protocols that coordination architectures operationalise.

¶4 **Helpful background:**

- ¶5 **TG-0.7 Quality Assurance Principles** – for the quality dimensions and assessment frameworks that data coordination arrangements must uphold, particularly the institutional environment dimension.

¶6 **Framework Position**

¶7 This Circular addresses the institutional infrastructure for data coordination across all ocean accounting domains. Data coordination arrangements support every edge in the Ocean Accounts Framework (TG-0.1 Figure 0.1.2), as each connection between accounting components requires data flows from multiple custodian agencies. The coordination mechanisms described here are prerequisites for the data harmonisation workflows described in **TG-4.6**.

3. Guidance Material

¶1 Ocean accounts draw on data from national statistical offices (economic statistics, national accounts), environmental agencies (ecosystem monitoring, biodiversity surveys), hydrographic organisations (bathymetry, tides, currents), fisheries management authorities (catch data, stock assessments), maritime administrations (vessel tracking, port statistics), and research institutions (earth observation, oceanographic surveys). Each of these agencies operates within its own legislative framework, with distinct mandates, data collection cycles, confidentiality requirements, and institutional cultures. The fundamental challenge for data coordination is to establish durable institutional mechanisms that enable these agencies to share data systematically while respecting their individual mandates and constraints.

¶2 The GSGF identifies five key elements that support implementation of its principles: governance and institutional capacity, policy and legal, human resources and capability, data and interoperability, and technology and infrastructure [2]. These elements provide an analytical lens for ocean accounting data coordination, recognising that effective data sharing requires not only technical standards but also institutional arrangements, legal frameworks, and skilled personnel.

¶3 This section examines six dimensions of national data coordination architecture: committee models and mandates; data sharing agreements; trust frameworks; integrated platform design; modular implementation strategies; and time-series data investment planning. Together, these elements form the institutional infrastructure for sustained ocean accounting data production. Figure 4.7.1 illustrates how they connect through a worked coastal-wetland example, in which multiple source agencies formalise their contributions through data-sharing agreements feeding a technical working group that governs a shared data platform.

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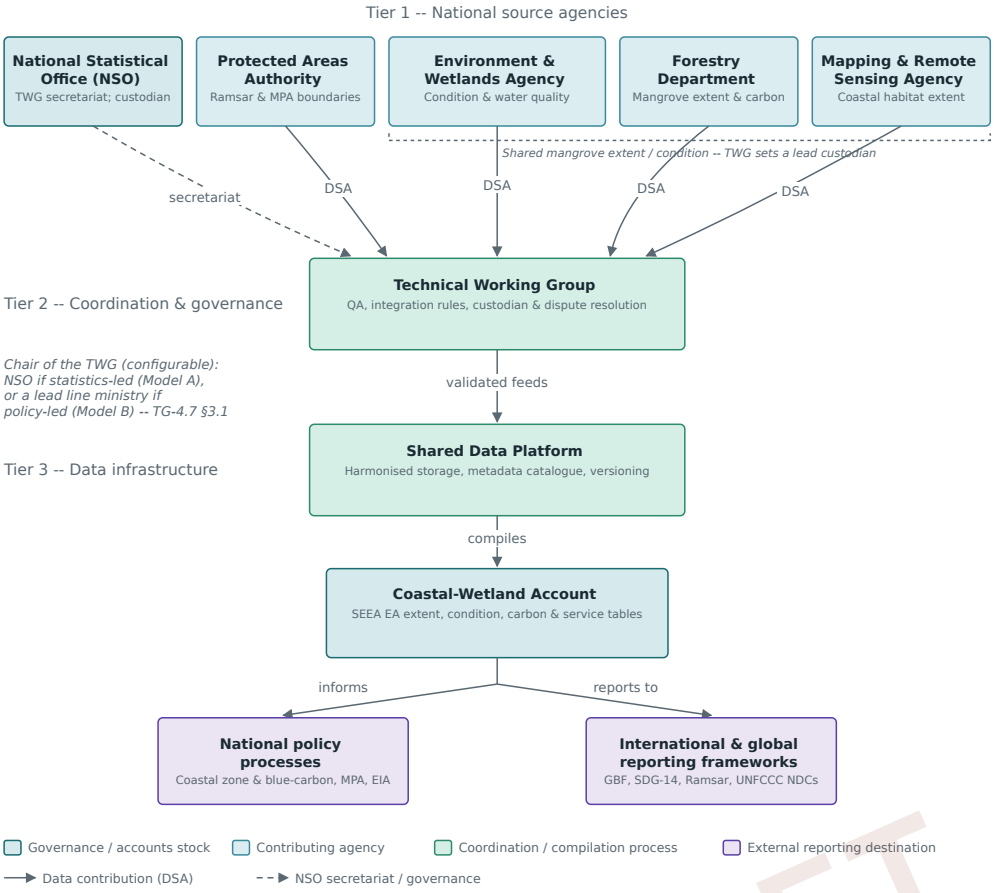


Figure 4.7.1 Five agencies share coastal-wetland data under an MOU into a TWG and shared platform that compiles the Ocean Account. NSO always provides TWG secretariat; chair is NSO (Model A) or ministry (Model B).

Source: TG-4.7, §3.1 (committee models and dispute resolution), §3.2 (data-sharing agreement requirements), §3.4 (shared platform design), and §3.5 Phase 1 (NSO + environmental-monitoring-agency anchor partnership).

3.1 National Data Coordination Committee Models and Mandates

¶1 The establishment of a dedicated data coordination committee is the foundational institutional step for ocean accounting. This committee provides the governance structure through which agencies negotiate data sharing arrangements, resolve methodological disagreements, and coordinate production schedules. The committee's design should reflect the country's existing institutional landscape and statistical system architecture, building on rather than duplicating existing coordination mechanisms.

¶2 The SEEA EA emphasises that "work is needed to fulfil a key objective, namely, the appropriate institutionalization of the processes (including data sharing), roles and responsibilities underpinning the compilation of ecosystem accounts"[3]. For ocean accounting specifically, this institutionalisation requires a committee structure that brings together data custodians from across the statistical, environmental, and marine science domains.

¶3 The choice of coordination arrangement — where the mandate sits, and what instrument carries it — is set out in **TG-0.8 Implementation Readiness Assessment** Section 3.5.1, which is normative for the publication. This section covers the operational design of the resulting committee: its mandate content, membership, and relationship to existing coordination bodies.

¶4 For reference, the three configurations most often met in data-coordination practice map onto that typology as follows:

¶5 **Model A: NSO-led steering committee.** The national statistical office establishes and chairs the committee, drawing authority from its statistical legislation mandate. This model draws on the NSO's institutional independence and established relationships with government agencies. The NSO's role as data steward — as described in SEEA EA, where NSOs have shifted "from functioning solely as statistics producers to acting also as service providers, which entails both facilitating a collaborative approach to data and statistics across different data and statistics communities and providing oversight and governance"[4] — provides a natural basis for convening data-sharing discussions. *Country example: Australia's Australian Bureau of Statistics (ABS) leads environmental-economic account compilation under its national statistics mandate, coordinating data inputs from the Department of Climate Change, Energy, the Environment and Water and other custodian agencies as part of an integrated accounts programme.*

¶6 **Model B: Multi-agency technical committee.** A joint committee is established with rotating or co-chair arrangements between the NSO and a lead ocean/environmental agency. This model distributes authority more evenly and may generate stronger buy-in from agencies that see themselves as equal partners alongside the statistical office, rather than as data suppliers to it. The model requires clear terms of reference to avoid ambiguity about decision-making authority, particularly when methodological disagreements arise. *Country example: Canada's joint environmental accounts programme pairs Statistics Canada with Environment and Climate Change Canada (ECCC) under a co-led technical arrangement, combining statistical expertise and environmental domain knowledge.*

¶7 **Model C: Nested committee structure.** An overarching ocean data coordination committee establishes domain-specific sub-committees for distinct data streams (e.g., fisheries data, ecosystem condition data, marine economic data). Each sub-committee handles the technical details of data sharing within its domain, whilst the overarching committee ensures cross-domain consistency and resolves inter-domain conflicts. This model scales well to large national statistical systems with many data custodians but introduces coordination overhead. *Country example: Interministerial technical working group (TWG) structures of the kind used in ASEAN GOAP pilot countries such as the Philippines and Indonesia illustrate this nested approach, with sector-specific sub-groups feeding a central coordination body.*

¶8 *Table 3.1.1: Indicative fit of the three configurations, by data-coordination factors (see TG-0.8 Section 3.5.1 for the full typology)*

Factor	Model A (NSO-led)	Model B (Multi-agency)	Model C (Nested)
Number of data custodian agencies	Few (3–5)	Moderate (6–8)	Many (9+)
NSO capacity for environmental data	Strong	Moderate	Variable
Existing inter-agency mechanisms	Weak or none	Moderate	Strong
Legislative backing	Statistical Act	MOU or executive order	Framework legislation
Decision-making speed	Faster	Moderate	Slower
Agency buy-in	Lower for non-NSO agencies	Higher	Highest
Coordination overhead	Low	Moderate	High

> *Note: The agency-count ranges are indicative. Countries whose situation falls near a boundary*

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> *should weight the qualitative factors in this matrix more heavily than the numeric threshold alone.*

¶9 Regardless of model, the committee mandate should specify at minimum: the scope of data coordination (which data streams and account types are covered); the authority to request data from member agencies; the decision-making process for resolving methodological disputes; the production schedule and reporting obligations; and the review cycle for data sharing arrangements. The mandate should also clarify the committee's relationship to any existing national statistics coordination bodies to avoid duplication.

¶10 Committee membership should include representatives with both subject-matter expertise and institutional authority to commit their agencies to data sharing arrangements. A common failure mode is to populate committees with technical staff who lack authority to agree to data release, or conversely with senior officials who lack the technical knowledge to resolve data integration questions. Effective committees typically include both levels, with a senior sponsoring official from each agency and a designated technical focal point.

¶11 The GSGF recommends that countries "scope the data sharing landscape in place at country level to support discussions and establish the needs for new arrangements"[5]. Before establishing new committee structures, countries should inventory existing data coordination mechanisms — such as inter-agency statistics committees, environmental data networks, or marine science consortia — and assess whether ocean accounting coordination can be accommodated within or alongside these existing structures. Creating entirely new coordination bodies when existing mechanisms can be adapted risks institutional fatigue and competition for senior attention.

3.2 NSO-Ocean Agency Data Sharing Agreements

¶1 Formal data sharing agreements provide the legal and operational foundation for regular, systematic exchange of data between agencies. Unlike ad hoc data requests — which depend on personal relationships, are vulnerable to staff turnover, and typically deliver data in inconsistent formats — formal agreements establish ongoing obligations, standard formats, and quality expectations that support sustained accounting production.

¶2 The GSGF notes that "establishing strong communication and institutional collaboration mechanisms between NSOs and NGIAs is essential" and that "this can be facilitated by, for example, country-level laws and policies, Memorandum of Understandings (MoUs), data sharing agreements, and other communities of practice"[6]. The UN Expert Group on the Integration of Statistical and Geospatial Information has developed a template MOU for joint work between NSOs and national geospatial information authorities that provides a useful starting point for ocean accounting data sharing agreements[7].

¶3 Data sharing agreements for ocean accounting should address the following elements:

¶4 **Scope and content.** The agreement should specify precisely which data variables are to be shared, at what level of disaggregation, and covering which geographic areas and time periods. For ocean accounting, this typically involves specifying the statistical unit (e.g., individual vessel, fishing zone, port, ecosystem asset), the variables (e.g., catch weight, landing value, ecosystem condition indicator), and the classification system to be applied (e.g., the current ISIC revision — Rev.4 or Rev.5 as nationally implemented — for economic activities[8]; FAO ASFIS codes for species; IUCN Global Ecosystem Typology (GET) for ecosystem types[9]). Reference to the data harmonisation standards in **TG-4.6 Data Harmonisation and Interoperability** should be included to establish shared expectations about exchange formats.

¶5 **Frequency and timeliness.** The agreement should specify the data delivery schedule aligned with the ocean accounting production calendar. This includes the reference period (e.g., calendar year), the expected delivery date, and any interim or provisional data releases. Timeliness benchmarks should be aligned with the national statistical release calendar — typical environmental-eco-

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nomic accounting cycles produce preliminary data within 6–12 months and final data within 12–24 months of the reference period close[10]. Actual schedules will depend on the production cycles of each contributing agency; differences in agency production cycles are one of the most persistent operational challenges in environmental-economic accounting. Aligning delivery schedules across multiple agencies requires explicit negotiation in every data sharing agreement.

¶6 **Quality standards.** The agreement should reference the quality assurance framework in **TG-0.7 Quality Assurance Principles** and specify the quality documentation expected to accompany each data delivery. At minimum, this should include metadata describing data sources, coverage, estimation methods, and known limitations. Where data are subject to revision, the agreement should specify revision policies and notification procedures.

¶7 **Confidentiality and access controls.** Ocean data sources may contain information governed by three distinct legal regimes, each with different release rules:

- ¶8 *Statistical confidentiality* (governed by national statistics acts and the UN Fundamental Principles of Official Statistics) applies to data collected under statistical mandate and prohibits release in identifiable form. Aggregated tables derived from confidential collections may be released, but unit-record data require secure-access protocols.
- ¶9 *Commercial sensitivity* applies to firm-level data shared under non-disclosure terms — for example, vessel-level economic data shared by a fisheries authority. Compilers should document the permitted uses and aggregation obligations under any such arrangement.
- ¶10 *Personal data protection* (governed by national data-protection legislation and, in many jurisdictions, GDPR-equivalent frameworks) applies to data relating to natural persons. Vessel-level data often engage this regime where vessel operators can be identified.

¶11 The agreement must clearly identify which regime applies to each data element, specify access controls and aggregation rules accordingly, and note where multiple regimes apply simultaneously. Where data cannot be provided at unit-record level, the implications for the achievable level of account detail should be documented.

¶12 **Format and transmission.** The agreement should specify the exchange format (referencing SDMX, GeoJSON, or other standards as appropriate from **TG-4.6**), the transmission method (secure file transfer, API access, shared platform), and the metadata standards to be applied (ISO 19115 for geospatial metadata, SDMX structural metadata for statistical data).

¶13 **Dispute resolution and review.** The agreement should include procedures for resolving disagreements about data quality, timeliness, or interpretation, and should specify a review cycle (typically every two to three years) to ensure the agreement remains fit for purpose as accounting requirements evolve.

¶14 The six elements above — scope, frequency, quality standards, confidentiality, format, and dispute resolution — constitute the minimum checklist for any ocean accounting data sharing agreement; the paragraphs above provide the operational detail for each.

¶15 Countries at early stages of ocean accounting may find it pragmatic to begin with lightweight data sharing arrangements — such as a letter of intent or an annex to an existing inter-agency agreement — rather than negotiating full MOUs from the outset. Initial arrangements can be formalised as the accounting programme matures and data requirements become better defined. The key requirement is that arrangements be documented and institutional rather than dependent on individual relationships.

3.3 Trust Frameworks for Data Sharing

¶1 Trust is the precondition for sustained data sharing between agencies. Even where formal agreements exist, effective data sharing requires that data custodians trust that their data will be used appropriately, that their contributions will be acknowledged, that quality concerns will be ad-

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dressed constructively, and that shared data will not be used in ways that undermine their agency's mandate or reputation. Trust frameworks formalise these expectations and provide mechanisms for building and maintaining inter-agency confidence over time.

¶2 The GSGF identifies four dimensions of interoperability derived from the European Interoperability Framework, of which organisational and legal interoperability are directly relevant to trust[11]. Organisational interoperability concerns the alignment of business processes and responsibilities between agencies, whilst legal interoperability ensures that agencies operating under different legislative frameworks can share data lawfully.

¶3 Trust frameworks for ocean accounting data sharing should address four dimensions:

¶4 **Data provenance and attribution.** Agencies are more willing to share data when they are confident that their role as data custodians will be acknowledged in published accounts. Trust frameworks should specify how source agencies are credited in published ocean accounts, including acknowledgement in methodology documentation, inclusion in data provenance metadata, and recognition in public communications. The SEEA EA notes the importance of NSOs providing "oversight and governance through provision of an independent and expert opinion on data"[12], and trust frameworks should clarify how this oversight role interacts with the custodian role of contributing agencies.

¶5 **Quality feedback loops.** Data sharing generates opportunities for quality improvement when receiving agencies identify anomalies, inconsistencies, or gaps in source data. Trust frameworks should establish constructive feedback channels through which the compiling agency can communicate quality concerns to source agencies without undermining confidence or creating adversarial dynamics. Framing quality feedback as a mutual benefit — where integration reveals patterns invisible to individual agencies — rather than as criticism encourages continued participation. Technical working groups (see §3.1) provide a natural forum for these discussions.

¶6 **Graduated access models.** Not all data need to be shared at the same level of detail or with the same access conditions. Trust frameworks can establish graduated access tiers that allow agencies to share aggregated data broadly while restricting access to unit-record data to authorised compilers under specific conditions. This approach allows data sharing to proceed where full disclosure of microdata is not feasible, while preserving the option for deeper integration as trust develops over time. Graduated access may be structured as follows:

¶7 *Table 3.3.1: Graduated data access tiers*

Tier	Access Level	Typical Content	Governance
Public	Open access	Published aggregates, indicators	Standard open data licence
Statistical	Designated compilers and accredited researchers under secure-access conditions	Confidential microdata, unit-record survey data	MOU with statistical confidentiality protocols; secure data environment
Released disaggregated	Broad authorised users	Disaggregated published tables, subnational breakdowns	Data sharing agreement or open data licence with attribution
Restricted	Designated compilers only	Commercially sensitive firm-level or vessel-level data	MOU with non-disclosure and access-control protocols
Embargoed	Compiling agency only	Pre-release data, provisional estimates	Time-limited embargo clause

¶8 **Mutual benefit demonstration.** Trust is sustained when all participating agencies derive benefit from the data coordination arrangement. Trust frameworks should identify and communicate the specific benefits that each agency receives from participation — whether improved data quality

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through cross-source validation, access to integrated datasets that support their own analytical needs, or enhanced visibility through association with a high-profile national accounting programme. Countries that have successfully sustained inter-agency data sharing for environmental-economic accounting often point to reciprocal data flows as a critical success factor: the NSO provides economic context data to environmental agencies, whilst environmental agencies provide ecosystem monitoring data to the NSO.

¶9 Building trust takes time and requires sustained investment in relationship management. The SEEA EA acknowledges that "traditionally, NSOs have less experience working with those types of environmental data" and that "collaboration with environmental policy and associated technical research agencies in the development of ecosystem accounts should be expected"[13]. Countries should anticipate that trust-building typically requires one to several years in practice, depending on prior working relationships between agencies and the frequency of joint working group meetings. Where inter-agency collaboration traditions are strong, sufficient trust for operational data sharing may develop within a year or two; in systems with limited prior coordination experience, the process may extend considerably longer.

3.4 Integrated Platform Architectures

¶1 Integrated data platforms provide the technical infrastructure through which agencies share, access, and manage ocean accounting data. Platform design choices carry consequences for the sustainability, scalability, and accessibility of ocean accounting data coordination. The platform architecture should align with the interoperability standards described in **TG-4.6 Data Harmonisation and Interoperability** and the quality assurance requirements in **TG-0.7 Quality Assurance Principles**.

¶2 The GSGF recommends that organisations "host appropriate technical infrastructures which support the use of the relevant standards where systems and services are linked through standard interfaces, services, and data formats"[14]. For ocean accounting, this translates to three broad platform architecture options:

¶3 **Centralised repository.** A single platform, typically hosted by the NSO or a designated data management agency, receives, stores, and manages all ocean accounting data. Contributing agencies upload data to the repository according to agreed schedules and formats. The compiling team accesses all data through the central platform. This architecture simplifies data management, ensures version control, and provides a single point of access for compilation. However, it requires substantial hosting infrastructure, places the maintenance burden on a single agency, and may raise concerns about data ownership among contributing agencies.

¶4 **Federated data network.** Each agency maintains its own data systems and exposes relevant datasets through standardised APIs (such as SDMX REST services or OGC web services). The ocean accounting compilation system queries these distributed data sources and integrates responses into accounting tables. This architecture respects agency autonomy over their data systems, distributes the infrastructure burden, and ensures that agencies always provide the most current version of their data. However, it requires that all participating agencies maintain API endpoints conforming to common standards, introduces dependency on multiple agencies' system availability, and may complicate version management. The SDMX Registry Specification (Section 5 of the SDMX technical standards) defines subscription and notification services that enable automated processing of registry updates in federated data environments[15].

¶5 **Hybrid approach.** The most common architecture in practice combines elements of both models. Core accounting data are maintained in a central repository, while large or frequently updated datasets (e.g., satellite imagery, real-time environmental monitoring) are accessed through federated services. This approach balances the governance benefits of centralisation with the flexibility and scalability of federation. The hybrid model allows agencies to contribute data through which-

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ever channel best suits their capacity: agencies with mature API infrastructure expose data through web services, while agencies with limited IT capacity upload data files to the central repository.

¶6 *Table 3.4.1: Platform architecture comparison*

Criterion	Centralised	Federated	Hybrid
Data governance	Single point of control	Distributed governance	Mixed
Infrastructure cost	Concentrated in one agency	Distributed across agencies	Distributed with central core
Technical prerequisite	Central repository + upload mechanisms	API endpoints at each agency	Central repository + selective APIs
Version control	Straightforward	Requires coordination	Moderate complexity
Data currency	Depends on upload frequency	Always current at source	Mixed
Scalability	Limited by central capacity	Scales with network	Scales selectively
Best suited to	Small–medium programmes	Mature IT environments	Most national contexts

¶7 Regardless of architecture, the platform should support the functional requirements summarised in Table 3.4.2 below.

Requirement	Description
Metadata management	Storage and retrieval of data provenance, quality documentation, and structural metadata conforming to SDMX and ISO 19115 standards.
Version control	Tracking of data revisions with timestamped snapshots enabling reproduction of previously published accounts.
Access control	Role-based access consistent with the graduated access tiers described in §3.3.
Data validation	Automated quality checks at data ingestion, implementing the validation procedures described in **TG-0.7 Quality Assurance Principles**.
Audit trail	Logging of data access, modifications, and exports for accountability.
Service-level expectations (federated architectures)	Documented uptime targets, maintenance window notification procedures, and fallback arrangements for API unavailability during compilation cycles; cross-reference **TG-4.6 Data Harmonisation and Interoperability** for technical interoperability protocols governing API service obligations.

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¶8 Platform investment should be proportionate to the scale of the ocean accounting programme. Countries at early stages may begin with a shared file system or spreadsheet-based workflow, progressing to database-backed platforms and API integration as the programme matures and data volumes grow. The critical requirement is not technological sophistication but rather that data management procedures are documented, reproducible, and not dependent on a single individual's knowledge.

3.5 Modular Implementation Strategies

¶1 Given the institutional complexity of multi-agency data coordination, a modular implementation strategy allows countries to establish coordination mechanisms incrementally, building on initial successes rather than attempting full coordination from the outset. Modular implementation recognises that different data streams present different coordination challenges and that agencies vary in their readiness to participate in formal data sharing arrangements.

¶2 The SEEA EA describes a spectrum of compilation approaches, noting that "in practice, the approach to compilation of ecosystem accounts lies between these two ends of the spectrum, with

implementation being dependent on (a) policy focus; (b) availability of source data; and (c) resources available for compilation"[16]. This same pragmatism should guide data coordination. Begin with the data streams that are most readily available and where coordination relationships are strongest, then extend to more challenging domains as institutional capacity develops.

¶3 A modular strategy typically proceeds through three phases:

¶4 **Phase 1: Anchor partnership.** Establish a data sharing arrangement between two agencies for a single, well-defined data stream. The most productive anchor partnerships typically involve the NSO and a fisheries management authority (where catch and economic data are relatively well-structured) or the NSO and an environmental monitoring agency (where ecosystem extent data from remote sensing are readily available). The anchor partnership serves as a proof of concept, demonstrating the feasibility and value of formal data coordination and providing a template for subsequent agreements. During this phase, the coordination mechanism may be informal — a working-level agreement between technical staff — with formal MOU development deferred until the collaboration has demonstrated its value.

¶5 **Phase 2: Network expansion.** Building on the anchor partnership, extend data coordination to additional agencies and data streams. Each new partnership can draw on the templates, workflows, and lessons learned from Phase 1. Priority for expansion should be guided by the accounting priorities identified through the implementation readiness assessment (see **TG-0.8 Implementation Readiness Assessment**). During this phase, the coordination committee (§3.1) is formalised, data sharing agreements (§3.2) are documented, and platform requirements (§3.4) are assessed. The network should aim to establish stable data flows for the minimum set of account types identified as priorities.

¶6 **Phase 3: System consolidation.** With multiple bilateral data sharing arrangements in place, the coordination architecture can be consolidated into a coherent system. This involves standardising data sharing agreements across agencies, establishing a shared platform architecture, formalising quality assurance procedures, and embedding the coordination arrangements in institutional mandates and budgets. During this phase, the focus shifts from establishing new partnerships to optimising existing ones: improving data timeliness, increasing spatial or temporal resolution, and extending time series.

¶7 *Table 3.5.1: Modular implementation pathway*

Phase	Duration	Activities	Outputs
1. Anchor partnership	6–12 months (indicative)	Identify lead agencies; negotiate initial data sharing; compile pilot account	Working data exchange; pilot account; lessons learned
2. Network expansion	12–24 months (indicative)	Extend to additional agencies; formalise committee; document agreements	Multiple data sharing MOUs; formal committee terms of reference; expanded account coverage
3. System consolidation	24–36 months (indicative)	Standardise agreements; deploy shared platform; embed in budgets	Operational coordination system; regular production cycle; sustained institutional commitment

> *Note: Durations are indicative and vary by country context, institutional capacity, and readiness level (see TG-0.8 Implementation Readiness Assessment). Anchor partnerships in some pilots have extended beyond 12 months; consolidation may remain incomplete after 3–5 years in contexts with high staff turnover or limited infrastructure.*

¶8 Countries should resist the temptation to proceed directly to Phase 3 without the experiential learning provided by Phases 1 and 2. Data coordination arrangements that are designed in full on

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paper but lack the foundation of practical inter-agency collaboration often fail to achieve sustained data flows.

¶9 Risk management matters throughout all phases. Common risks include loss of key personnel (mitigated by documenting procedures and distributing knowledge across multiple staff), changes in agency leadership or priorities (mitigated by embedding coordination in formal mandates rather than personal commitments), and budget constraints (mitigated by demonstrating the value of coordination to decision-makers through early publication of useful accounting outputs). Countries should identify these risks explicitly in their implementation plans and develop mitigation strategies as part of the coordination committee's work programme.

3.6 Time-Series Data Investment Planning

¶1 The SEEA EA emphasises that "ecosystem accounts are most informative when they are not compiled as one-off, irregular or short-term studies" and that "progressively, long time series of ecosystem accounting data can be established"[17]. Achieving this requires deliberate investment in data coordination arrangements that sustain data flows over time, rather than project-based arrangements that lapse when initial funding expires.

¶2 Time-series data investment planning addresses three challenges: ensuring continuity of data supply from contributing agencies; managing methodological changes that affect comparability over time; and building the institutional memory needed to maintain consistent production practices.

¶3 **Continuity of data supply.** Data coordination arrangements should be designed for permanence rather than project duration. This means embedding data sharing obligations in agencies' recurrent work programmes and budgets rather than relying on project funding. The coordination committee should maintain a data supply register that documents, for each data stream, the custodian agency, the legal basis for data collection, the funding source, and any known risks to continuity. Where data streams are at risk — for example, because a monitoring programme faces budget cuts — the committee can advocate for continued investment by demonstrating how the data contribute to multiple accounting and policy uses.

¶4 As established in §3.5 Phase 1, coordination should build on existing legislative mandates rather than requiring new ones. Where alignment exists between ocean accounting data requirements and existing collection mandates (such as fisheries catch reporting or biodiversity convention reporting), data sharing agreements should reference the existing legal mandate to strengthen the case for continued data supply.

¶5 **Managing methodological change.** Over the lifetime of an ocean accounting programme, contributing agencies will revise their data collection methods, classification systems, and estimation procedures. These changes can disrupt time-series comparability if not managed carefully. The coordination committee should establish a change notification protocol through which agencies inform the compiling team of planned methodological changes before they take effect. This advance notice allows the compiling team to assess the impact on accounting time series and, where necessary, develop bridging estimates or concordance procedures.

¶6 The classification concordance guidance in **TG-4.6 Data Harmonisation and Interoperability** Section 3.4 provides the technical framework for managing classification transitions. At the institutional level, the coordination committee should maintain documentation of all methodological changes that affect time-series comparability, including the date of change, the nature of the change, the concordance or bridging procedure applied, and any residual comparability limitations. This documentation should be published alongside the accounting data as a "changes and revisions" annex consistent with the quality documentation requirements set out in **TG-0.7 Quality Assurance Principles**.

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¶7 **Institutional memory.** Sustained time-series production depends on institutional memory — the accumulated knowledge about data sources, compilation methods, quality issues, and inter-agency relationships that resides within the compiling team. Staff turnover poses a serious risk to institutional memory, particularly in small statistical offices where ocean accounting may be the responsibility of one or two individuals. Mitigation strategies include thorough documentation of compilation procedures (including data source contacts, file locations, processing scripts, and known data quality issues); cross-training of staff so that multiple individuals can perform each compilation step; and periodic compilation reviews where the full production process is documented and assessed.

¶8 The coordination committee should also maintain a shared knowledge base that records decisions made about data integration issues, methodological choices, and their rationale. This knowledge base serves both as institutional memory and as a transparency tool, enabling external reviewers to understand how compilation decisions were made. Over time, this knowledge base becomes a useful resource for countries that are establishing similar coordination arrangements, supporting the knowledge exchange objectives of the broader ocean accounting community.

¶9 **Investment sequencing.** Countries should plan their data investment strategically, recognising that different data streams require different levels of investment and deliver value at different timescales. The following sequence reflects the dependency structure of ocean accounts as described in SEEA EA: ecosystem extent accounts provide the spatial framework upon which condition accounts are built; condition accounts underpin the assessment of ecosystem services; and ecosystem services flows are a prerequisite for monetary valuation (SEEA EA paras. 1.56–1.58). Countries with strong pre-existing ocean economy data or specific policy drivers may adapt this sequence to their circumstances — this ordering should be read as a starting point informed by the dependency logic of ocean accounts, not as a mandatory pathway.

¶10 *Table 3.6.1: Data investment sequencing framework (indicative)*

Priority	Data Domain	Typical Sources	Investment Type	Value Horizon
Immediate	Economic activity (ocean economy)	National accounts, business surveys	Coordination with NSO economic statistics division	Short-term (1–2 years)
Near-term	Ecosystem extent	Remote sensing, land/sea cover maps	Coordination with geospatial/environmental agency	Medium-term (2–3 years)
Medium-term	Ecosystem condition	Environmental monitoring networks	Coordination with multiple environmental agencies	Medium-term (3–5 years)
Longer-term	Ecosystem services (physical)	Biophysical modelling, survey data	Coordination with research institutions	Longer-term (3–5+ years)
Sustained	Monetary valuation	Economic modelling, market data	Integration across all coordination partners	Ongoing

¶11 This sequencing reflects both the relative availability of data and the dependency structure of ocean accounts. Cross-references: **TG-3.3 Economic Activity Relevant to the Ocean** and **TG-3.1 Asset Accounts**.

4. Summary

¶1 National data coordination architectures provide the institutional foundation for sustained ocean accounting. The key elements are:

- ¶2 **Coordination committee models** should be selected to match the country's institutional landscape, with a clear mandate covering scope, authority, and decision-making processes.
- ¶3 **Data sharing agreements** should formalise bilateral data flows using harmonisation standards from **TG-4.6**.
- ¶4 **Trust frameworks** sustain agency participation by addressing provenance, quality feedback, and mutual benefit.
- ¶5 **Platform architectures** — centralised, federated, or hybrid — should match national IT capacity while supporting metadata management, version control, and access control.
- ¶6 **Modular implementation** proceeds through three phases (anchor partnership, network expansion, system consolidation), building institutional capacity incrementally.
- ¶7 **Time-series investment planning** ensures coordination arrangements are sustained beyond initial project cycles through continuity, change management, and institutional memory.

¶8 These elements interlock in the architecture shown in Figure 4.7.1[18]: agencies coordinate through a technical working group that governs a shared data platform, which in turn produces the ocean accounts.

¶9 The broader implementation readiness context that complements this data-specific coordination focus is provided in **TG-0.8 Implementation Readiness Assessment**, which guides countries through evaluating institutional, data, and human capacity prerequisites across all dimensions of ocean accounting implementation.

¶10 Data coordination for ocean accounting should build upon existing national statistical system coordination mechanisms wherever possible, adapting proven models from economic statistics, agricultural statistics, and environmental-economic accounting. The GSGF's key elements — governance and institutional capacity, policy and legal, human resources and capability, data and interoperability, and technology and infrastructure — provide a useful checklist for assessing the completeness of coordination arrangements[19].

¶11 Guidance on the broader governance context for embedding ocean accounts in national planning is provided in **TG-1.10 OA and National Planning Integration**. Data source-specific integration guidance is provided in the companion Circulars: **TG-4.1 Remote Sensing and Geospatial Data**, **TG-4.2 Survey Methods for Ocean Economic Activity**, **TG-4.3 Administrative Data Sources**, **TG-4.4 Citizen Science and Community-Based Monitoring**, and **TG-4.5 Integrating Research Data into Official Statistics**.

Implementation Considerations

¶1 For minimum institutional capacity, data infrastructure, and human skills requirements for implementing these data methods, see TG-0.8 Implementation Readiness Assessment.

5. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

6. References

1. ¶1 United Nations, "System of Environmental-Economic Accounting — Ecosystem Accounting" (2021), para 1.52.
2. ¶2 United Nations Expert Group on the Integration of Statistical and Geospatial Information, "Global Statistical Geospatial Framework (GSGF), Version 2.0" (2025), Stage 2: The Key Elements. The five key elements are: Governance and Institutional Capacity; Policy and Legal; Human Resources and Capacity; Data and Interoperability; and Technology and Infrastructure.
3. ¶3 SEEA EA (2021), para 1.52.
4. ¶4 SEEA EA (2021), para 1.51.

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5. ¶5 GSGF v2 (2025), Principle 1, Policy and Legal section.
6. ¶6 GSGF v2 (2025), Principle 1, Policy and Legal section.
7. ¶7 United Nations Expert Group on the Integration of Statistical and Geospatial Information, "MoU template for joint work between the NSO and the NGIAs for the integration of statistical and geospatial information." Available at https://ggim.un.org/meetings/GGIM-committee/14th-Session/documents/Background_document_Institutional_agreement_for_GSGF.pdf (https://ggim.un.org/meetings/GGIM-committee/14th-Session/documents/Background_document_Institutional_agreement_for_GSGF.pdf)
8. ¶8 ISIC Rev.5 was approved by the UN Statistical Commission in 2023 and is being progressively adopted. Countries still reporting under Rev.4 should apply the applicable revision and document the version used in metadata.
9. ¶9 Keith, D.A., et al. (2022). *A function-based typology for Earth's ecosystems*. Nature, 610, 513–518. The IUCN Global Ecosystem Typology (GET) v2.0 is the authoritative classification referenced throughout the Technical Guidance.
0. ¶10 Timeliness benchmarks should be aligned with the national statistical release calendar. No single authoritative standard specifies T+6 and T+18 month targets for environmental-economic accounting; the 6–12 month (preliminary) and 12–24 month (final) ranges cited here reflect observed practice in environmental-economic accounting programmes and should be adapted to the production cycles of each contributing agency as negotiated in individual data sharing agreements.
1. ¶11 GSGF v2 (2025), Principle 4: Statistical and geospatial interoperability. The four interoperability dimensions (legal, organisational, semantic, technical) are derived from the European Interoperability Framework (EIF).
2. ¶12 SEEA EA (2021), para 1.54.
3. ¶13 SEEA EA (2021), para 1.53.
4. ¶14 GSGF v2 (2025), Principle 4, Technology and Infrastructure section.
5. ¶15 Statistical Data and Metadata eXchange (SDMX), "SDMX Technical Standards, Section 5: Registry Specification – Logical Interfaces" (SDMX 3.1, 2025). Section 5 of the SDMX technical standards defines the logical functionality and interfaces for the SDMX registry, including subscription and notification services that allow automated processing of updates to registered structural metadata and data sources. The current version is available at https://sdmx.org/standards-2/ (https://sdmx.org/standards-2/).
6. ¶16 SEEA EA (2021), para 1.58.
7. ¶17 SEEA EA (2021), para 1.56.
8. ¶18 Figure 4.7.1 illustrates the architecture by which multiple data custodian agencies contribute to ocean accounts through a technical working group that governs a shared data platform.
9. ¶19 GSGF v2 (2025), Stage 2: The Key Elements. The GSGF maturity self-assessment tool, adapted from the UN-IGIF baseline assessment methodology, provides a structured approach to evaluating institutional readiness across these dimensions.

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Physical Condition Measurement

Provides guidance on measuring the physical condition of ocean and coastal ecosystems for use in SEEA EA ecosystem condition accounts.

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

OUTCOME

This Circular provides guidance on measuring the physical condition of ocean and coastal ecosystems for use in SEEA EA ecosystem condition accounts. On completing this Circular, users will be able to select appropriate physical state variables, establish reference conditions, rescale variables to dimensionless condition indicators on a 0–1 scale, and integrate physical condition data into the asset account structure defined in TG-3.1 Asset Accounts.

Physical condition measurement addresses the abiotic subset of ecosystem condition (temperature, salinity, dissolved oxygen, pH, turbidity, nutrients, and light attenuation), corresponding to ECT Classes A1 and A2 as defined in SEEA EA Table 5.1. This Circular does not cover biological condition variables (covered by TG-4.9) or the compilation of condition account tables (covered by TG-3.1).

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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> *Framework position:* *TG-4.8 sits in the data methods layer. It provides the measurement protocols and variable selection guidance for physical state variables that feed upstream into the ecosystem condition indicators described in TG-2.1 and TG-2.8, and from there into asset accounts compiled under TG-3.1. Users compiling condition accounts should read this Circular alongside TG-4.9 Biological Condition Measurement, which covers the biotic counterpart to the abiotic variables described here.*

¶1 **Framework Position**

¶2 TG-4.8 sits within Section 4 (Data Methods). It owns the abiotic condition variable — ECT Classes A1 and A2 — from selection through measurement protocol, data source and tier, reference condition, and rescaling to a dimensionless 0–1 score against that documented reference, with its uncertainty. It does not own what is built from those scores. Combining variables into an ECT-class or overall condition index is **TG-2.1 Aggregate Biophysical Indicators of Environmental State**; the SEEA EA Table 5.2 condition account is **TG-3.1 Asset Accounts** Section 3.5.2. Biotic variables are **TG-4.9 Biological Condition Measurement**.

1. Outcome

¶1 This Circular provides guidance on measuring the physical condition of ocean and coastal ecosystems for use in SEEA EA ecosystem condition accounts. On completing this Circular, users will be able to select appropriate physical state variables, establish reference conditions, rescale variables to dimensionless condition indicators on a 0–1 scale, and integrate physical condition data into the asset account structure defined in TG-3.1 Asset Accounts.

¶2 Physical condition measurement addresses the abiotic subset of ecosystem condition (temperature, salinity, dissolved oxygen, pH, turbidity, nutrients, and light attenuation), corresponding to ECT Classes A1 and A2 as defined in SEEA EA Table 5.1[1]. This Circular does not cover biological condition variables (covered by TG-4.9) or the compilation of condition account tables (covered by TG-3.1).

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2. Requirements

¶1 Users should be familiar with the following circulars before working through this guidance:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** — for the overall structure and purpose of ocean accounts
- ¶3 **TG-0.6 Glossary of Key Terms** — for canonical definitions of “condition variable”, “condition indicator”, and “reference condition”
- ¶4 **TG-0.7 Quality Assurance Principles** — for data quality, metadata, and uncertainty documentation requirements
- ¶5 **TG-4.1 Remote Sensing and Geospatial Data** — for satellite sensor selection, pre-processing, and spatial data handling
- ¶6 **TG-4.5 Integrating Research Data into Official Statistics** — for admitting in-situ oceanographic survey and monitoring data, including quality thresholds, spatial interpolation, and cross-validation
- ¶7 **TG-4.4 Citizen Science and Community-Based Monitoring** — for citizen science and community-based monitoring data in data-poor contexts

3. Guidance Material

3.1 Conceptual Framework

¶1 Physical condition measurement is anchored in SEEA EA Chapter 5, which establishes the Ecosystem Condition Typology (ECT), the concept of reference condition, and the rescaling of state variables to dimensionless condition indicators on a 0–1 scale. Physical condition captures the abiotic state of the ocean environment. The SEEA EA Ecosystem Condition Typology (Table 5.1) groups condition characteristics into three groups and six classes – Group A (abiotic) with classes A1 and A2, Group B (biotic) with classes B1 to B3, and Group C (landscape) with class C1. Abiotic condition is the two classes of Group A:

- ¶2 **ECT Class A1 – Physical state characteristics:** the thermal, hydrodynamic and optical properties of the water column (temperature, salinity, water clarity, stratification).
- ¶3 **ECT Class A2 – Chemical state characteristics:** the chemical composition of the water column (pH and aragonite saturation, dissolved oxygen, dissolved inorganic nutrients).

¶4 Class labels follow SEEA EA Table 5.1 exactly. TG-3.1 Asset Accounts Section 3.5.2 uses the same six classes, and a variable must carry the same class label in both circulars.

¶5 Physical condition is distinct from biological condition (TG-4.9 Biological Condition Measurement): physical variables measure the abiotic habitat envelope within which organisms live, whilst biological variables capture the biotic response of living organisms to that environment. Both are components of ecosystem condition as defined by SEEA EA Chapter 5 and both feed into asset accounts (TG-3.1 Asset Accounts).

¶6 **Reference condition** is the baseline against which current state is compared. SEEA EA paras 5.65–5.75 and Appendix A5.2 establish four approaches, and this framework is canonical for both physical and biological condition accounts (TG-4.9 cross-refers here).

Approach	Description
Historical / pre-impact baseline	Earliest available consistent dataset for the accounting unit (national monitoring series, paleoecological records, legacy survey data).
Pristine or least-disturbed reference site	Minimally impacted contemporary site of equivalent ecosystem type, biogeographic region, and depth range.
Modelled natural state	Model-derived estimate calibrated on undisturbed sites; used where empirical references are unavailable.
Regulatory or management target	Policy-defined value (e.g., MPA recovery target, CBD Kunming-Montreal GBF Target 3); least preferred, flag explicitly.

¶7 **Fixed reference condition for time-series accounts.** For time-series accounting, the reference condition value for each indicator must be fixed at the start of the series and held constant across all subsequent periods. Revisions are permitted only at a formally documented major methodological review and require complete re-compilation of the historical series from the new baseline. Document the reference-condition vintage (year established) in account metadata. New accounting units introduced mid-series establish their own baseline at first measurement, and are flagged as a new series start.

¶8 **Ecosystem-specific physical priorities** vary by habitat type:

Habitat type	Key physical condition variables	Notes
Coral reef	SST anomaly, pH/ Ωaragonite, turbidity	Thermal bleaching and acidification are primary stressors; see §3.2 for coral-specific SST rescaling
Seagrass and saltmarsh	Water clarity (Kd490), dissolved inorganic nutrients, salinity	Light availability governs productivity

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Habitat type	Key physical condition variables	Notes
Mangrove	Salinity, turbidity, tidal inundation frequency	Salinity tolerance range defines condition envelope
Open ocean / pelagic	SST, dissolved oxygen, mixed layer depth	Oxygen minimum zone expansion is a key condition trend; see §3.2 for MLD guidance

¶9 For detailed habitat-specific guidance, see TG-6.1 Coral Reef Ecosystem Accounting, TG-6.2 Mangrove and Coastal Wetland Accounting, TG-6.3 Seagrass Ecosystem Accounting, and TG-6.5 Pelagic and Open Ocean Accounting.

3.2 Indicator Selection

¶1 Indicators are selected according to four criteria set out in SEEA EA paras 5.22–5.27. Table 3.2.1 below summarises these criteria.

Criterion	Description
Measurability	The variable can be quantified with available technology at the required spatial and temporal resolution.
Ecological relevance	It reflects a key aspect of ecosystem functioning or integrity for the habitat type in question.
Sensitivity to change	It responds detectably to the pressures of concern within the accounting period.
Data availability	Consistent national or regional time series exist or can be established within the capacity of the compiling agency.

¶2 **Recommended physical condition indicators by ECT class**

¶3 *ECT Class A1 — Physical state characteristics*

- ¶4 **Sea Surface Temperature (SST):** primary indicator of thermal stress and climate forcing. Unit: °C. Reference condition: long-term climatological mean (e.g., the 1985–2012 NOAA Coral Reef Watch CoralTemp climatology[2]). Where the full 1985–2012 period is unavailable nationally, use the longest consistent national record as the reference baseline, document the period explicitly in metadata, and note the departure from the global standard baseline. Rescaling: temperature anomaly relative to baseline. The condition indicator decreases as anomaly increases above the reference variability range. *For coral reef accounting units:* threshold-based rescaling using the Maximum Monthly Mean (MMM) climatology is the preferred approach. When sea surface temperature exceeds the MMM, Degree Heating Weeks (DHW) begin to accumulate, and DHW ≥ 8°C-weeks corresponds to significant bleaching risk. The MMM/DHW method is the global operational standard for bleaching heat-stress monitoring. NOAA Coral Reef Watch provides ready-to-use global 5-km DHW and MMM products.[2] The same indices can equally be derived from Copernicus Marine Service (CMEMS) or ESA Climate Change Initiative (CCI) SST inputs where an alternative provider is preferred.
- ¶5 **Salinity:** indicator for estuarine and coastal boundary zones. Unit: practical salinity units (PSU). Reference condition: long-term climatological mean from WOA[3] or ARGO programme[4] for the accounting unit.
- ¶6 **Water clarity / light attenuation (Kd490):** relevant for seagrass and coral light requirements. Unit: m^{-1}. Reference condition: site-specific long-term mean from satellite ocean colour products. Condition indicator decreases as Kd490 increases beyond the reference level (higher attenuation = reduced light penetration = poorer condition).
- ¶7 **Mixed layer depth (MLD):** indicator of ocean stratification and vertical mixing, relevant for pelagic and open-ocean accounting units. Unit: metres. Reference condition: long-term climatological mean MLD from ARGO programme or CMEMS reanalysis. Shoaling of MLD beyond the climatological range indicates increased stratification, which constrains nutrient upwelling and

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affects productivity. Condition indicator decreases as MLD shoals beyond the climatological reference range. Source: ARGO programme density profiles; CMEMS physical reanalysis products. See TG-6.5 Pelagic and Open Ocean Accounting for guidance on MLD in pelagic condition accounts.

¶8 *ECT Class A2 — Chemical state characteristics*

- ¶9 **Ocean pH / aragonite saturation (Ω):** indicator of ocean acidification state. Unit: pH units (dimensionless Ω). Reference condition: pre-industrial pH (~8.18) or a regional multi-decadal baseline from SOCAT/GLODAP. Condition indicator decreases as pH declines or Ω falls below the aragonite saturation threshold (Ω = 1), below which shell-forming organisms cannot maintain calcified structures.
- ¶10 **Dissolved oxygen (DO):** indicator of habitat viability and eutrophication stress. Unit: mg/L or % saturation. Hypoxia threshold: < 2 mg/L (below which most marine fauna cannot persist). Reference condition: site-specific or regional historical baseline.
- ¶11 **Dissolved inorganic nutrients (NO_3, PO_4):** eutrophication indicators for coastal zones. Unit: µmol/L. Reference condition: oligotrophic background level for the relevant ocean region. Condition indicator decreases as nutrient concentrations exceed reference levels.

¶12 **Tiered indicator selection approach**

¶13 Indicator selection follows a three-tier framework based on data availability. The tiering draws on the graduated capacity framework described in **TG-0.7 Quality Assurance Principles**. Table 3.2.2 below summarises the three tiers.

Tier	Description
Tier 1	Variables with nationally monitored, consistent time series of at least 10 years. These are the preferred source for condition trend assessment. In-situ networks and national survey programmes are the primary data source.
Tier 2	Variables derived from model output or regional satellite products where in-situ series are absent or incomplete. The CMEMS Physical Analysis and Forecast System[5] and satellite-derived ocean colour composites are typical Tier 2 sources. Trend assessment requires the full 1993–present satellite altimetry era where possible.
Tier 3	Data-poor contexts where global reanalysis climatologies (WOA decadal climatologies and 1991–2020 climate normals, ERA5-ocean) provide the only available series. Tier 3 variables carry the highest uncertainty and should be flagged as such in condition account metadata.

¶14 **Rescaling and aggregation pathway**

¶15 The transition from raw measurement to reported condition indicator follows three steps, consistent with SEEA EA paras 5.44–5.58. Figure 4.8.1 traces the pathway from a raw ECT Class A1 or A2 variable, through quality control and benchmarking against the reference condition, to a rescaled and aggregated SEEA EA Table 5.2 condition account row. Table 3.2.3 below summarises these steps.

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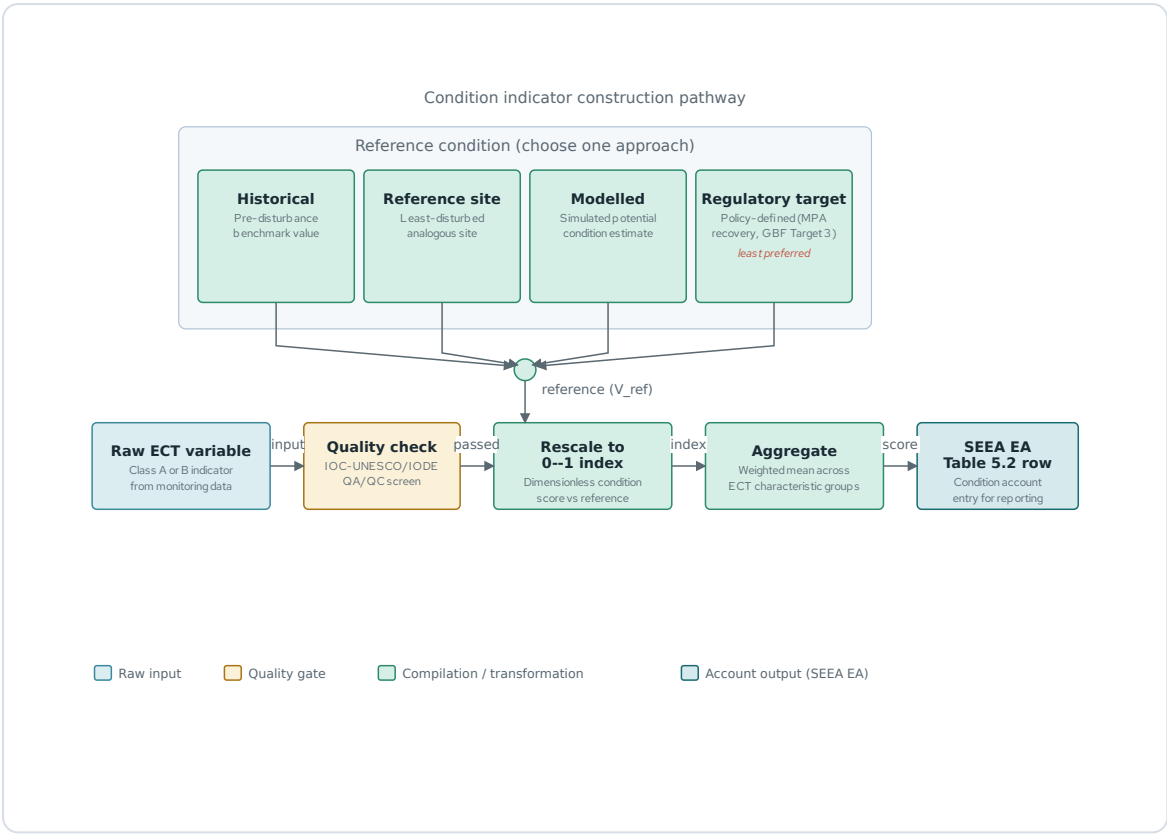


Figure 4.8.1 Pathway from an ECT Class A or B variable through quality check, reference benchmarking, rescaling, and aggregation to a SEEA EA Table 5.2 row. Four reference-condition approaches; regulatory or management target is least preferred.

Source: TG-4.8, §3.1–3.5 (conceptual framework, indicator selection, measurement & integration); ECT Class A/B structure per SEEA EA 2024 Table 5.1; reference-condition approaches per SEEA EA 2024 §§5.65–5.75 and Appendix A5.2.

Step	Description
Raw variable normalisation	Standardise units, apply quality flags, and aggregate to the spatial and temporal resolution of the accounting unit.
Rescaling to 0–1 condition indicator	Apply the rescaling function (see §3.5 for the explicit formula) to map the variable onto the 0–1 condition scale relative to the reference condition.
ECT-class and composite indices	Aggregate individual condition indicators within each ECT class (A1, A2) to produce class-level and whole-ecosystem condition indices, following the weighting approach documented by the compiling agency. Cross-reference TG-2.1 Aggregate Biophysical Indicators of Environmental State for indicator aggregation methods.

3.3 Measurement Protocols

¶1 In-situ measurement

¶2 CTD (conductivity-temperature-depth) casts provide vertical profiles of temperature, salinity, and (where equipped) dissolved oxygen and fluorescence. Moored buoys record continuous surface and sub-surface time series. ARGO profiling floats provide open-ocean profiles to 2,000 m depth with near-real-time transmission. Repeat hydrography programmes (WOCE/GO-SHIP sections) supply basin-scale reference data for calibration.

¶3 For coastal and estuarine zones, national tide gauge networks, fixed moored sensors, and periodic survey cruises provide the primary in-situ data. Water sampling for nutrient and pH analysis should follow IOC-UNESCO/IODE standard operating procedures, including certified reference materials for pH (NOAA-distributed CRMs) and oxygen (Winkler titration).

¶4 **Remote sensing**

¶5 Satellite-derived SST (MODIS Aqua, AVHRR, Sentinel-3 SLSTR) provides daily global coverage with approximately 1 km spatial resolution. Ocean colour products (MODIS Aqua, SeaWiFS, Sentinel-3 OLCI) deliver Kd490 and turbidity estimates at 300 m – 4 km resolution. Gap-filling via optimal interpolation (OI) is standard for SST products (NOAA OISST, CMEMS, GHRSST Level 4). See TG-4.1 Remote Sensing and Geospatial Data for sensor selection and pre-processing protocols.

¶6 **Tiered minimum time requirements**

¶7 Table 3.3.1 below summarises the minimum time-coverage requirements for each tier.

Tier	Minimum time requirement
Tier 1	A minimum of 10 years of consistent observations is required for trend-reliable condition assessment; longer series should be used where available to capture multi-decadal variability.
Tier 2	Satellite-era products should span the full 1993–present period where possible; where national capacity limits coverage, use the longest available continuous record and document the gap in metadata.
Tier 3	WOA decadal climatologies, or the 1991–2020 climate normal, are the minimum standard. The WOA 2023 edition (Reagan et al. 2024)[3] is the current default; report the specific WOA edition and climatological period used in all metadata.

¶8 **Abiotic SOP references**

¶9 The standards listed in Table 3.3.2 are the canonical SOPs for the abiotic variables enumerated in Section 3.2. Compiling agencies should record the cited standard (and its version/year) in metadata for each variable per **TG-0.7 Quality Assurance Principles**. Documented departures from the SOP (sampling depth, replication, gear substitution) should be recorded alongside the measurement. Satellite-derived alternatives are listed in the remote-sensing subsection above and in Table 3.4.

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Variable	Measurement / sample type	Standard protocol	Source
Temperature, salinity (profile)	CTD cast, WOCE/GO-SHIP-compatible QA	GO-SHIP repeat-hydrography protocol; IOC-UNESCO/IODE Manuals & Guides 54[6], [7]	go-ship.org
Dissolved oxygen (discrete)	Winkler titration on bottle samples	IOC-UNESCO/IODE Manual; ISO 5813 / ISO 5814[8]	IOC-UNESCO; ISO
Dissolved oxygen (in-situ profile)	Calibrated optode on CTD or BGC-Argo	BGC-Argo Quality Control Manual[9]	Argo Data Management Team
pH / pCO2 / aragonite saturation	Discrete bottle samples; CRM-referenced spectrophotometric pH	Dickson et al. (2007) *Guide to Best Practices for Ocean CO2 Measurements*; SOCAT and GLODAP submission protocols[10]	PICES Special Publication 3
Nutrients (NO_3, PO_4, SiO_4)	Auto-analyser on filtered water samples	GO-SHIP nutrient protocol; ISO 13395 (nitrate); ISO 6878 (phosphate)[7], [11]	IOC/GO-SHIP; ISO
Turbidity / Kd490 (in-situ)	Secchi depth; PAR profiler	IOC-UNESCO ocean optics protocols (Mueller & Fargion 2003)[12]	NASA Ocean Optics Protocol Revisions

Variable	Measurement / sample type	Standard protocol	Source
Sediment grain size, organic carbon	Sediment grab/core; sieving and loss-on-ignition or elemental analyser	ISO 16665 (marine benthos sampling); ISO 11464 (sample pretreatment)[13]	ISO

¶10 **Quality control and data-poor contexts**

¶11 Apply IOC-UNESCO/IODE QA procedures (anomaly flagging, measurement precision, gap-filling documentation) within the **TG-0.7** framework. All stations georeferenced to WGS84. Annual composites are the minimum for accounts. Where national in-situ programmes are limited, global reanalysis (CMEMS, ERA5-ocean, WOA) is a viable Tier 3 alternative. Document source, version, and known biases, especially in shallow coastal and enclosed seas. Supplement with **TG-4.4 Citizen Science** data where coverage is sparse.

3.4 Data Requirements and Sources

¶1 The following matrix specifies the minimum data requirements for each recommended physical condition indicator:

Variable	Unit	Primary Source	Update Frequency (accounts: annual composite recommended)	Data-Poor Alternative
Sea Surface Temperature	°C	NOAA OISST / CMEMS SST	Daily source; monthly composites; annual mean for accounts	HadISST reanalysis (monthly, 1°×1°)
Salinity	PSU	ARGO programme / national CTD surveys	Monthly profiles; annual climatology for accounts	World Ocean Atlas (decadal climatology; 1991–2020 normal)
Dissolved Oxygen	mg/L	ARGO BGC floats / moored sensors	Near-real-time profiles; annual composite for accounts	World Ocean Database reanalysis fields
pH / Ωaragonite	pH / dimensionless	SOCAT, GLODAP, ARGO BGC	SOCAT/GLODAP: annual update; ARGO BGC: near-real-time; annual composite for accounts	CMEMS biogeochemical analysis and forecast
Water clarity (Kd490)	m^{-1}	MODIS Aqua / Sentinel-3 OLCI	Monthly composites; annual mean for accounts	CMEMS ocean colour multi-observation product
Dissolved inorganic nutrients	µmol/L	National marine surveys / ICES Data Centre	Annual survey; near-real-time for some ICES regions; annual composite for accounts	World Ocean Atlas (all-years climatology; WOA publishes no decadal nutrient fields)
Mixed layer depth	m	ARGO programme density profiles / CMEMS physical reanalysis	Monthly profiles; annual mean for accounts	CMEMS global ocean reanalysis (GLORYS12)

¶2 **Key institutional data sources:** Copernicus Marine Service (CMEMS), NOAA CoastWatch, NOAA Coral Reef Watch, IMOS (Australia), ICES Data Centre, IOC-UNESCO IODE, national oceanographic institutes, national meteorological services, Argo Data Assembly Centres (GDAC).

¶3 **Known data limitations:**

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- ¶4 Sparse in-situ coverage in developing-country EEZs creates reliance on Tier 2–3 products with higher uncertainty.
- ¶5 Satellite retrievals are degraded by cloud cover, sun glint, river plumes, and coastal adjacency effects within approximately 1 km of the shoreline.
- ¶6 Reanalysis products may not resolve sub-mesoscale processes in enclosed seas, shallow bays, or areas of strong tidal forcing.
- ¶7 BGC-ARGO pH and oxygen profiles are sparse in coastal and shelf regions, whilst WOD/GLODAP cover is more complete in the open ocean.
- ¶8 MLD estimates from density profiles are sensitive to the threshold criterion applied (density or temperature criterion), and the criterion used must be documented for reproducibility.

¶9 Compiling agencies should document data source, product version, spatial resolution, and temporal coverage for every variable in the condition account metadata. See TG-4.6 Data Harmonisation and Interoperability for guidance on integrating data from multiple sources.

3.5 Reporting and Integration

¶1 **Reporting format**

¶2 Each physical condition variable is delivered with the following fields: ECT class, variable name, unit of measurement, reference condition value, current condition value, and rescaled condition indicator (0–1 scale). Arranging those fields as rows of the SEEA EA Table 5.2 condition account is done in **TG-3.1 Asset Accounts** Section 3.5.2; combining variables into an ECT-class or overall condition index is **TG-2.1 Aggregate Biophysical Indicators of Environmental State**. This Circular is responsible for the variable and its rescaling to a 0–1 score against a documented reference, not for the aggregate or the account.

¶3 **Rescaling formula**

¶4 For variables where higher values indicate better condition (e.g., dissolved oxygen, aragonite saturation):

> $CI = (V - V_{min}) / (V_{ref} - V_{min})$

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¶5 For variables where lower values indicate better condition (e.g., temperature anomaly, nutrient loading, turbidity):

> $CI = 1 - [(V - V_{min}) / (V_{max} - V_{min})]$

¶6 Where:

- ¶7 CI = condition indicator (0–1 scale; 1 = at or above reference condition; 0 = fully degraded or absent)
- ¶8 V = observed variable value for the accounting period
- ¶9 V_ref = reference condition value (the value of the variable under the chosen reference condition)
- ¶10 V_min = minimum observed value or ecologically meaningful lower bound (e.g., 0 mg/L for dissolved oxygen; Ωaragonite = 0; pH = 7.75). Examples by variable: dissolved oxygen V_min = 0 mg/L; Ωaragonite V_min = 0; pH V_min = 7.75; temperature anomaly V_min = 0. Compiling agencies must document the V_min and V_max values applied for each variable, and deliver them alongside the variable.
- ¶11 V_max = maximum observed value or ecologically meaningful upper bound (used in negative-condition formula only)

¶12 For binary threshold indicators (e.g., DO hypoxia): CI = 1 if V ≥ threshold (2 mg/L), and CI = 0 if V < threshold (step rescaling). Figure 4.8.2 works a numerical example of these formulas: continuous-variable rescaling (an SST anomaly on a coral reef unit) and threshold (step) rescaling (dissolved oxygen about the hypoxia threshold). Its third panel shows, for orientation only, where the delivered scores go — the ECT-class aggregate and the Table 5.2 rows are compiled under TG-2.1 and TG-3.1 respectively, not here.

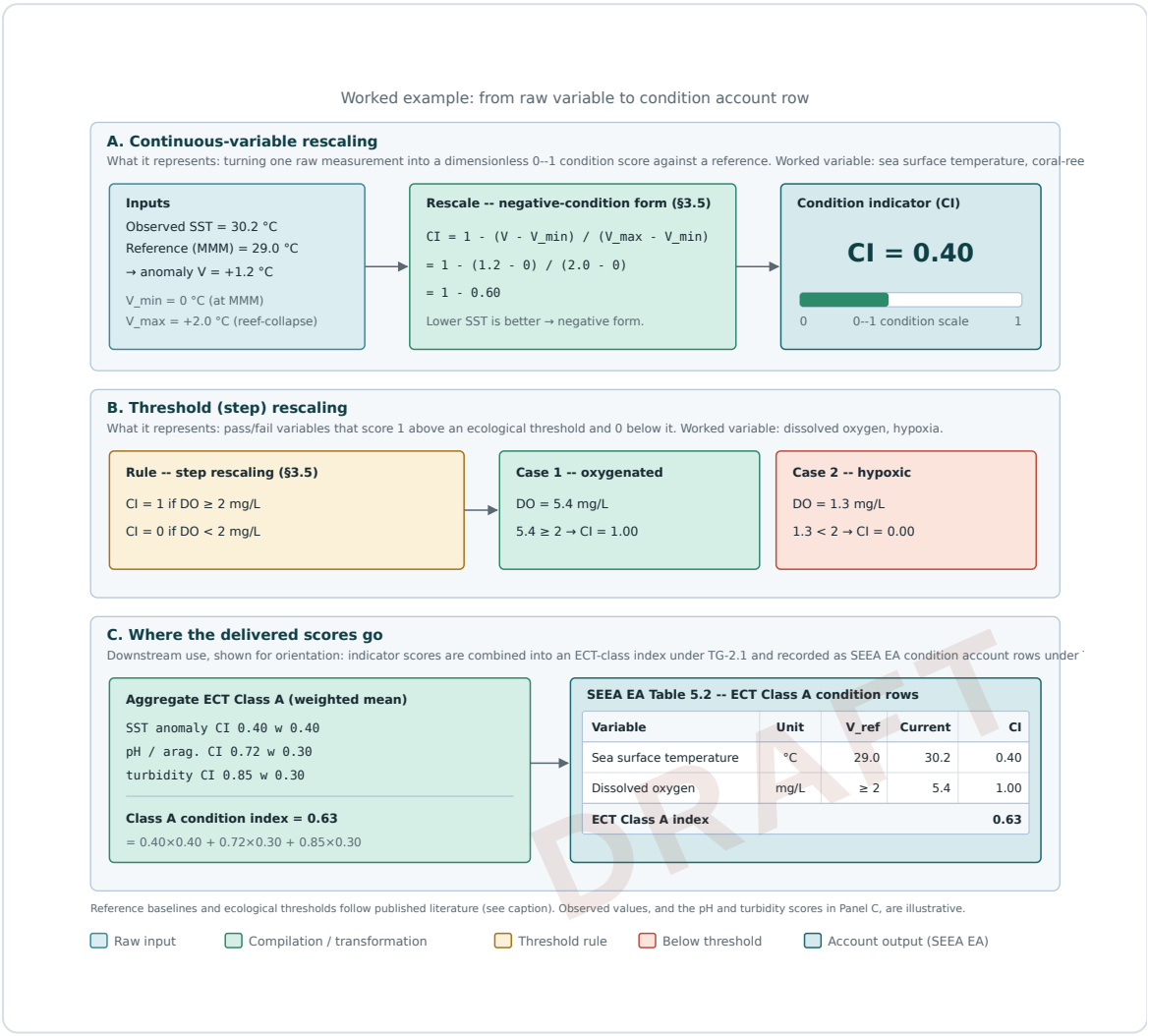


Figure 4.8.2 Panels A and B show the rescaling this Circular performs: continuous rescaling and threshold rescaling. Panel C shows where the resulting scores go -- ECT Class A aggregation and SEEA EA Table 5.2 rows, both compiled elsewhere. Observed values and weights are illustrative.

Source: TG-4.8 §3.5 (rescaling, bounds, binary threshold); TG-2.1 (aggregation); TG-3.1 §3.5.2 (condition account); SEEA EA 2024 §§5.44--5.58 and Table 5.2. Baselines: Liu et al. 2014 (MMM/DHW); IPCC 2018 / Frieler et al. 2013 (+2°C); Diaz & Rosenberg 2008 / Vaquer-Sunyer & Duarte 2008 (2 mg/L hypoxia).

¶13 Where current condition exceeds the reference baseline (CI > 1 in the positive-condition formula), CI is delivered as 1.0 and the raw calculated value is recorded in the accompanying metadata. A CI above 1 can arise where recent conservation gains have improved condition above the historical reference.

¶14 **Integration with biological condition**

¶15 Physical variables establish the abiotic habitat envelope for **TG-4.9** indicators. Joint reporting of SST, DO, turbidity, and pH enables attribution analysis (e.g., distinguishing thermal stress from direct anthropogenic impact).

¶16 **Uncertainty reporting**

¶17 Each indicator requires measurement-uncertainty, representativeness, and model-uncertainty components, plus the data tier (1–3) and gap-filling method. Metadata documentation follows **TG-0.7**.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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Biological Condition Measurement

Translates biotic field measurements and remote-sensing products into SEEA EA ecosystem condition indicators (ECT Classes B1–B3 and C1).

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular translates biotic field measurements and remote-sensing products into SEEA EA ecosystem condition indicators (ECT Classes B1–B3 and C1). Upon implementation, compilers will be able to (1) select bio-indicators by ecosystem type, (2) apply standardised in-situ, remote-sensing, and citizen-science protocols, (3) compile condition variable tables conforming to SEEA EA Table 5.2, and (4) apply tiered data approaches in data-poor contexts.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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> *Framework position: Biotic counterpart to TG-4.8 Physical Condition Measurement. Feeds the ecosystem-specific accounting circulars TG-6.1 through TG-6.5, and draws on TG-4.4 Citizen Science for community-based survey data.*

¶1 **Framework Position**

¶2 TG-4.9 sits within Section 4 (Data Methods). It owns the biotic condition variable — ECT Classes B1, B2, B3 and C1 — from indicator selection and core sets by ecosystem type, through in-situ survey protocol, taxonomic resolution, quality control and the tiered data source hierarchy, to the indicator delivered against a documented reference with its sampling error and tier flag. It does not own the composites or the account. Aggregation weights for class sub-indices and overall condition indices are set under **TG-2.1 Aggregate Biophysical Indicators of Environmental State**; the condition account is **TG-3.1 Asset Accounts** Section 3.5.2. Abiotic variables are **TG-4.8 Physical Condition Measurement**.

1. Outcome

¶1 This Circular translates biotic field measurements and remote-sensing products into SEEA EA ecosystem condition indicators (ECT Classes B1–B3 and C1). Upon implementation, compilers will be able to (1) select bio-indicators by ecosystem type, (2) apply standardised in-situ, remote-sensing, and citizen-science protocols, (3) compile condition variable tables conforming to SEEA EA Table 5.2, and (4) apply tiered data approaches in data-poor contexts.

2. Requirements

- ¶1 **TG-0.1** — SEEA EA framework.
- ¶2 **TG-0.7** — QA framework.
- ¶3 **TG-3.1** — ecosystem condition account structure (SEEA EA Table 5.2).
- ¶4 **TG-4.4** — citizen-science collection protocols. TG-4.9 governs indicator construction from such data.
- ¶5 **TG-4.8** — canonical for reference-condition framework, indicator selection criteria, variable → indicator → index pathway, and rescaling formulas. TG-4.8 also provides the abiotic envelope for joint attribution analysis.

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3. Guidance Material

3.1 Conceptual Framework

3.1.1 Defining Biological Condition

¶1 Biological condition is the biotic state of an ecosystem (composition, abundance, biomass, diversity, functional integrity) relative to a reference condition.[1] It is a subset of biodiversity and narrower than ecological integrity — an operational, measurable construct yielding standardised indicators for national accounts.[2] The abiotic component (physical and chemical condition) is in **TG-4.8**.

3.1.2 SEEA EA Ecosystem Condition Typology (ECT)

¶1 The SEEA EA organises ecosystem condition variables into the Ecosystem Condition Typology (ECT), a hierarchical classification of condition characteristics.[3] The ECT groups condition characteristics into three groups and six classes: Group A (abiotic), with classes A1 Physical state and A2 Chemical state; Group B (biotic), with classes B1 Compositional state, B2 Structural state and B3

Functional state; and Group C (landscape), with class C1 Landscape and seascape characteristics. Biological condition variables fall in Group B and, where they describe the biotic seascape, in class C1. Table 3.1.2.1 below summarises the ECT classes within which biological condition variables primarily fall.

ECT class	Description
ECT Class B1 — Compositional state	Species composition, taxonomic richness, and presence/absence of indicator taxa. This class records which taxa are present in the ecosystem.
ECT Class B2 — Structural state	Species abundance, biomass, population density, and size-structure metrics. This class records the number of organisms present and their physical characteristics.
ECT Class B3 — Functional state	Biotic integrity indices, productivity indicators (e.g., litterfall biomass), and trophic structure metrics. This class records biological functioning of the ecosystem.
ECT Class C1 — Landscape and seascape characteristics	Habitat patch structure, connectivity, fragmentation, and reef geomorphology, where these characteristics reflect the biotic state of the ecosystem (e.g., coral framework integrity, mangrove canopy cover).

¶2 Physical and chemical condition variables (ECT Classes A1 and A2) are addressed in TG-4.8. Compilers must classify each biological indicator by its ECT class before entering it in the condition account table.

3.1.3 Reference Condition

¶1 The four-approach reference-condition framework (historical, reference site, modelled, regulatory target) and the **fixed-baseline rule for time-series accounts** apply equally to biological and physical condition. See **TG-4.8 Physical Condition Measurement** §3.1 for the canonical framework.[4] Bio-specific reference sources for individual indicators are listed in §3.2.3.

3.1.4 Scope Boundaries

¶1 **Boundary with TG-4.8.** Boundary-case variables are assigned by ECT class: e.g., turbidity → TG-4.8 (Class A1), and seagrass shoot density (response to turbidity) → TG-4.9 (Class B2).

¶2 **Boundary with TG-4.4.** TG-4.4 governs citizen-science collection protocols, and TG-4.9 governs indicator construction from that data.

3.2 Biological Indicator Selection

3.2.1 Selection Criteria and Indicator Framework

¶1 The SEEA EA indicator-selection criteria (measurability, ecological relevance, sensitivity to change, data availability) and the variable → indicator → index three-level hierarchy are in **TG-4.8** §3.2 and apply to biological indicators without modification. Biological selection additionally weights **sensitivity to anthropogenic pressures** (overfishing, nutrient loading, temperature stress, physical disturbance, invasive species) and **interpretability** for non-specialist account users. For data-poor contexts, a simpler indicator reliably measured is preferable to a theoretically superior indicator with large sampling uncertainty. Aggregation into composite indices is addressed in TG-3.1 Asset Accounts.

3.2.2 Core Indicators by Ecosystem Type

¶1 The following table specifies minimum biological condition indicators by ocean ecosystem type. Indicators are classified by ECT class, assigned a data tier (see §3.4), and linked to their standard measurement protocol.

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Ecosystem type	Indicator	Variable	Unit	ECT class	Data tier	Protoc referer
Coral reef	Live coral cover	% substrate covered by living coral	%	B2	1–2	GCRM Reef C
Coral reef	Coral species richness	Number of coral species per transect	count	B1	1–2	GCRM
Coral reef	Coral bleaching extent	% of colonies bleached	%	B2	1–2	CoralW Reef C
Coral reef	Reef fish biomass	Total fish biomass per area	g/m²	B2	1–2	UVC b transec BRUVS
Coral reef	Non-indigenous species (NIS) presence	Presence/absence or % cover	binary / %	B1	1–3	GCRM iNatura
Seagrass meadow	Seagrass cover	% substrate covered by seagrass	%	B2	1–2	Seagra
Seagrass meadow	Shoot density	Shoots per unit area	shoots/m²	B2	1–2	Seagra
Seagrass meadow	Species diversity	Shannon diversity index (H′)	dimensionless	B1	1–2	Seagra
Mangrove	Canopy cover	% canopy closure	%	C1	1–2	Nationa est inv tory, TC
Mangrove	Stem density	Stems per unit area	stems/ha	B2	1–2	Nationa est inv
Mangrove	Litterfall biomass (productivity proxy)	Dry weight litter per area per time	g/m²/yr	B3	1–2	Plot-ba litterfal traps
Kelp forest / temperate reef	Kelp canopy cover	% substrate covered by kelp canopy	%	B2	1–2	REEF s vey, na reef monito
Kelp forest / temperate reef	Stipe density	Kelp stipes per unit area	stipes/m²	B2	1–2	Belt tra sect, R survey
Kelp forest / temperate reef	Sea urchin density	Individuals per unit area (trophic state indicator)	individuals/m²	B2	1–2	Belt tra sect, R survey
Pelagic / open ocean	Phytoplankton biomass (chlorophyll-a)	Concentration	µg/L	B2	1–4	MODIS Aqua, Sentine OLCI
Pelagic / open ocean	Fish stock biomass	Exploited stock biomass	tonnes	B2	1–2	RAM L Databa stock assessi
Pelagic / open ocean	Marine mammal abundance index	Survey-based abundance estimate	individuals	B2	2–3	Nationa cetace survey gramm (IWC Scienti Commi framev

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Ecosystem type	Indicator	Variable	Unit	ECT class	Data tier	Protoc referer
Soft-sediment benthos	Macro-invertebrate diversity	Shannon diversity index (H′)	dimensionless	B1	1–2	MOSS benthic survey
Soft-sediment benthos	Macro-invertebrate biomass	Wet or dry weight per area	g/m²	B2	1–2	MOSS benthic survey
Soft-sediment benthos	Biotic integrity index	AMBI or BENTIX score	score	B3	1–2	ICES W protoc
All ecosystems	Non-indigenous/invasive species (NIS)	Relative abundance or occurrence	% / occurrence	B1	1–3	Nationa pro-gramm IUCN

¶2 *NIS indicators should reference EU MSFD Descriptor D2 (Non-indigenous species) for harmonisation in European seas.*[5]

¶3 *Sea urchin density (kelp forest / temperate reef) is an ecosystem state-shift indicator — elevated density signals a phase shift to urchin barrens. Compilers should record it as a supplementary condition variable and flag threshold exceedance rather than rescaling it to a 0–1 indicator on the same basis as canopy cover.*

¶4 **Fish stock biomass (dual-role note):** Fish stock biomass (pelagic/open ocean row) serves a dual role in the SEEA EA framework. When used to characterise the biological condition of a pelagic ecosystem unit (specifically the structural state of the fish community), it is a biological condition indicator (ECT Class B2) and belongs in the ecosystem condition account. When used to track the resource stock as an economic asset, it is a natural resource asset variable belonging in the natural resource sub-account of the asset account. NSO compilers should determine which account context applies before entering the variable, and use the same data source consistently between both accounts where the variable appears in both. Cross-reference TG-6.5 Pelagic and Open Ocean Accounting for the stock account treatment.

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3.2.3 Reference Condition Values

¶1 For each indicator, compilers must identify a reference condition value (the value expected at optimal biological condition) before rescaling. Reference condition values should be derived using the hierarchy described in §3.1.3. Where an empirical reference is unavailable, the approach used and its limitations should be explicitly documented in the metadata. Global products that may assist in setting reference values include:

- ¶2 ReefBase historical coral cover data for coral reef reference conditions
- ¶3 Global Mangrove Watch for mangrove canopy reference values
- ¶4 CMEMS ocean colour climatologies for phytoplankton biomass baselines
- ¶5 OBIS species occurrence archives for pre-impact species richness estimates

¶6 OBIS historical records carry geographic and taxonomic coverage bias. Compilers should assess record density for the accounting unit and supplement with regional literature or expert elicitation where coverage is sparse.

3.3 Measurement Protocols

3.3.1 In-Situ Survey Methods

¶1 **Transect surveys** are the primary method of in-situ biological condition monitoring. Three configurations are standard in ocean environments, summarised in Table 3.3.1.1 below.

Configuration	Description
Belt transects (50 m × 4 m or similar)	Used primarily for counting and measuring reef fish (for fish biomass) and mobile macroinvertebrates. Standard protocol: GCRMN fish survey module. [6]
Line-intercept transects (50 m)	Used for benthic composition, principally live coral cover, dead coral, and other substrate categories. Standard protocol: GCRMN benthic module.
Point-contact method (quadrat or video transect)	50 points or more per quadrat; records benthic composition at each point. Used for seagrass cover (SeagrassNet protocol [7]) and soft-sediment benthos.

¶2 Surveys should be replicated (minimum three transects per habitat stratum per site) and sites georeferenced to WGS84 with at least ±10 m accuracy. Survey data should record observer, time, depth, visibility, and sea state as ancillary variables.

¶3 **BRUVS (Baited Remote Underwater Video Systems):** BRUVS provide standardised, non-destructive estimates of reef fish abundance (MaxN metric — the maximum number of individuals of a species visible simultaneously in a frame) and can be deployed in depths and locations inaccessible to diver surveys. BRUVS data are increasingly accepted as Tier 1 data for fish biomass accounts. Compilers should report MaxN per deployment with standard uncertainty metrics. Where BRUVS and UVC transect data are both available, calibration relationships should be developed to enable time-series comparability.

¶4 **Acoustic methods:** Hydroacoustic biomass surveys (scientific echosounders, 38–200 kHz) are the standard for pelagic fish and zooplankton biomass in open-water environments. Passive acoustic monitoring (PAM) using hydrophone arrays provides abundance and distribution indices for cetaceans and acoustic soundscape indicators. Both methods require specialised expertise. NSOs should explore partnership with fisheries research agencies that operate acoustic survey vessels.

¶5 **eDNA methods:** Environmental DNA (eDNA) sampling provides species detection and community characterisation without physical capture of organisms. Two analytical workflows serve different purposes in biological condition accounts:

- ¶6 **eDNA metabarcoding** (12S rRNA for fish; 16S rRNA for bacteria/archaea; CO1 for invertebrates): identifies the species present in a water sample through sequencing. Metabarcoding provides species detection (presence/absence) and species richness or diversity indices (ECT Class B1). Sequence read counts from metabarcoding are used as occupancy proxies but are not reliable relative abundance metrics without careful calibration — read-count ratios are affected by primer efficiency, extraction yield, and PCR amplification bias. Compilers should not report metabarcoding read counts as abundance without explicit calibration evidence.
- ¶7 **Quantitative eDNA (qPCR or ddPCR with species-specific primers):** provides species-specific eDNA concentration in water, which can correlate with biomass or abundance for target species (ECT Class B2) where calibration studies are available. This workflow requires species-specific primer development and a separate analytical pipeline from metabarcoding.

¶8 Sampling protocols for both approaches should follow OBIS eDNA guidelines. [8] Critical quality controls include: field blank samples (contamination check), positive controls (known-species spike), replication (minimum three water samples per site), and preservation in ethanol or CTAB buffer with controlled-temperature shipping. eDNA data should be deposited in OBIS or GBIF to facilitate cross-account comparison.

3.3.2 Taxonomic Resolution and Invasive Species

¶1 Biological condition surveys should aim for species-level identification wherever feasible. Where species identification is impractical in the field (e.g., cryptic polychaete taxa, small crustaceans), genus or family-level identification is acceptable, provided this is consistent across time-series

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measurements and documented in the metadata. Morphospecies categories (e.g., "encrusting coral morphospecies A") may be used where expertise is limited, but should be flagged as a data quality limitation.

¶2 Non-indigenous species (NIS) should be recorded as a dedicated condition indicator. NIS presence/absence (or relative abundance) is a SEEA EA-recognised biotic pressure indicator and corresponds to EU MSFD Descriptor D2.[5] Where a national NIS database exists, cross-reference occurrence records to validate field identifications. NIS data should also be reported to OBIS where feasible.

3.3.3 Remote Sensing Contributions

¶1 Remote sensing provides spatial coverage for biological condition monitoring that is not achievable with in-situ surveys alone. Key remote sensing products for biological condition include:

- ¶2 **Seagrass and mangrove extent:** Sentinel-2 multispectral imagery (10 m resolution) can map seagrass and mangrove canopy cover with appropriate water column correction and training data. Global Mangrove Watch (JAXA ALOS-2 SAR) provides national mangrove area and canopy cover baselines. Cross-reference TG-4.1 Remote Sensing and Geospatial Data for processing guidance.
- ¶3 **Phytoplankton biomass:** Ocean colour sensors (MODIS Aqua, Sentinel-3 OLCI) provide chlorophyll-a concentration as a proxy for phytoplankton biomass. Monthly composites at 1–4 km resolution are available globally, and regional 300 m resolution products are available for coastal areas. Chlorophyll-a data should be validated against in-situ fluorometry or water samples where feasible.
- ¶4 **Coral reef bleaching and thermal stress:** NOAA Coral Reef Watch Degree Heating Week (DHW) products provide near-real-time and archive thermal stress data that can be used to document bleaching events. Satellite-based bleaching assessment from high-resolution imagery (Planet, WorldView) is emerging as a complement to in-situ bleaching surveys.

¶5 Remote sensing products should be validated against in-situ data before use in accounts. Accuracy assessments should be documented per the QA requirements in TG-0.7 Quality Assurance Principles.

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3.3.4 Citizen Science Integration

¶1 Citizen science data (collected under protocols governed by TG-4.4 Citizen Science and Community-Based Monitoring) may supply biological condition variables including:

- ¶2 Reef fish species occurrence and relative abundance (Reef Life Survey,[9] REEF Volunteer Survey)
- ¶3 Coral condition and bleaching (CoralWatch, Reef Check – trained observer tiers)
- ¶4 Species occurrence records (iNaturalist, eBird marine species)
- ¶5 eDNA water samples (community eDNA programmes)

¶6 Before integrating citizen science data into condition indicators, compilers should apply the quality control tiers defined in TG-4.4 and assess whether the spatial and temporal coverage is sufficient to represent the accounting unit. Where citizen science data are aggregated with professional survey data, the data source should be recorded as a metadata field for each account row.

3.3.5 Biotic Survey SOP References

¶1 The methods above (§3.3.1–3.3.4) describe survey families. Field implementation should follow a published, standardised protocol for the ecosystem × indicator pair being measured. Compilers should cite the SOP applied in account metadata, and document any departure (sample design, gear, replication, taxonomic resolution) against the cited reference. Indicators selected per §3.2 map to the protocols below.

Ecosystem / target	Indicator	Standard protocol	Source
Coral reef benthic	Live coral cover, substrate composition	Line-intercept transect / point-contact	GCRMN Methods Manual (2nd ed., 2021);[6] AIMS Long-Term Monitoring Program[10]
Coral reef fish	Reef fish biomass, species composition	Belt transect (50 m × 5 m) underwater visual census	GCRMN fish module;[6] Reef Life Survey[9]
Coral reef invertebrates	Macroinvertebrate density	Belt transect (50 m × 2 m)	GCRMN invertebrate module;[6] Reef Check[11]
Seagrass meadow	Shoot density, cover, canopy height	Quadrat sampling (0.25 m²) along fixed transects	SeagrassNet Manual (Short et al. 2001)[7]
Mangrove forest	Stem density, basal area, canopy cover	Fixed-area plots (10 m × 10 m or larger)	Kauffman & Donato (2012) CIFOR mangrove protocol[12]
Soft-sediment benthos	Macroinvertebrate diversity, biomass	Grab/core sampling with sieving (≥0.5 mm mesh)	ISO 16665:2014;[13] ICES benthos WG protocols

3.3.6 Quality Control Requirements

¶1 Apply the QA framework in **TG-0.7**. Bio-specific requirements:

- ¶2 **Minimum replication:** at least three transects or quadrats per habitat stratum per site, with stratified design preferred.
- ¶3 **Detection probability** reported for BRUVS (MaxN) and acoustic surveys.
- ¶4 **eDNA contamination controls:** field blank results, positive controls, and replication metadata.
- ¶5 **Observer effect:** inter-observer reliability assessed for visual survey methods.
- ¶6 **Temporal coverage:** annual preferred, biennial accepted where resourcing constrains, and a 3-year rolling average for composite indices to smooth interannual variability.

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3.4 Data Requirements and Sources

3.4.1 Tiered Data Source Hierarchy

¶1 Most national statistical offices, particularly in small island developing states and lower-income coastal countries, will lack systematic in-situ biological monitoring at full national scale. A tiered data source hierarchy allows compilers to identify the best available data for each indicator and to document the quality limitations of lower tiers:

Tier	Data source type	Suitability	Quality flag
1	National monitoring programmes (government agencies, research institutes) with consistent methodology and annual coverage	Preferred; use directly	None
2	Research and academic datasets (OBIS, GBIF, Reef Life Survey database); regional survey programmes	Acceptable with QC	Document temporal/spatial gaps
3	Citizen science programmes (per TG-4.4 protocols)	Acceptable for occurrence, relative abundance	Apply TG-4.4 QC tier; flag observer bias

Tier	Data source type	Suitability	Quality flag
4	Remote sensing proxies (per TG-4.1)	Acceptable for spatial extent, phytoplankton; limited for abundance/biomass	Validate against in-situ; report accuracy
5	Expert elicitation, modelled products, global default values	Last resort; use only where Tiers 1–4 are unavailable	Flag clearly; assess sensitivity

¶2 Where Tier 4 or 5 data are used, the revision log and metadata should record this explicitly and quantify the additional uncertainty introduced.

3.4.2 Variable Data Requirements Table

Variable	Unit	Primary source	Update frequency	Data-poor alternative
Live coral cover	%	GCRMN national surveys, Reef Check	Annual	CoralNet from photo-quadrats
Reef fish biomass	g/m²	UVC belt transects, BRUVS	Annual	RAM Legacy Stock Assessment
Coral bleaching extent	%	Reef Check bleaching survey, CoralWatch	Annual or event-driven	NOAA CRW DHW product (thermal proxy)
Seagrass cover	%	SeagrassNet, national monitoring	Annual	Sentinel-2 remote sensing (TG-4.1)
Seagrass shoot density	shoots/m²	SeagrassNet	Annual	Seagrass cover as proxy (document relationship)
Mangrove canopy cover	%	National forest inventory	Biennial	Global Mangrove Watch (TG-4.1)
Mangrove stem density	stems/ha	National forest inventory	Biennial	Global Mangrove Watch canopy height product
Kelp canopy cover	%	National reef monitoring, REEF survey	Annual	Sentinel-2 near-infrared mapping
Chlorophyll-a (phytoplankton)	µg/L	MODIS Aqua, Sentinel-3 OLCI	Monthly composites	CMEMS biogeochemical reanalysis
Fish stock biomass (pelagic)	tonnes	National stock assessment	Annual	RAM Legacy Database v4.65
Macro-invertebrate diversity (H′)	dimensionless	MOSSCO benthic surveys	Biennial	OBIS occurrence data (modelled diversity)
Marine mammal abundance index	IWC units	National survey programme	3–5 year	IWC Scientific Committee survey programmes (POWER, SOWER, or national equivalent)
NIS occurrence	presence/count	National NIS programme, OBIS	Annual	GBIF occurrence records

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3.4.3 Key Institutional Data Sources

¶1 Compilers should draw on the standard global repositories and monitoring networks for marine biological condition data.[14] See TG-4.6 Data harmonisation for full treatment of inter-source comparability and metadata standards.

3.5 Reporting and Integration

3.5.1 Pathway from Measurement to Delivered Indicator

¶1 The variable → indicator → index pathway, rescaling formulas, and SEEA EA Table 5.2 row format are in **TG-4.8** §3.2 and §3.5. Figure 4.9.1 traces this pathway for biological condition: each biotic ECT class (B1, B2, B3, C1) supplies measured values to a shared condition variable, the variable is ranked against the 5-tier data source hierarchy (§3.4.1), then normalised to an indicator against a documented reference. The indicator is the deliverable. The figure's later stages — aggregation into a class index, and the Table 5.2 row — are shown to place the deliverable in context; they are compiled under **TG-2.1 Aggregate Biophysical Indicators of Environmental State** and **TG-3.1 Asset Accounts** Section 3.5.2 respectively.

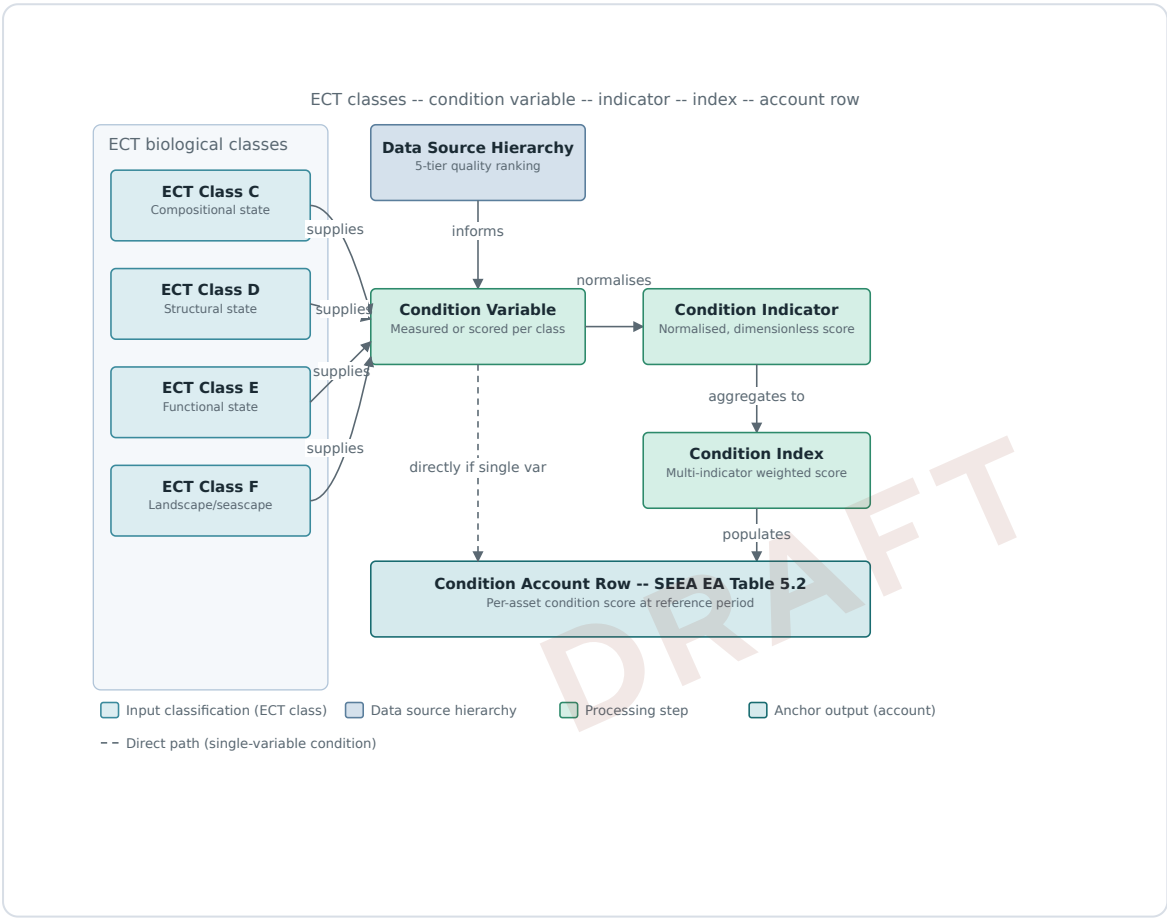


Figure 4.9.1 Four ECT biological classes feed measured values through normalisation and aggregation into a SEEA EA Table 5.2 condition-account row. Classes C--F; 5-tier hierarchy ranks data quality. A single-variable path can bypass indicator and index steps.

Source: TG-4.9, Section 4 (condition measurement pathway); SEEA EA 2024, Table 5.2 (condition variable account structure), paras. 5.30--5.32 (Ecosystem Condition Typology) and 5.60--5.68 (rescaling of condition variables to indicators and indices).

¶2 Worked bio example: live coral cover measured at 24 reef sites, mean = 28%, SE = 4%, reference year 2024. Reference (ReefBase 1990–1999 historical mean) = 55%. Indicator = 28/55 = 0.51, SE = 4/55 = 0.07 (the reference being fixed). That indicator, with its standard error, reference basis and data tier, is what TG-4.9 delivers. Figure 4.9.2 carries the coral-reef core indicator set (§3.2.2) through the same pathway, scoring each indicator per ECT class and then showing the downstream class sub-indices (Class B1 = 0.71, Class B2 = 0.59) and overall Coral Reef Biological Condition Index (0.65). The aggregation weights those composites require are set under **TG-2.1**, not here. Coordinate with **TG-3.1 Asset Accounts** on ECT classification before delivering, so that indicator identifiers match the account's rows.

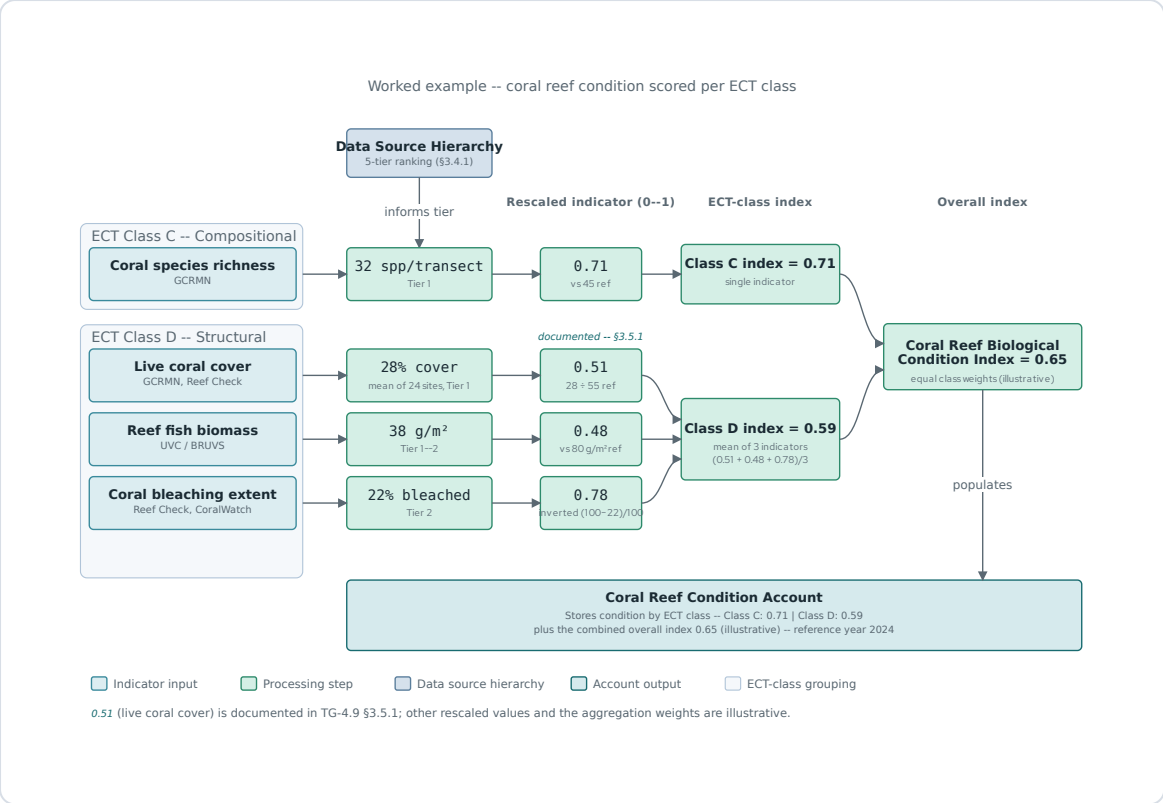


Figure 4.9.2 Coral-reef worked example scores compositional and structural indicators into class sub-indices and an overall biological condition index. Class C and D indicators aggregate per SEEA EA Table 5.2. Non-cover scores and weights are illustrative.

Source: TG-4.9 §3.2.2 (coral-reef indicator set, ECT classes, data tiers), §3.4.1 (5-tier data source hierarchy), §3.5.1 (worked live-coral-cover rescaling), §3.5.3 (account populated by ECT class); SEEA EA (2021), Table 5.2 (condition account structure) and §§5.65--5.75 (reference condition) and §§5.60--5.68 (rescaling to condition indicators). Rescaled values other than live coral cover, and the aggregation weights, are illustrative.

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3.5.2 Integration with Physical Condition (TG-4.8)

¶1 Biological condition indicators should be delivered alongside physical condition variables (compiled per TG-4.8) for the same accounting period. Joint reporting enables attribution analysis: for example, a decline in coral cover (biological) co-occurring with elevated Degree Heating Weeks (physical — thermal stress) supports attribution of the biological change to bleaching pressure. Compilers should flag where biological condition indicators are likely responding to changes in physical condition variables observed in the same accounting period.

3.5.3 Handover to Condition Accounts Compilation

¶1 The biological condition indicators compiled following this Circular supply the ECT Class B1 and Class B2 rows of the ecosystem condition account, which is compiled in **TG-3.1 Asset Accounts** Section 3.5.2. Compilers using TG-3.1 should cross-reference the indicator identifiers used in this Circular's variable table (§3.4.2) with the ECT classification scheme in the account template, to ensure consistent labelling across ecosystem types and accounting periods.

3.5.4 Uncertainty Reporting

¶1 General uncertainty reporting (measurement, representativeness, model) is in **TG-4.8** §3.5 and **TG-0.7**. Bio-specific metadata additions: sampling design SE (transect/quadrat means), detection probability for BRUVS and acoustic surveys, clustering bias in citizen-science data, data-tier flag (§3.4.1), and reference-condition basis. Spatial data follow ISO 19115, and occurrence records follow Darwin Core (OBIS/GBIF).

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

5. References

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3. ¶3 SEEA EA (2021), §§5.46–5.68. The ECT is reproduced in full in Annex 5A.
4. ¶4 SEEA EA (2021), §§5.65–5.75 and Appendix A5.2 (reference-condition framework; see TG-4.8 §3.1 for the canonical write-up).
5. ¶5 European Commission (2008). Marine Strategy Framework Directive (2008/56/EC), Annex I, Descriptor D2 (Non-Indigenous Species).
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3. ¶13 International Organization for Standardization (2014). *ISO 16665:2014 — Water quality — Guidelines for quantitative sampling and sample processing of marine soft-bottom macrofauna*. ISO, Geneva.
4. ¶14 Key institutional data sources include OBIS (Ocean Biodiversity Information System, https://obis.org/ (https://obis.org/)), GBIF (Global Biodiversity Information Facility, https://www.gbif.org/ (https://www.gbif.org/)), IUCN Red List (https://www.iucnredlist.org/ (https://www.iucnredlist.org/)), Reef Life Survey, RAM Legacy Stock Assessment Database (v4.65, https://www.ramlegacy.org/ (https://www.ramlegacy.org/)), GCRMN (Global Coral Reef Monitoring Network, methods manual 2021 ed.), SeagrassNet, and NOAA Coral Reef Watch (v3.1 Daily 5km, https://coralreefwatch.noaa.gov/ (https://coralreefwatch.noaa.gov/)) — see TG-4.6 for full treatment.

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Extending Fisheries Statistics for Ecosystem-Based Management

Provides guidance on extending conventional fisheries statistics to support ecosystem-based management (EBM).

Version 0.9.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on extending conventional fisheries statistics to support ecosystem-based management (EBM) — the coordination of human uses of an ecosystem so that the combined effects do not compromise its function, structure, and capacity to sustain services over time. For ocean accounting purposes, this Circular is specifically concerned with the provisioning-service accounts defined in the SEEA Ecosystem Accounting (SEEA EA) framework and with the EBM indicators that are derivable from those accounts (such as catch composition indices, resource-rent-based effort proxies, and stock-extent linkages). Broader fisheries-stock-assessment EBM frameworks (e.g., fishing mortality relative to Fmsy, spawning stock biomass relative to SSBmsy) are not in scope here but are addressed in TG-1.5 OA and Fisheries Management.

Section 3.8 sets out the fisheries data sources that feed the accounts — catch and landing statistics, stock assessment reports, vessel and licence registries, economic and employment surveys, trade statistics and the intergovernmental series — together with the accounting treatment and estimation of illegal, unreported and unregulated catch, and of subsistence and recreational removals. The management decisions those data support are in TG-1.5 OA and Fisheries Management.

Conventional fisheries statistical systems are built around FAO FishStat capture-production reporting, national logbook and landings registers, and stock-assessment models. These systems are well established for tracking yield and effort, but they do not disaggregate catch to providing ecosystems, value the catch as an ecosystem service flow, or record parallel provisioning flows such as gleaning and aquaculture. By following the candidate workflows in this Circular, statistical compilers may extend their existing systems to deliver ecosystem-attributed catch quantities, and the cost and price series a resource rent calculation needs, at the granularity the provisioning-service accounts require. Those accounts — the physical supply table, the resource rent computation and the monetary supply table — are compiled in TG-3.9 Aquaculture Accounts and TG-6.7 Fisheries Accounting: Integrating Stock Assessment, and support EBM decision use cases including allocation of access rights across competing provisioning flows and ecosystem-aware coastal investment.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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¶1 **Framework Position**

¶2 TG-4.10 sits within Section 4 (Data Methods) and addresses how conventional fisheries statistical systems — typically organised around stock assessment and landings reporting — may be extended to deliver the ecosystem-attributed catch, cost and price variables that provisioning-service accounting requires. It owns those variables and their attribution, tier and uncertainty; it does not own the supply table they populate, the resource rent computed from them, or the fisheries asset account, which are **TG-3.9 Aquaculture Accounts**, **TG-3.1 Asset Accounts** Section 3.3 and **TG-6.7 Fisheries Accounting: Integrating Stock Assessment** respectively. The circular covers four parallel workflows (wild capture, aquaculture cross-reference, gleaning, and wood/NTFP provisioning). EBM indicators derivable from these accounts are introduced in §3.1.

1. Outcome

¶1 This Circular provides guidance on extending conventional fisheries statistics to support **ecosystem-based management (EBM)** — the coordination of human uses of an ecosystem so that the combined effects do not compromise its function, structure, and capacity to sustain services over time. For ocean accounting purposes, this Circular is specifically concerned with the provisioning-service accounts defined in the SEEA Ecosystem Accounting (SEEA EA) framework[1] and with the EBM indicators that are derivable from those accounts (such as catch composition indices, resource-rent-based effort proxies, and stock-extent linkages). Broader fisheries-stock-assessment EBM frameworks (e.g., fishing mortality relative to Fmsy, spawning stock biomass relative to SSBmsy) are not in scope here but are addressed in **TG-1.5 OA and Fisheries Management**.

¶2 Section 3.8 sets out the fisheries data sources that feed the accounts — catch and landing statistics, stock assessment reports, vessel and licence registries, economic and employment surveys, trade statistics and the intergovernmental series — together with the accounting treatment and estimation of illegal, unreported and unregulated catch, and of subsistence and recreational removals. The management decisions those data support are in **TG-1.5 OA and Fisheries Management**.

¶3 Conventional fisheries statistical systems are built around FAO FishStat capture-production reporting, national logbook and landings registers, and stock-assessment models. These systems are well established for tracking yield and effort, but they do not disaggregate catch to providing ecosystems, value the catch as an ecosystem service flow, or record parallel provisioning flows such as gleaning and aquaculture. By following the candidate workflows in this Circular, statistical compilers may extend their existing systems to deliver ecosystem-attributed catch quantities, and the cost and price series a resource rent calculation needs, at the granularity the provisioning-service accounts require. Those accounts — the physical supply table, the resource rent computation and the monetary supply table — are compiled in **TG-3.9 Aquaculture Accounts** and **TG-6.7 Fisheries Accounting: Integrating Stock Assessment**, and support EBM decision use cases including allocation of access rights across competing provisioning flows and ecosystem-aware coastal investment.

2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** — for the conceptual framework
- ¶3 **TG-2.4 Environmental (including Ecosystem) Goods and Services** — for ecosystem service definitions and the indicator context within which provisioning-service accounts are interpreted
- ¶4 **TG-4.3 Administrative Data Sources** — for the use of agency landings, licensing, and logbook registers
- ¶5 **TG-4.5 Integrating Research Data into Official Statistics** — for the integration of fishery-independent research data into accounting systems

¶6 **Related Circulars:**

- ¶7 **TG-3.9 Aquaculture Accounts** — for the parallel cultivated-resource workflow. TG-4.10 provisioning-service supply tables feed into the broader accounts in TG-3.9
- ¶8 **TG-1.5 OA and Fisheries Management** — for the fisheries-management decision context and stock-assessment EBM frameworks
- ¶9 **TG-4.1 Remote Sensing and Geospatial Data** — for the upstream remote sensing methods that underpin habitat-extent data used in the §3.4 data matrix
- ¶10 **TG-6.7 Fisheries Accounting: Integrating Stock Assessment** — for the thematic methods that link the provisioning-service supply tables compiled here to full fisheries asset accounts

3. Guidance Material

3.1 Conceptual Framework

¶1 Conventional fisheries statistics report what was landed — catch by species, gear, and reporting area — and, in more developed systems, what biomass remains through stock assessment models. EBM and ecosystem accounting require two additional dimensions: where the catch came from in ecological terms (which providing ecosystem) and what economic value the providing ecosystem contributed (the resource rent attributable to the natural resource itself, distinct from labour and capital). The SEEA EA framework (Chapter 6) sets out the provisioning-service account structure that organises catch location and economic contribution[1].

¶2 Three related management frameworks use overlapping terminology that this Circular distinguishes. The **Ecosystem Approach to Fisheries (EAF)**, as defined by FAO, extends single-species management to consider interactions between target species, bycatch, and habitat[2]. **Ecosystem-Based Fisheries Management (EBFM)**, as practised under frameworks such as the US Magnuson-Stevens Act, further integrates multi-species dynamics and socio-economic considerations into harvest strategies. **Ecosystem-Based Management (EBM)** is the broadest term, covering the full range of human uses of an ecosystem. This Circular adopts the EBM framing but focuses on the provisioning-service account extensions that support all three approaches, whilst the underlying accounting infrastructure remains the same regardless of which management framework a country employs.

¶3 The EBM indicators that are derivable from the extended accounts described in this Circular include (1) catch composition indices (the share of total provisioning supply attributable to each species group or providing ecosystem), (2) resource-rent trends as a proxy for fishing pressure relative to ecosystem capacity, and (3) cross-account consistency checks between provisioning-service use rates and ecosystem extent or condition accounts. FAO Code of Conduct for Responsible Fisheries principles on economic sustainability[3] provide the normative context for interpreting these indicators.

¶4 The four workflows introduced in the Outcome section are detailed in Sections 3.3–3.6 respectively.

3.2 Extending Existing Statistical Systems

¶1 The starting point for most national compilers is an established FAO FishStat-aligned capture-production reporting system, supplemented by national landings registers, logbooks, port-sampling programmes, and (in better-resourced systems) stock-assessment models[4]. The base system may be extended in three directions: ecological attribution (§3.3), economic attribution (§3.3.2), and coverage extension (§§3.6–3.7). Figure 4.10.1 demonstrates how the three extensions compile into a single SEEA EA provisioning supply-use table, closed by an EBM consistency loop against extent and condition accounts.

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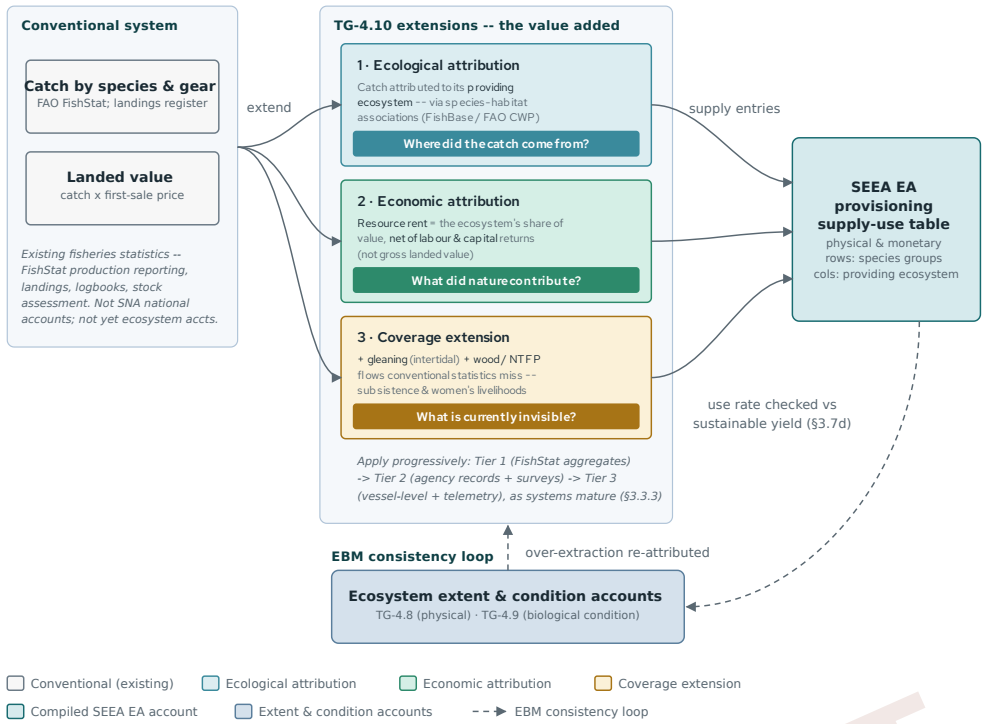


Figure 4.10.1 Fisheries statistics gain ecological and economic attribution plus coverage extension to compile a SEEA EA provisioning supply-use table. Dashed EBM loop checks use rates against extent and condition accounts.

Source: TG-4.10, §3.1 (conceptual framework -- ecological and economic attribution), §3.2 (extending existing statistical systems), §3.3.1 (species x providing-ecosystem physical supply table), §3.3.2 (resource-rent valuation), §3.3.3 (tiered implementation), §3.6 (gleaning), §3.7 (wood / NTFP, incl. §3.7d cross-account consistency), §3.8 (reporting and integration); TG-4.8 / TG-4.9 (extent and condition accounts); SEEA EA (2021) Chapter 6 (provisioning-service supply-use tables).

3.3 Wild-Capture Catch Data

¶1 This section covers the catch data an account needs and where they come from. The supply table those data populate, and the choice of valuation method applied to them, are compiled following **TG-3.2 Flows from Environment to Economy** Section 3.3 and **TG-3.9 Aquaculture Accounts** Section 3.7.2.

3.3.1 Assembling the catch series

¶1 a) Compile total annual landed catch (kg/yr) from the national fisheries authority landings register, FAO FishStat returns, and, where coverage is thin, structured fisher surveys.

¶2 b) Disaggregate by (i) species or species group; (ii) gear type — typical categories include pole-and-line, handline, gillnet, longline, trap, and trawl; and (iii) providing ecosystem, using species-habitat associations (standard sources include FishBase species-habitat associations [5] and the FAO CWP Handbook of Fishery Statistical Standards habitat classifications [6]).

¶3 c) Where landings surveys cover only a fraction of total fishing trips, calibrate survey coverage against provincial or regional statistics to derive an extrapolation factor, and record the factor and its basis in metadata.

¶4 d) Map the spatial distribution of fishing effort using vessel monitoring data, logbooks, or structured fisher reporting.

¶5 The deliverable to the account is catch in kg/yr by species group and providing ecosystem, with its coverage, extrapolation factor and quality tier attached.

3.3.2 Cost data for resource rent

¶1 Resource rent is computed in the account, not here; the resource rent formula and its treatment of a negative residual are in **TG-3.1 Asset Accounts** Section 3.3. What this Circular specifies is the cost data the calculation consumes, which is usually the binding constraint:

- ¶2 Operational expenses (consumables, fuel, maintenance, repairs)
- ¶3 Labour costs, with regional agricultural wages as a documented proxy where direct fisher wage data are unavailable
- ¶4 Capital costs comprising vessel and gear depreciation plus a return on fixed capital at the national weighted-average cost of capital

¶5 Fisher cost surveys are typically run every three to five years rather than annually, so the cost side of the series is usually interpolated between survey years. State the interpolation in metadata.

3.3.3 Tiered implementation

Tier	Catch data	Ecosystem allocation	Cost data
Tier 1	National aggregate statistics (FAO FishStat)	Single global habitat-dependence fraction	Value transferred from comparable contexts
Tier 2	Landings by species and gear from agency records, validated against fisher surveys	Species-habitat literature with local species composition	Domestically sourced fisher cost surveys
Tier 3	Fishery-independent surveys plus logbook data	Acoustic telemetry, otolith microchemistry, or diel habitat use models	Vessel-level production accounts with site-specific capital stock valuation

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¶1 Practitioners may begin at Tier 1 and progress as data systems mature. Value-transfer accuracy is limited, and Tier 1 entries should be flagged in metadata as indicative.

3.4 Data Requirements and Sources

¶1 The following matrix sets out the minimum data items required for each workflow, with typical source agencies, recommended update frequencies, and alternatives for data-poor contexts.

Variable	Unit	Source agency (typical)	Update frequency	Data-poor alternative
Wild-capture fisheries				
Catch by species / species group	kg/yr	National fisheries department; FAO FishStatJ	Annual	FAO-modelled estimates (FishStat global capture production); Sea Around Us reconstructions
Catch by gear type	kg/yr by gear	National logbook system; port-sampling programme	Annual	Gear-composition ratios from FAO CWP national statistics

Variable	Unit	Source agency (typical)	Update frequency	Data-poor alternative
Fishing effort (trips, vessel-days, hook-hours)	Vessel-days/yr, fishing trips/yr, or hook-hours/yr	National logbook system; VMS/AIS records	Annual	Regional effort proxies from RAM Legacy Stock Assessment Database
Catch per unit effort (CPUE) index	kg/vessel-day	Logbook system; scientific observer programme	Annual	Stock-status narrative from FAO SOFIA regional assessment
Stock biomass index	Index or t	Fishery-independent trawl survey; acoustic survey	Periodic (1–5 years)	RAM Legacy SSCOM/CMSY estimates; FAO stock-status categories
Discards and bycatch	kg/yr	Scientific observer programme; video monitoring	Annual	Regional discard fraction from FAO (2019) third global discard assessment
First-sale price by species group	USD/kg or local currency/kg	Fish landing-site price monitors; national statistics office	Annual	Regional price series from FAO GLOBEFISH
Fisher operating costs (fuel, labour, gear, maintenance)	USD/vessel/yr or % of gross revenue	Fisher cost survey; vessel production accounts	Periodic (3–5 years)	Value-transfer from comparable fleet cost studies in same region
Aquaculture				
Production by species and system type (ponds, cages, longlines)	t/yr	National aquaculture authority; national statistics office	Annual	FAO FishStatJ aquaculture-production database
Farm-gate price by species and system	USD/kg	Market price monitoring; national aquaculture authority	Annual	FAO GLOBEFISH aquaculture price series
EBM-relevant indicators				
Prey availability index	Index	Ecosystem monitoring survey; scientific observer programme	Periodic (1–5 years)	Regional forage-fish abundance indices from large marine ecosystem assessments
Predator abundance index (large pelagics, marine mammals)	Index or individuals/km²	Biodiversity monitoring programme; OBIS records	Periodic (1–5 years)	IUCN Red List population trend data
Habitat extent (coral reef, seagrass, mangrove, pelagic zone)	km²	**TG-4.1** / **TG-4.9**; remote sensing	Periodic (3–5 years)	Global habitat databases (Global Mangrove Watch, Allen Coral Atlas)
Gleaning harvest by species group	kg/yr	Household survey; community monitoring	Periodic (2–5 years)	Spatial proxy model using household distance-to-shore and resource density estimates

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Variable	Unit	Source agency (typical)	Update frequency	Data-poor alternative
Wood and NTFP extraction from coastal forests	m³/yr (wood); kg/yr (NTFP)	Household survey; community forestry records	Periodic (2–5 years)	Spatial proxy model calibrated against regional biomass extraction studies

¶2 **Notes on data-poor contexts.** Where national survey data are unavailable, practitioners should use the alternatives listed above as Tier 1 starting points, disclosing the source and any assumptions in metadata. The RAM Legacy Stock Assessment Database[7] provides modelled reference points for a large number of assessed stocks. The Sea Around Us reconstruction methodology[8] provides catch time series for countries with limited official reporting. FAO-modelled estimates are routinely used in official reporting contexts and are acceptable for Tier 1 compilation provided provenance is documented.

3.5 Aquaculture, Gleaning, and Wood and NTFP Provisioning

¶1 Three further provisioning flows share the coastal accounting area with capture fisheries, and a fisheries statistical system is usually the only instrument in a position to pick them up. Their compilation — physical measurement into the account, valuation method, and use-table allocation — is specified once, in **TG-3.9 Aquaculture Accounts** Section 3.7. This Circular covers only what the statistical system must deliver to those accounts.

¶2 **Aquaculture.** Compiled as a cultivated provisioning flow under TG-3.9 Sections 3.2–3.3. The statistical requirement here is reconciliation: cross-check aquaculture output recorded in production accounts against FAO FishStatJ national aquaculture-production figures[9], and collect cultivated and wild-capture volumes on a common species and period basis so that the two can be recorded in adjacent columns of one supply table for trade-off analysis.

¶3 **Gleaning.** Hand-collection of molluscs, crustaceans, echinoderms and seaweeds from intertidal mudflats, reef flats and mangrove edges — a flow that both aquaculture and conventional fisheries statistics routinely miss, despite its weight in coastal household food security and in women's livelihoods. It will not appear in a landings register, so the statistical requirement is a household survey module (see **TG-4.2 Survey Methods**) estimating per-collector annual harvest by target species group, with a spatial proxy model to extrapolate where survey coverage is incomplete. Collect the collector's disposition of the catch — sold, consumed, gifted — because TG-3.9 Section 3.7.3 allocates gleaning distinctly in the use table and cannot do so without it.

¶4 **Wood and NTFP provisioning from coastal forests.** Where the accounting area includes mangroves, fuel wood, building poles, charcoal feedstock, honey, dye and traditional medicine continue to flow from the standing forest. The statistical requirement is per-household extraction, by survey where possible and otherwise by a spatial proxy model calibrated on distance to the mangrove edge, accessible deadwood stock and a literature-derived household demand parameter. Record the parameters and their sources: TG-3.9 Section 3.7.4 requires the implied use rate to be tested against a sustainable yield benchmark and reconciled with the mangrove extent account, which cannot be done from an aggregate volume alone.

3.6 Reporting and Integration

¶1 The four workflows above deliver a common record shape: catch quantity by species group and providing ecosystem, with the allocation parameters, tier and uncertainty attached, and the cost and price series alongside it where they exist. Delivering all four on that shape is what allows them to be assembled into a single provisioning-service supply and use table for the coastal accounting area. That assembly, and the resource rent computation and monetary valuation that go with it, are done in the compiling circulars named below.

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¶2 The catch, cost and provisioning-flow data assembled under Sections 3.3–3.5 are direct inputs to the cultivated-resource accounts in **TG-3.9 Aquaculture Accounts** and the fisheries asset accounts described in **TG-6.7 Fisheries Accounting: Integrating Stock Assessment**. The provisioning-service flows also contribute to ecosystem service indicator analysis described in **TG-2.4 Environmental (including Ecosystem) Goods and Services**. Compilers should document in metadata:

- ¶3 Data sources, vintage, and coverage for each component
- ¶4 Allocation parameters and their sources (species-habitat literature, distance elasticity values, use rates)
- ¶5 Tier of implementation for each sub-procedure
- ¶6 Components flagged as data-deficient or indicative
- ¶7 Cross-account consistency checks performed

3.7 Data Quality and Limitations

Issue	Impact	See also
Limited cost-survey data or low response rates in artisanal contexts	Unreliable resource rent calculation	§3.3.2
Subsistence and gleaning catch poorly captured by formal statistics	Underestimates total provisioning supply	§3.5 (Gleaning)
Species-habitat allocations from regional literature may not reflect local conditions	Mis-attribution to providing ecosystems	§3.3.1
Spatial proxy parameters for wood and NTFP provisioning are literature-derived	Model outputs sensitive to elasticity and use-rate assumptions	§3.5 (Wood and NTFP provisioning)
Temporal mismatch between catch records and accounting period	Misaligned physical account	§3.3.1
Data-poor alternative sources (Sea Around Us, RAM Legacy) carry model uncertainty	Tier 1 entries may have wide confidence intervals	§3.4

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3.8 Fisheries Data Sources and Compilation Considerations

3.8.1 Primary data sources

¶1 Compilation of fisheries accounts typically draws on:

¶2 **Catch and landing statistics:** Recorded by fisheries agencies, port authorities, or fish market operators. FAO collects and publishes global capture and aquaculture production data annually through **FishStatJ** (www.fao.org/fishery/statistics/software/fishstatj (http://www.fao.org/fishery/statistics/software/fishstatj)) [10] . FishStatJ covers capture production and aquaculture output for over 200 countries and territories, disaggregated by species group and FAO major fishing area, with time series typically updated annually with a one- to two-year lag. The database is the primary global benchmark for national catch reconciliation and is freely downloadable as a desktop application. Key limitations include: (a) data are reported at country level on the basis of declared landings and may not reflect unreported or illegal catch; (b) discards are not included in standard production tables and must be estimated separately using observer or logbook data; and (c) government subsidies to the sector are not captured within FishStatJ and require separate compilation from national budget sources or the OECD Fisheries Support Estimate database.

¶3 **Stock assessment reports:** Produced by national fisheries research institutions, regional fisheries management organisations (e.g., WCPFC, IOTC, CCSBT for tuna), or international bodies. The RAM Legacy Stock Assessment Database provides standardised stock assessment outputs.

¶4 **Vessel and licence registries:** Providing data on fishing capacity, effort, and fleet composition.

¶5 **Economic surveys:** Dedicated fisheries economic surveys or general business surveys covering fishing enterprises.

¶6 **Trade statistics:** Customs data on fish imports and exports, compiled according to the Harmonized System (HS) commodity classification.

¶7 **Employment surveys:** Labour force surveys or dedicated fisheries employment surveys.

3.8.2 Species classification

¶1 The Food and Agriculture Organization (FAO) Aquatic Sciences and Fisheries Information System (ASFIS) provides a standard species classification containing over 11,500 species. ASFIS is linked to the International Standard Statistical Classification of Aquatic Animals and Plants (ISSCAAP), which divides commercial species into 50 groups based on taxonomic, ecological, and economic characteristics. For accounting purposes, aquatic resources can be grouped into nine divisions:

1. ¶2 Freshwater fishes
2. ¶3 Diadromous fishes (species migrating between fresh and salt water)
3. ¶4 Marine fishes
4. ¶5 Crustaceans
5. ¶6 Molluscs
6. ¶7 Whales, seals and other aquatic mammals
7. ¶8 Miscellaneous aquatic animals
8. ¶9 Miscellaneous aquatic animal products
9. ¶10 Aquatic plants

3.8.3 Intergovernmental fisheries data sources

¶1 Intergovernmental organisations collect and harmonise fisheries data across countries. Key active sources and initiatives relevant to compiling ocean accounts for fisheries are summarised in Table 3.8.1 below[11].

¶2 **Table 3.8.1: Intergovernmental fisheries data sources and initiatives**

Source	Description
Coordinating Working Party on Fishery Statistics (CWP)	Coordinates global fishery statistical programmes and maintains standards for fishery data collection, processing, and dissemination.
Aquatic Sciences and Fisheries Abstracts (ASFA)	Comprehensive bibliographic database covering aquatic science and fisheries literature.
Fisheries and Resources Monitoring System (FIRMS)	A global partnership that provides access to information on the status and trends of marine resources and fisheries.
FishStatJ	FAO software for retrieving, analysing, and disseminating fishery and aquaculture statistical time series.
GLOBEFISH	FAO programme providing analysis and information on world fish trade, including market trends and price data.

3.8.4 Illegal, unreported and unregulated (IUU) fishing

¶1 IUU fishing presents measurement challenges. The accounting treatment differs depending on whether the illegal catch is by residents or non-residents, and compilers must apply these treatments separately.

¶2 **Illegal catches by residents** (domestic IUU) are still treated as production by the national fishing industry regardless of legality, per SEEA CF para 5.435. They are recorded as gross catch/extraction in the physical asset account and as output in the production account. Residence,

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not legality, determines the production boundary. Where domestic IUU can be estimated, it should be added to reported landings in the gross catch row of the asset account.

¶3 **Illegal catches by non-residents** are recorded as "uncompensated seizures" in the asset account (a separate reductions line), distinguishing them from production by the country's nationals. These represent a transfer of natural capital to foreign operators without compensation, per SEEA CF para 5.436.

¶4 Following these accounting principles, illegal catches by residents should still be recorded as production with income accruing to the fisher[12]. The practical implication: resident IUU must be included in the gross catch figure that flows into the depletion calculation, whilst non-resident IUU appears in the separate "uncompensated seizure" line as shown in the worked example in **TG-1.5 OA and Fisheries Management** Section 3.4.2.

¶5 Estimates of IUU fishing are inherently uncertain but important for understanding true extraction levels and their impact on stock sustainability. Global IUU catch has been estimated at 11–26 million tonnes annually (Agnew et al., 2009), with wide regional variation.

¶6 Countries should develop national IUU estimation approaches appropriate to their data environment and fishery characteristics. Commonly used methods include (1) comparison of reported landings with independent estimates of total removals derived from port sampling, at-sea observer programmes, or vessel monitoring system (VMS) data, (2) stock assessment-based back-calculation, in which the difference between model-estimated total removals and reported catch provides an implied IUU component, (3) trade-based analysis, comparing declared domestic landings with apparent consumption (production plus imports minus exports) to identify discrepancies, and (4) aerial and satellite surveillance data, which can detect unreported fishing activity by matching vessel positions with licence registers. Regardless of the method chosen, IUU estimates should be presented with explicit uncertainty bounds and documented in the metadata accompanying the accounts. Where multiple methods yield different estimates, compilers should report a range and indicate the preferred central estimate[13].

3.8.5 Subsistence and recreational fishing

¶1 Fisheries accounts should encompass all harvesting activity, not only commercial operations. Subsistence fishing for household consumption represents production for own final use. Recreational fishing, whilst not undertaken for commercial purposes, still removes fish from stocks and should be recorded[14].

¶2 These non-commercial catches may require special estimation approaches based on:

- ¶3 Household surveys with questions on fishing activity and consumption
- ¶4 Recreational fishing licence data (where licensing exists)
- ¶5 Creel surveys at popular fishing locations
- ¶6 Proxy indicators based on boat ownership or coastal population

¶7 Small-scale and subsistence fisheries are of particular importance in developing countries and in many GOAP member countries in the Asia-Pacific region, where they may represent a substantial proportion of total catch and provide essential food security and livelihoods for coastal communities. In several Pacific Island States, for example, subsistence and artisanal catches may equal or exceed commercial catches in volume, yet remain largely unreported. Countries compiling fisheries accounts should assess the relative importance of non-commercial catches in their national context and allocate survey resources accordingly. Where full survey programmes are not feasible, countries may consider periodic benchmark surveys at representative landing sites combined with extrapolation methods, integration of fisheries questions into existing multi-purpose household surveys (such as Household Income and Expenditure Surveys), and use of food balance sheet data and per-capita fish consumption estimates to cross-check catch figures. The FAO Guidelines for

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Securing Sustainable Small-Scale Fisheries provide an international framework that can inform the design of data collection strategies for this sector [15].

¶8 These sources feed the physical and monetary asset accounts specified in **TG-3.1 Asset Accounts** Section 3.4.1 and **TG-6.7 Fisheries Accounting: Integrating Stock Assessment**, and the management decisions they support are set out in **TG-1.5 OA and Fisheries Management**.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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Aligning Research Statistical Modelling with Official Statistical Methods

Provides guidance on aligning research-derived statistical models with the concepts and classifications used in official ocean accounts.

Version 0.6.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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ABOUT THIS CIRCULAR

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OUTCOME

This Circular provides guidance on aligning research-derived statistical models with the concepts, classifications, and estimation standards used in official statistical production for ocean accounts. "Alignment" is understood across three operational dimensions:

- Conceptual harmonisation — ensuring that the variables, spatial units, and time periods used in a research model correspond to the definitions and classifications of SEEA EA (e.g., ecosystem asset boundaries, condition variable definitions, service-flow categories as set out in SEEA EA Chapter 5).
- Classification mapping — establishing explicit correspondence between research-model outputs and the account rows, column headings, and measurement units used in extent, condition, and ecosystem services supply-and-use tables.
- Estimator reconciliation — determining whether, and under what conditions, a research-derived point estimate or distribution can substitute for, supplement, or be benchmarked against an official survey-based or design-based estimate.

Compilers who complete this Circular will be able to (a) categorise a candidate research model by type and purpose, (b) apply a structured decision framework to determine how the model's outputs may enter official accounts, (c) specify a validation and uncertainty protocol consistent with the United Nations National Quality Assurance Frameworks (UN NQAF), and (d) document provenance in a way that meets international metadata standards.

Emerging Methods within an Applied Circular

TG-4.11 is classified Applied: it provides practical implementation guidance grounded in established statistical frameworks, whilst several subsections address methods at the methodological frontier where consolidated international guidance is still developing. Specifically, Section 3.2 (reconciliation involving model-assisted estimation), Section 3.3 (Bayesian uncertainty quantification), and Section 3.4 (data requirements for machine learning models) cover Emerging approaches. Compilers applying these methods should treat associated guidance as indicative rather than prescriptive, and should monitor evolving UNECE HLG-MOS and Eurostat methodological publications for updates.

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¶1 **Framework Position**

¶2 TG-4.11 sits at the boundary between research science and official statistical production. It provides the methodological bridge by which NSO compilers assess, validate, and integrate research-derived statistical models into ocean accounts compiled in accordance with the *System of Environmental-Economic Accounting — Ecosystem Accounting* (SEEA EA).[1] Readers should be familiar with quality assurance principles (TG-0.7 Quality Assurance Principles) and research data integration practices (TG-4.5 Integrating Research Data into Official Statistics) before proceeding.

1. Outcome

¶1 This Circular provides guidance on aligning research-derived statistical models with the concepts, classifications, and estimation standards used in official statistical production for ocean accounts. "Alignment" is understood across three operational dimensions:

- ¶2 **Conceptual harmonisation** — ensuring that the variables, spatial units, and time periods used in a research model correspond to the definitions and classifications of SEEA EA (e.g., ecosystem asset boundaries, condition variable definitions, service-flow categories as set out in SEEA EA Chapter 5[1]).
- ¶3 **Classification mapping** — establishing explicit correspondence between research-model outputs and the account rows, column headings, and measurement units used in extent, condition, and ecosystem services supply-and-use tables.
- ¶4 **Estimator reconciliation** — determining whether, and under what conditions, a research-derived point estimate or distribution can substitute for, supplement, or be benchmarked against an official survey-based or design-based estimate.

¶5 Compilers who complete this Circular will be able to (a) categorise a candidate research model by type and purpose, (b) apply a structured decision framework to determine how the model's outputs may enter official accounts, (c) specify a validation and uncertainty protocol consistent with the United Nations National Quality Assurance Frameworks (UN NQAF)[2], and (d) document provenance in a way that meets international metadata standards.

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¶6 **Emerging Methods within an Applied Circular**

¶7 TG-4.11 is classified Applied: it provides practical implementation guidance grounded in established statistical frameworks, whilst several subsections address methods at the methodological frontier where consolidated international guidance is still developing. Specifically, Section 3.2 (reconciliation involving model-assisted estimation), Section 3.3 (Bayesian uncertainty quantification), and Section 3.4 (data requirements for machine learning models) cover Emerging approaches. Compilers applying these methods should treat associated guidance as indicative rather than prescriptive, and should monitor evolving UNECE HLG-MOS and Eurostat methodological publications for updates.

2. Requirements

- ¶1 **TG-0.1 General Introduction to Ocean Accounts** — foundational concepts and scope of ocean accounts
- ¶2 **TG-0.7 Quality Assurance Principles** — UN NQAF quality dimensions and QA protocols applied throughout this Circular
- ¶3 **TG-4.1 Remote Sensing and Geospatial Data** — geospatial and remote sensing inputs that frequently serve as primary data for research models
- ¶4 **TG-4.5 Integrating Research Data into Official Statistics** — broader data integration framework within which research modelling sits

3. Guidance Material

3.1 Conceptual Framework

3.1.1 Research Models in Ocean Accounting

¶1 As used in this Circular, research statistical models are quantitative models developed outside the official statistical production process, typically in academic, government research agency, or international organisation settings, whose outputs are candidates for incorporation into official ocean accounts. They fall into four broad classes:

Research model class	Examples in ocean context	Primary purpose
Ecological process models	InVEST (coastal protection, fishery), Atlantis (ecosystem dynamics), EwE (trophic structure)	Predict ecosystem service flows under scenarios
Spatial-statistical models	Kriging, species distribution models (MaxEnt, BRT), habitat suitability indices	Estimate spatial distribution or abundance from point observations
Econometric models	Hedonic pricing (coastal property values), travel cost (recreation), production function (fishery rent)	Estimate monetary values of ecosystem services; see TG-1.9 Safe Usage of Monetary Valuation
Machine-learning and AI models	Random forests for habitat mapping, neural networks for ocean colour classification	Classification or regression from high-dimensional remote sensing inputs

¶2 The last class, machine-learning (ML) and artificial intelligence (AI) models, is still developing as a basis for official statistics. Where ML methods are applied, compilers should consult the UNECE HLG-MOS guidance on machine learning for official statistics[3], together with the parallel guidance issued by Eurostat[4], FAO[5] and the OECD[6], and treat associated results with hedged uncertainty language pending further methodological consolidation.

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3.1.2 Official Statistical Estimation Paradigms

¶1 Official statistical production relies on established estimation paradigms that carry known statistical properties. Compilers should understand how research model outputs relate to each paradigm:

Official paradigm	Description	Research model role
Design-based	Estimates derived from probability samples; variance from sampling design	Research model can serve as auxiliary variable or domain post-stratifier
Model-assisted	Design-based framework augmented by a working model to improve precision (e.g., GREG estimator)	Research model can supply the working model used for calibration
Model-based (small-area estimation)	Borrows strength across domains using mixed models; Rao-Molina framework[7]	Research model can contribute covariates or specify the linking model
Synthetic and composite	Applies higher-level model to lower-level domains	Research model provides the synthetic component

¶2 The crosswalk between research model class and official paradigm determines the methodological requirements for integration, particularly the extent to which design-based uncertainty estimates remain available to bound the research-model contribution. Anchoring the crosswalk to

SEEA EA Chapter 5[1] and the UN-GGIM Integrated Geospatial Information Framework (IGIF)[8], [9] keeps spatial and temporal resolution decisions coherent with account structure.

> ¶3 **Key Takeaway**
> ¶4 Not all research models can enter official accounts directly. The decision depends on which official estimation paradigm is available and on the bias, variance, and coherence properties of the research model relative to it.

3.2 Reconciling Research and Official Methods

3.2.1 Three-Mode Decision Framework

¶1 When a research-derived estimate is a candidate for inclusion in an official ocean account, compilers should classify the intended mode of use before proceeding with technical validation. Three modes are recognised. The full decision sequence, from mode classification through the four admissibility and governance gates, is summarised in Figure 4.11.1.

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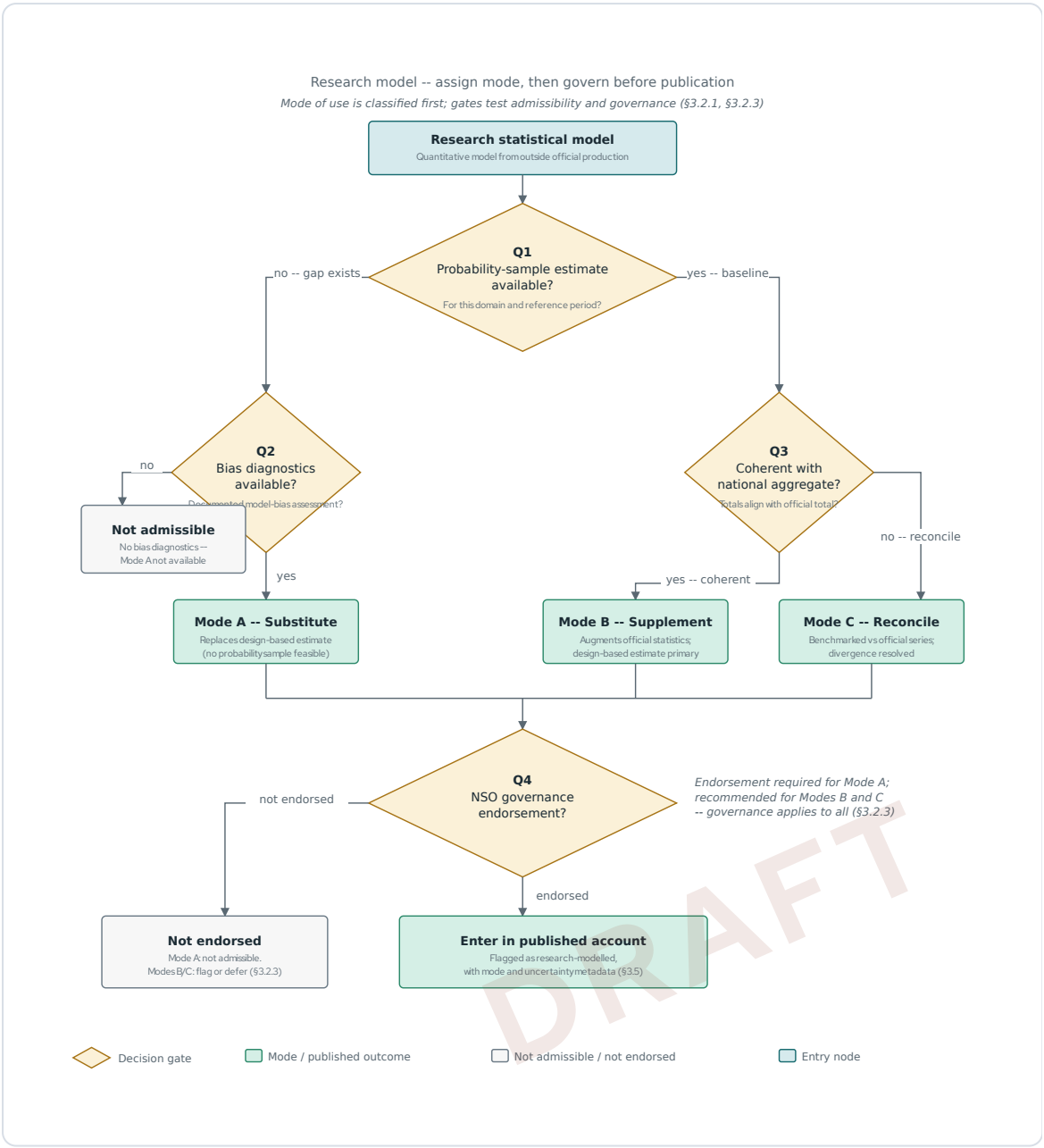


Figure 4.11.1 Four sequential gates route an external research statistical model to Mode A, B, or C use, or to rejection, before NSO endorsement.

Source: TG-4.11 §3.2.1 (three-mode decision framework, steps 1--4 and modes A--C) and §3.2.3 (governance acceptance).

¶2 **Mode A — Substitute.** The research estimate replaces a survey-based or design-based estimate. This is appropriate only when: (i) no probability-sample design is operationally feasible for the domain (e.g., deep-sea extent estimates); (ii) the research estimator has demonstrated negligible bias relative to an independent benchmark or external validator; and (iii) uncertainty is explicitly quantified and disclosed. Substitution requires the highest level of governance endorsement (see Section 3.2.3 below).

¶3 **Mode B — Supplement.** The research estimate is used as an auxiliary variable or covariate within an official design-based or model-assisted estimation framework, improving precision without replacing the probability-sample estimator. The design-based estimate remains the primary figure, whilst the research model improves its precision. This is the most common and least restrictive mode of integration, consistent with established model-assisted survey estimation practice.[10]

¶4 **Mode C — Reconcile.** An independently produced research estimate is benchmarked against an existing official total using temporal or spatial benchmarking techniques. Discrepancies are investigated and resolved, either by adjusting the research series or by flagging the official series for revision. This mode is appropriate when both a research-derived time series and an official survey series exist but diverge, and the compiler must determine which is more reliable for a given period or domain.

¶5 Compilers should apply the following decision sequence:

1. ¶6 Is a probability-sample-based (design-based) estimate available for this domain and reference period? If yes, consider Mode B first. Consider Mode A only where design-based estimates are demonstrably infeasible.
2. ¶7 Does the research estimator have documented bias diagnostics (e.g., cross-validation RMSE, comparison against holdout samples or external benchmarks)? If no, Mode A is not admissible.
3. ¶8 Is the research estimate coherent with any established national or regional aggregate (e.g., does the spatially disaggregated estimate sum to an independently known total)? Where no such aggregate exists, this coherence check should be conducted against the most closely related official or internationally reported figure available (e.g., FAO fishery statistics, regional remote sensing baselines). Document the reference used. Incoherence must be resolved before any mode is finalised.
4. ¶9 Has the NSO methodology committee or equivalent governance body endorsed the use of this model? Endorsement is required for Mode A, and recommended for Modes B and C.

3.2.2 Classification Mapping

¶1 Before entering an account, the research model's output variable must be mapped explicitly to an account row. This mapping should state: (a) the SEEA EA account type (extent, condition, ecosystem services supply, or monetary); (b) the measurement unit and conversion applied; (c) the spatial and temporal scope; and (d) any aggregation or disaggregation step performed. Misaligned classification mapping is a common source of double-counting or scope errors, for example including both a research-derived "coastal protection service flow" and a separately compiled defensive expenditure figure without netting.

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3.2.3 Governance Acceptance

> ¶1 ⓘ **Governance Requirement**
>
> ¶2 A technically valid research model is not automatically eligible for official statistical use. Before a research model's outputs are incorporated into published ocean accounts, the following governance steps should be completed:
>
> 1. ¶3 **Peer review** — the model and its ocean-account application should have been reviewed by at least two independent domain experts not involved in the original modelling, with review documented and accessible.
> 2. ¶4 **Methodology committee endorsement** — the NSO or equivalent statistical authority should record formal endorsement of the model for the specific application and reference period, consistent with the UN Fundamental Principles of Official Statistics (Principle 2: professional standards and scientific principles). [11]
> 3. ¶5 **Replication check** — a second analyst should be able to reproduce the model outputs from the stated inputs and code (see Section 3.4.3 on reproducibility).
> 4. ¶6 **Revision protocol** — a documented plan for updating or replacing the model estimate in future revision cycles, including triggers for re-validation.

3.3 Model Validation and Uncertainty

3.3.1 Validation Framework

¶1 Model validation should be structured around the UN NQAF quality dimensions as the umbrella framework, [2] applied as set out in Table 3.3.1.1 below for research models entering official accounts.

Quality dimension	Application to research models
Relevance	The model's output variable corresponds to the intended SEEA EA account variable (see Section 3.2.2).
Accuracy and reliability	Demonstrated through a documented validation protocol (see Section 3.3.2).
Timeliness	The model reference period aligns with the account reference period; lag between data collection and model output is documented.
Accessibility and clarity	Model documentation, code, and outputs are accessible to account users and auditors (see Section 3.4.3).
Coherence and comparability	Estimates are consistent with related account aggregates and comparable across time and space.
Completeness	Coverage of the domain is stated; gaps are flagged and quantified where possible.

3.3.2 Validation Protocol Requirements

¶1 Every research model submitted for inclusion in official accounts must have a documented validation protocol that addresses, at minimum:

- ¶2 **Internal validation** — at least one form of resubstitution, cross-validation (k-fold), or bootstrap validation on the training dataset, with performance metrics (e.g., RMSE, MAE, R^2) reported.
- ¶3 **Holdout validation** — performance metrics on a withheld test dataset not used in model fitting or tuning. For spatial models, holdout samples should be spatially blocked to avoid spatial autocorrelation inflating apparent accuracy.
- ¶4 **External benchmark** — where an independent dataset or survey estimate exists for any portion of the domain, model predictions must be compared against it. Systematic divergence exceeding an agreed tolerance threshold (e.g., ±10% of the benchmark estimate, or a threshold agreed in the model's validation protocol and recorded in its metadata — see Section 3.5.2) must be investigated before integration.

¶5 Compilers should document the validation protocol in the model's metadata record (see Section 3.5).

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3.3.3 Tiered Uncertainty Reporting

¶1 Uncertainty in research-model estimates must be disclosed in the account record. The following three-tier framework provides minimum standards scaled to NSO analytical capacity:

¶2 **Tier 1 — Expert range (minimum requirement).** The compiler documents a plausible lower and upper bound derived from sensitivity analysis over key model parameters or input assumptions. The range should reflect at least the 10th–90th percentile of expert elicitation or scenario variation. This tier is accessible to all NSOs and constitutes the floor for uncertainty disclosure.

¶3 *Example:* A species distribution model produces a mean coral reef extent estimate of 12,400 ha. Sensitivity runs varying the habitat-suitability threshold between 0.35 and 0.65 produce a range of 10,800–14,100 ha. The account record states: "Estimated extent 12,400 ha (expert range 10,800–14,100 ha; threshold sensitivity)."

¶4 **Tier 2 — Monte Carlo confidence interval (recommended).** The compiler propagates parametric uncertainty through the model using Monte Carlo simulation (minimum 1,000 iterations), producing an empirical distribution of estimates. The 95% confidence interval (2.5th–97.5th percentile) is reported alongside the point estimate. Tier 2 is recommended whenever computational resources permit.

¶5 *Example:* Monte Carlo propagation of parameter uncertainty across 5,000 runs yields a 95% CI of 11,200–13,700 ha. The account record states: "Estimated extent 12,400 ha (95% CI 11,200–13,700 ha; Monte Carlo, 5,000 iterations)." (The Monte Carlo CI is narrower than the Tier 1 expert

range because it propagates only parametric uncertainty around a fitted model, whereas the expert range also captures structural uncertainty from threshold choice.)

¶6 **Tier 3 — Bayesian credible interval (advanced).** For models specified in a Bayesian framework, the posterior predictive distribution is used directly to report credible intervals. Where small-area estimation methods are applied (e.g., Rao-Molina mixed models [7]), the empirical best linear unbiased predictor (EBLUP) and its mean squared error estimate should be reported. Note that Bayesian approaches in marine small-area estimation are still developing — results should be labelled as experimental pending broader methodological consensus.

> ¶7 **Key Takeaway**
> ¶8 Tier 1 uncertainty disclosure is the minimum for any research-model estimate entering an official ocean account. NSOs should progress to Tier 2 as computational capacity allows. Tier 3 is appropriate only where the model is Bayesian by specification or small-area estimation methods are applied.

3.4 Data Requirements and Sources

3.4.1 Mapping Research Data Inputs to Account Rows

¶1 Research models used in ocean accounting draw on a range of input data types. The following table maps common input types to SEEA EA account targets, suitable model classes, and key quality caveats. Compilers should treat this as a starting checklist rather than an exhaustive specification, and should consult TG-4.1 Remote Sensing and Geospatial Data and TG-4.4 Citizen Science and Community-Based Monitoring for source-specific data quality guidance.

Input data type	SEEA EA account type	Suitable model class	Quality caveat
Satellite imagery (optical, SAR)	Extent (habitat mapping); Condition (spectral indices)	Spatial-statistical; ML/AI	Atmospheric correction; cloud cover; sensor drift across time series
Airborne LiDAR / acoustic bathymetry	Extent (reef, seagrass); Condition (structural complexity)	Spatial-statistical	Coverage gaps; temporal mismatch with account period
Ecological field survey (transects, trawls)	Condition (biotic variables); Extent (fine-scale)	Ecological process; spatial-statistical	Survey design may not be probability-based; spatial coverage limited
Citizen science observations	Condition (species presence/absence); Extent (intertidal)	Spatial-statistical (occupancy models)	Detection bias; spatial clustering near access points — see TG-4.4
Oceanographic sensors / Argo floats	Condition (temperature, DO, pH, salinity)	Ecological process; spatial-statistical	Calibration drift; spatial sparsity in coastal zones
Catch and effort logbooks	Flows from environment to economy (fish biomass removal)	Ecological process (stock assessment)	Reporting compliance; misidentification
Stock assessment model outputs (VPA, surplus production, integrated models such as SS3 or MULTIFAN-CL)	Asset accounts (fish biomass stock); Flows from environment to economy (sustainable yield proxy)	Ecological process (stock assessment)	Model uncertainty rarely reported as CI; point estimates common — apply Tier 1 uncertainty disclosure at minimum (see Section 3.3.3)
Household / firm survey data	Ecosystem services (recreation, subsistence, cultural)	Econometric	Recall bias; incomplete market coverage — see TG-4.2

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Input data type	SEEA EA account type	Suitable model class	Quality caveat
Land-use / land-cover change data	Extent change (mangrove, seagrass loss); Condition (disturbance)	Spatial-statistical	Classification accuracy; minimum mapping unit

3.4.2 Minimum Data Quality Standards

¶1 Input datasets must meet minimum quality standards before being used to estimate account values. As a minimum, compilers should document: (a) spatial and temporal resolution and coverage; (b) known biases and their estimated magnitude; (c) calibration and cross-validation status; and (d) licence and access conditions. Where input datasets are derived from citizen science or community monitoring programmes, the additional quality considerations in TG-4.4 apply.

3.4.3 Reproducibility Requirements

¶1 Research models feeding official accounts must be reproducible: a second analyst, given the same inputs and following the same documented steps, should be able to replicate the model outputs within numerical precision. Table 3.4.3.1 below summarises the requirements that apply.

Requirement	Description
Versioned code repository	Model code must be deposited in a publicly or institutionally accessible repository (e.g., GitHub, GitLab, national data repository) and assigned a persistent identifier (DOI or equivalent) that is recorded in the account metadata.
Model card	A structured summary document following the model card template (Mitchell et al. 2019[12]) or an equivalent agreed format should accompany the model, covering: intended use, model inputs, key assumptions, known limitations, and validation results.
Environment specification	The computational environment (software versions, dependencies) should be specified via a container image (e.g., Docker), environment lockfile (e.g., `requirements.txt` , `renv.lock`), or equivalent, so that the model can be re-run in a future revision cycle without dependency conflicts.

¶2 The reproducibility requirements in Table 3.4.3.1 align with the FAIR data principles (Findable, Accessible, Interoperable, Reusable) and with the broader open-statistics agenda reflected in UNECE HLG-MOS guidance.[3]

3.5 Reporting and Integration

3.5.1 Embedding Research-Modelled Values in Official Accounts

¶1 When research-modelled values are incorporated into published ocean accounts, the account record must allow users to identify and trace those values. Transparency serves two purposes. It preserves statistical integrity, since users need to understand what is officially surveyed and what is modelled. It also supports revision management, since modelled values may need updating when a better model or a new survey becomes available.

3.5.2 Minimum Metadata Fields

¶1 Every account cell or table entry that derives partly or wholly from a research model must be accompanied by, or linked to, a metadata record containing at minimum the following fields:

Metadata field	Content required
Source type	"Research model" (distinguishing from "official survey", "administrative data", "expert estimate")
Model identifier	Name, version, and persistent identifier (DOI or URL) of the model and code repository

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Metadata field	Content required
Model card reference	Persistent identifier or location of the model card document
Input datasets	List of primary input datasets with version/date and source identifier
Validation summary	Validation protocol components applied (internal, holdout, external benchmark; Section 3.3.2) and key performance metric(s)
Uncertainty statement	Tier (1/2/3), method, and numerical range or interval (Section 3.3.3)
Reference period	Start and end date of the model's reference period
Spatial scope	Geographic extent and coordinate reference system
Governance endorsement	Date and authority of methodology committee or equivalent endorsement
Revision trigger	Condition under which the estimate will be updated in the next revision cycle

3.5.3 Dissemination Standards

¶1 Account dissemination should apply the international metadata and exchange standards covered in TG-4.6 Data harmonisation.[13] In particular, quality flags should distinguish research-modelled cells from survey-based cells, for example using the SDMX Observation Status code "E" (estimated) or a user-defined code agreed within the national statistical system. Geographic metadata lineage should be completed for all spatially referenced research-model outputs, recording the source datasets, processing steps, and transformation methods applied.

> ¶2 ⚠ **Common Misconception**
> ¶3 Embedding a research-modelled value in an account table without a quality flag or metadata link gives it the same apparent status as a probability-sample-based estimate. This is misleading to users and obscures the revision risk associated with modelled values. All research-model-sourced cells must be flagged.

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4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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3. ¶13 Relevant dissemination and metadata standards include SDMX 3.0 (Statistical Data and Metadata eXchange), ISO 19115-1:2014 (geographic metadata), and the Data Documentation Initiative (DDI) Codebook — see TG-4.6 for full treatment.

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Transboundary Data Sharing and Integration

Enables ocean account compilers to establish data exchange agreements and technical pipelines for acquiring cross-border data on shared marine ecosystems.

Version 0.7.2 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular enables ocean account compilers to establish data exchange agreements and technical pipelines for acquiring cross-border data on shared marine ecosystems, jointly managed fish stocks, and transboundary ecosystem services, and to integrate that data into national SEEA EA accounts. After completing this Circular, a practitioner will be able to: (1) identify the legal basis — including UNCLOS obligations and regional seas conventions — under which their country may share ocean accounting data with neighbouring states; (2) select appropriate metadata and exchange standards (ISO 19115, OGC, SDMX, Darwin Core) for a specific transboundary data flow; (3) design bilateral or regional institutional arrangements that complement the national coordination architectures in TG-4.7 National Data Coordination Architectures; (4) document data received under transboundary agreements in a manner that meets the quality assurance requirements of TG-0.7 Quality Assurance Principles; and (5) report the resulting integrated data to regional seas bodies, global frameworks (SDG 14, Kunming-Montreal Global Biodiversity Framework), and the GOAP central registry.

This Circular extends the national data coordination architecture in TG-4.7 to the international domain. Where TG-4.7 addresses coordination among domestic agencies, the present Circular addresses coordination between countries — including the distinct legal instruments, institutional actors, and technical standards that apply when data cross national boundaries.

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ABOUT THIS CIRCULAR

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¶1 **Framework Position**

¶2 TG-4.12 sits within Section 4 (Data Methods). It owns the acquisition of data across a national boundary: the legal basis under UNCLOS and regional seas conventions, bilateral and regional institutional arrangements, the technical exchange standards a transboundary flow requires, and the documentation and attribution that must accompany data received from another state. It extends **TG-4.7 National Data Coordination Architectures** from the domestic to the international domain. It does not own the accounts that shared data enter; where a shared stock or ecosystem spans a boundary, the accounting treatment of the shared asset is **TG-3.1 Asset Accounts** and, for areas beyond national jurisdiction, **TG-6.6 Deep Sea and ABNJ Accounting**.

1. Outcome

¶1 This Circular enables ocean account compilers to establish data exchange agreements and technical pipelines for acquiring cross-border data on shared marine ecosystems, jointly managed fish stocks, and transboundary ecosystem services, and to integrate that data into national SEEA EA accounts. After completing this Circular, a practitioner will be able to: (1) identify the legal basis — including UNCLOS obligations and regional seas conventions — under which their country may share ocean accounting data with neighbouring states; (2) select appropriate metadata and exchange standards (ISO 19115, OGC, SDMX, Darwin Core) for a specific transboundary data flow; (3) design bilateral or regional institutional arrangements that complement the national coordination architectures in **TG-4.7 National Data Coordination Architectures**; (4) document data received under transboundary agreements in a manner that meets the quality assurance requirements of **TG-0.7 Quality Assurance Principles**; and (5) report the resulting integrated data to regional seas bodies, global frameworks (SDG 14, Kunming-Montreal Global Biodiversity Framework), and the GOAP central registry.

¶2 This Circular extends the national data coordination architecture in TG-4.7 to the international domain. Where TG-4.7 addresses coordination among domestic agencies, the present Circular addresses coordination between countries — including the distinct legal instruments, institutional actors, and technical standards that apply when data cross national boundaries.

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2. Requirements

¶1 **Essential prerequisites:**

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** — for the conceptual framework and core accounting components that transboundary data must feed into.
- ¶3 **TG-4.6 Data Harmonisation and Interoperability** — for the baseline data standards and interoperability protocols applied within and between countries, which TG-4.12 extends to cross-border contexts.
- ¶4 **TG-4.7 National Data Coordination Architectures** — for the domestic institutional arrangements upon which transboundary coordination builds. TG-4.12 is explicitly a cross-border extension of TG-4.7.

¶5 **Helpful background:**

- ¶6 **TG-0.7 Quality Assurance Principles** — for the quality dimensions that must be maintained when integrating externally sourced data into national accounts.
- ¶7 **TG-4.2 Survey Methods for Ocean Economic Activity** — for survey design in shared sea areas, including harmonising survey frames between neighbouring countries.

¶8 **Data requirements:**

- ¶9 Existence of a national ocean accounts focal point or coordinating body with authority to engage in bilateral data exchange discussions.

- ¶10 Access to existing bilateral or multilateral frameworks (treaty, convention, MoU) under which a data exchange channel can be formalised or activated.

¶11 **Legal and institutional requirements:**

- ¶12 National statistical legislation or data sharing policy that explicitly permits sharing of statistical data with foreign counterparts (or a privacy and confidentiality assessment confirming that exchange is lawful).
- ¶13 Identified counterpart agency in partner country with comparable data mandate.

¶14 **Technical requirements:**

- ¶15 Common or mappable spatial reference systems (WGS84 recommended) and agreed temporal reference period.
- ¶16 Metadata standard adopted by both parties. ISO 19115 is the minimum recommended standard for geographic data.

3. Guidance Material

¶1 Ocean accounting is inherently transboundary. Large Marine Ecosystems (LMEs) span multiple jurisdictions[1]. Shared fish stocks cannot be assessed without data exchange between the flag states and coastal states involved, and ecosystem processes — ocean currents, pollution plumes, species migrations — do not respect political boundaries. The SEEA Ecosystem Accounting framework acknowledges that "ecosystem accounting may cover sub-national to supranational domains"[2], implicitly requiring cooperative data input wherever accounting areas straddle national boundaries.

¶2 This section provides guidance across five dimensions: conceptual framing (Section 3.1), governance and legal arrangements (Section 3.2), technical standards for data exchange (Section 3.3), institutional coordination mechanisms (Section 3.4), and reporting and integration (Section 3.5).

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3.1 Conceptual Framework

¶1 "Transboundary" in the ocean accounting context carries three distinct but interrelated meanings, each with implications for what data are needed and how they should be exchanged.

¶2 **Geographic transboundary.** Ecosystems and the resources they host straddle Exclusive Economic Zone (EEZ) boundaries. The Coral Triangle — shared among Indonesia, Malaysia, the Philippines, Papua New Guinea, Solomon Islands, and Timor-Leste — is a canonical example: any single-country coral reef account captures only a fraction of an ecologically coherent system. Shared fisheries stocks (assessed under UNCLOS Articles 63 and 64) and transboundary pollution events similarly require data from multiple national systems for a complete accounting picture. UNCLOS Article 63 covers stocks occurring within the EEZs of two or more coastal states and stocks straddling the EEZ and adjacent high seas. Article 64 covers highly migratory species (such as tuna and billfish) managed primarily through Regional Fisheries Management Organisations (RFMOs). Compilers should route data access requests to the appropriate body: bilateral or sub-regional arrangements for Article 63 straddling stocks, and the relevant RFMO for Article 64 highly migratory species.

¶3 **Jurisdictional transboundary.** Data collected by one state are needed by another to compile accounts. A fishing vessel flagged in State A but landing catch in State B may appear in neither country's accounts without an exchange of vessel monitoring and landing records. Similarly, economic activity data for ocean industries that operate across borders — maritime transport, offshore energy exploration — may be held by the country where the activity is registered rather than the country where the environmental impact occurs. Jurisdictional transboundary data exchange addresses these mismatches between data custody and accounting need.

¶4 **Ecosystem transboundary.** Ecological processes that sustain ocean ecosystem services operate independently of political boundaries. Ocean currents that distribute nutrients, larval dispersal that connects reef systems across EEZs, and migratory species that cycle through the high seas all generate ecosystem services that accrue to multiple countries. Accounting for these services — and for the degradation they may suffer — requires integrating biophysical data from multiple national monitoring systems and, in some cases, from international observation platforms such as Argo floats and the Global Ocean Observing System (GOOS).

¶5 These three senses are not mutually exclusive. A shared mangrove ecosystem (geographic transboundary) may generate carbon sequestration services (ecosystem transboundary) that are relevant to both countries' nationally determined contributions under the Paris Agreement, requiring exchange of both extent and condition data (jurisdictional transboundary). Compilers should identify which sense or senses apply to each data gap they face, as this determines which legal instruments and coordination mechanisms are relevant.

¶6 **Relationship to TG-4.7.** TG-4.7 addresses coordination among domestic agencies — the NSO, fisheries authority, environmental monitoring body, and other national actors that hold relevant data. TG-4.12 extends this to international coordination: the same committee models, data sharing agreement elements, and trust frameworks described in TG-4.7 have regional analogues, but the legal instruments differ (bilateral treaties rather than national MOUs), the institutional actors differ (regional fisheries bodies and regional seas secretariats rather than national line agencies), and the confidentiality regime differs (considerations of national sovereignty alongside statistical confidentiality). Compilers should read TG-4.7 before TG-4.12. This Circular assumes familiarity with TG-4.7's three committee models, trust framework dimensions, and modular implementation phases.

¶7 **SEEA EA boundary-setting.** The SEEA EA permits ocean accounting areas to be defined at any scale, from a sub-national coastal zone to a multi-country Large Marine Ecosystem.[3] Where a country chooses to compile accounts for an LME or shared sea, transboundary data exchange is a structural requirement of the accounting boundary chosen. Countries should therefore clarify their intended accounting boundary (see TG-4.7 Section 3.1 and **TG-0.8 Implementation Readiness Assessment**) before designing transboundary data exchange arrangements, so that exchange agreements are scoped to match the accounting area.

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3.2 Governance and Legal Arrangements

¶1 Transboundary data exchange for ocean accounting operates within a layered architecture of international legal instruments, regional conventions, and bilateral agreements. This section describes that architecture using a tiered framework and identifies the key instruments at each tier.

¶2 **Tier 1 — Global treaty obligations.**

¶3 UNCLOS (UN Convention on the Law of the Sea, 1982) is the foundational instrument[4]. Several provisions create direct obligations or permissions for data sharing relevant to ocean accounting:

- ¶4 *Articles 61–63*: Coastal states must cooperate in the conservation and management of straddling stocks. This obligation creates a legal basis for exchanging stock assessment data, catch records, and effort data with neighbouring states, and provides a ready instrument for including shared fisheries data in national accounts.
- ¶5 *Article 64*: Coastal states and states fishing for highly migratory species must cooperate, directly or through RFMOs, to ensure conservation and optimum utilisation of such species throughout the region. RFMO data access is therefore the primary channel for accounting data on tuna, billfish, and other highly migratory species.
- ¶6 *Article 123*: States bordering semi-enclosed seas (as defined in Article 122 — gulfs, basins, or seas surrounded or nearly surrounded by two or more states and connected to another sea or ocean by a narrow outlet, such as the Mediterranean, Baltic, Caribbean, and Persian Gulf) are required to coordinate the exercise of their rights and duties, including in relation to the protection

of the marine environment. Regional bodies established under Article 123 frequently have associated data sharing protocols that can be activated for ocean accounting purposes. Compilers in open-coast jurisdictions without semi-enclosed sea borders should rely instead on Part XII and RFMO frameworks.

- ¶7 *Part XII (Articles 192–237)*: Obligations to protect and preserve the marine environment include information sharing on pollution events and environmental impacts, and provide a basis for exchanging ecosystem condition data that feeds ocean accounts.
- ¶8 *Part XIII (Article 238–265)*: States and international organisations have the right to conduct marine scientific research, and sharing of research data is encouraged (Article 244). Whilst it does not directly create an obligation to share accounting data, Part XIII provides a permissive legal framework within which accounting data can be shared under scientific cooperation agreements.

¶9 The Agreement under UNCLOS on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement, 2023) introduces new data sharing obligations for marine genetic resources and Environmental Impact Assessments in the high seas.[5] Countries with accounting interests in the high seas or in exclusive economic zones adjacent to areas beyond national jurisdiction should assess the BBNJ Agreement's data provisions as a potential source of both obligations and data flows for ocean accounting. (As of May 2026 the BBNJ Agreement had not yet entered into force. Countries should monitor ratification progress and assess data provision obligations accordingly.)

¶10 The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization (2010, in force 2014) creates obligations for access to and sharing of biological samples and associated genetic resource data.[6] Where ocean accounting extends to marine genetic resources or biodiversity observation data that include genetic resource information — relevant for ecosystem condition accounts in high-biodiversity areas — compilers should assess whether the Nagoya Protocol's access and benefit-sharing provisions apply to the data exchange. The BBNJ Agreement's data sharing provisions build on the Nagoya Protocol framework for areas beyond national jurisdiction.

¶11 The UN Fundamental Principles of Official Statistics (Principle 6) affirms that individual data collected by statistical agencies are confidential[7] and are to be used exclusively for statistical purposes. This principle applies when a country shares statistical microdata internationally, and data sharing agreements must include provisions confirming that statistical confidentiality is upheld by the receiving party.

¶12 **Tier 2 — Regional seas conventions and equivalent bodies.**

¶13 Regional seas conventions provide the most operationally accessible legal framework for transboundary ocean accounting data exchange. Each convention establishes a secretariat, working groups, and often data exchange protocols that can serve as the institutional infrastructure for accounting data sharing:

- ¶14 *OSPAR Convention* (NE Atlantic): OSPAR's Coordinated Environmental Monitoring Programme (CEMP) requires contracting parties to submit environmental monitoring data to the OSPAR Commission[8]. These data streams — covering marine biodiversity, hazardous substances, eutrophication, and radioactive substances — are directly relevant to ocean condition accounts and are already aggregated and quality-assured by the OSPAR Secretariat. Compilers should note that the aggregation is the constraint as well as the service: see §3.5.4 below on requesting regional data at a resolution an account can use.
- ¶15 *HELCOM* (Baltic Sea): HELCOM's COMBINE monitoring programme and its Baltic Sea Environment Fact Sheets provide harmonised environmental data for the Baltic. The HELCOM system is directly applicable to countries compiling accounts for shared Baltic Sea ecosystems[9].

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- ¶16 *Nairobi Convention* (Western Indian Ocean): Covers the coastal and marine environment of East Africa and the Western Indian Ocean island states, and provides a coordination framework for countries such as Kenya, Tanzania, Mozambique, Madagascar, Comoros, Seychelles, and Mauritius.
- ¶17 *Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security* (CTI-CFF): A multilateral partnership among the six Coral Triangle countries providing a platform for harmonised data collection and exchange on reef health, fisheries, and coastal communities[10] — directly applicable to ocean accounting in one of the world's highest-biodiversity marine areas.
- ¶18 *South Pacific Regional Environment Programme* (SPREP) and *Pacific Community* (SPC): These organisations support harmonised environmental and fisheries data collection across Pacific Island countries, and provide data infrastructure that ocean accounting can draw upon.
- ¶19 *Regional Fisheries Management Organisations (RFMOs)*: WCPFC, IOTC, CCAMLR, ICCAT, and equivalent bodies compile and hold stock assessment data, vessel monitoring records, and catch statistics that are directly usable in ocean accounts. RFMOs typically have observer status provisions and data access protocols for member states.

¶20 **Tier 3 — Bilateral and sub-regional agreements.**

¶21 Where global or regional instruments do not provide a sufficient legal basis for the specific data exchange needed, bilateral MOUs or data sharing agreements between countries provide a pragmatic alternative. The elements of such agreements are analogous to those described for domestic data sharing agreements in **TG-4.7 §3.2**, with the following additional considerations specific to bilateral international agreements:

- ¶22 *Scope and reciprocity*: International agreements should specify whether the exchange is reciprocal (both parties provide equivalent data types) or asymmetric (one party provides data the other lacks), and should include provisions for reviewing the scope as accounting programmes mature.
- ¶23 *Confidentiality and national sovereignty*: The agreement must confirm that data exchanged will be used solely for ocean accounting purposes, will not be shared with third parties without consent, and will not be used for regulatory, enforcement, or trade purposes. National sovereignty considerations may mean that certain data (e.g., vessel positions in near-real-time, military maritime activity) are excluded from exchange even when they would be relevant to accounting.
- ¶24 *Dispute resolution*: Transboundary agreements should specify a dispute resolution mechanism — typically through the relevant regional seas secretariat or through diplomatic channels — in the event of disagreements about data quality, interpretation, or use.
- ¶25 *Review and termination*: A defined review cycle (typically three to five years) and a termination clause with appropriate notice period are standard in bilateral data agreements.

¶26 *Table 3.2.1: Governance framework for transboundary ocean accounting data*

Tier	Instrument type	Examples	Data types typically available
1. Global	UNCLOS, BBNJ Agreement, Nagoya Protocol, UN Fundamental Principles	UNCLOS Arts. 61–64, 123	Shared fisheries data, MSR data, pollution event data, genetic resource data
2. Regional	Regional seas conventions, RFMOs	OSPAR, HELCOM, CTI-CFF, WCPFC	Environmental monitoring, catch/effort, ecosystem condition
3. Bilateral	MoU, data sharing agreement	Country-to-country agreements	Any agreed data type, including statistical microdata

3.3 Technical Standards for Data Exchange

¶1 Transboundary data exchange requires both parties to adopt compatible technical standards for data structure, metadata, and transmission. The full catalogue of standards relevant to ocean accounting — spanning geospatial metadata, web service interfaces, statistical exchange, biodiversity occurrence records, and catalogue discovery — is treated in **TG-4.6 Data Harmonisation and Interoperability**. This section identifies only the cross-border-specific requirements that supplement that baseline.[11]

¶2 For transboundary flows specifically, three commitments should be embedded in every bilateral or regional data exchange arrangement: (a) ISO 19115 metadata must accompany every geospatial dataset transferred, so that receiving compilers can assess fitness for purpose before integration, consistent with the quality assurance principles in **TG-0.7 Quality Assurance Principles**; (b) WGS84 (EPSG:4326) and ISO 8601 date-time notation should be used as common reference systems unless a regional authority specifies otherwise, with fisheries data referenced to FAO Major Fishing Areas or ICES statistical rectangles as appropriate to the region; and (c) catalogue records should be registered in the IOC-UNESCO Ocean Data and Information System (ODIS) using DCAT-compatible metadata, which enables partner countries to discover and access data without ad hoc requests.

¶3 Receiving countries should apply the data harmonisation procedures described in **TG-4.6 Data Harmonisation and Interoperability** to all data received under transboundary agreements before integrating them into national accounts. This includes classification concordance where partner countries use different species taxonomies, sector classifications, or spatial aggregation units.

3.4 Institutional Coordination Mechanisms

¶1 TG-4.7 describes three national committee models (NSO-led, multi-agency, nested) through which domestic agencies coordinate ocean accounting data. These models have regional analogues, and the TG-4.7 typology provides a useful reference for understanding the corresponding international coordination structures. The defining difference is authority: at the domestic level, a committee can compel data sharing through statutory mandate or Ministerial direction, whilst at the international level, participation is voluntary. Trust and mutual benefit (as described in TG-4.7 Section 3.3) therefore become even more central to effective coordination.

¶2 **Bilateral Technical Working Groups (BTWGs).** The closest international analogue to the TG-4.7 Model A (NSO-led) bilateral data sharing agreement is the BTWG: a small expert group drawn from the NSO or lead environmental agency of each country, meeting annually to agree data exchange schedules, resolve quality discrepancies, and review data use. BTWGs are most appropriate where two countries share a well-defined accounting area (e.g., a jointly managed strait or shared mangrove coast) and have existing statistical cooperation at the national level. The BTWG should operate under a bilateral MoU (see Section 3.2) that formalises its mandate and data exchange obligations.

¶3 **Regional coordination nodes.** IOC Sub-Commissions (IOCARIBE for the Caribbean, IOCINDIO for the Indian Ocean, WESTPAC for the Western Pacific) provide pre-existing intergovernmental infrastructure for ocean data exchange. These bodies function as a regional analogue to the TG-4.7 Model C (nested) committee, coordinating data flows across many countries through a regional secretariat. Countries should map their existing participation in IOC Sub-Commission activities and assess whether ocean accounting data can be routed through those existing channels rather than requiring new bilateral arrangements. Holdings exposed through the IOC's Ocean Data and Information System (ODIS) can be discovered without a bilateral request at all[12].

¶4 Regional seas secretariats (OSPAR, HELCOM, Nairobi Convention, CTI-CFF, SPREP) serve a similar coordination function within their geographic scope. Their joint monitoring programmes and quality assurance frameworks provide harmonised data that countries can draw upon directly for ocean accounts, reducing the need for country-to-country bilateral exchanges.

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¶5 **Regional Fisheries Management Organisations (RFMOs).** For shared fisheries accounts, RFMOs are the primary institutional coordination mechanism. WCPFC (Western and Central Pacific), IOTC (Indian Ocean), CCAMLR (Antarctic), ICCAT (Atlantic tunas), and their equivalents compile and hold catch and effort data, stock assessment outputs, and vessel monitoring records. Member states have existing obligations to submit data to these bodies and existing rights to access compiled data products. Ocean accounting compilers should engage with their country's RFMO focal points to establish data access arrangements that feed directly into fisheries ecosystem accounts and asset accounts for fish stocks. The guidance in **TG-6.7 Fisheries Accounting: Integrating Stock Assessment** (when available) provides further detail on using RFMO data in national accounts.

¶6 **Data stewardship responsibilities.** In transboundary arrangements, each country retains stewardship of the primary data it generates, whilst regional bodies and bilateral partners hold derived products agreed under the exchange arrangement. Data sharing agreements should specify: (a) which party holds the authoritative version of each dataset; (b) embargo periods before data are made publicly available; (c) attribution requirements when data are used in published accounts; and (d) update obligations — the frequency with which the custodian party will refresh the shared data.

¶7 **Capacity building.** Transboundary data sharing typically requires aligned data collection infrastructure — common survey methods, equipment calibration standards, and metadata practices — before exchange becomes operationally feasible. Capacity building in the transboundary context encompasses three types of support: technical training on the metadata standards and exchange formats specified in Section 3.3; equipment harmonisation for joint surveys where two countries collect biophysical data in a shared sea area under a coordinated protocol; and staff exchanges that transfer institutional knowledge about data systems and compilation practices between partner organisations. Capacity gaps should be documented explicitly in the bilateral MoU rather than left as informal intent: the agreement should identify which party (or which external programme) will address each gap and within what timeframe, so that capacity asymmetry is managed as a scheduled workplan item rather than left as an open risk. The GOAP Secretariat is the primary entry point for accessing GOAP-funded technical assistance. Countries may also engage IOC capacity development initiatives (including the IOC Ocean Teacher Global Academy) and the capacity-building provisions of the relevant RFMO. Unequal capacity between partners that is not explicitly addressed frequently causes transboundary data exchange to default to one-directional flows that do not sustain long-term cooperation.

¶8 This architecture is illustrated in Figure 4.12.1.

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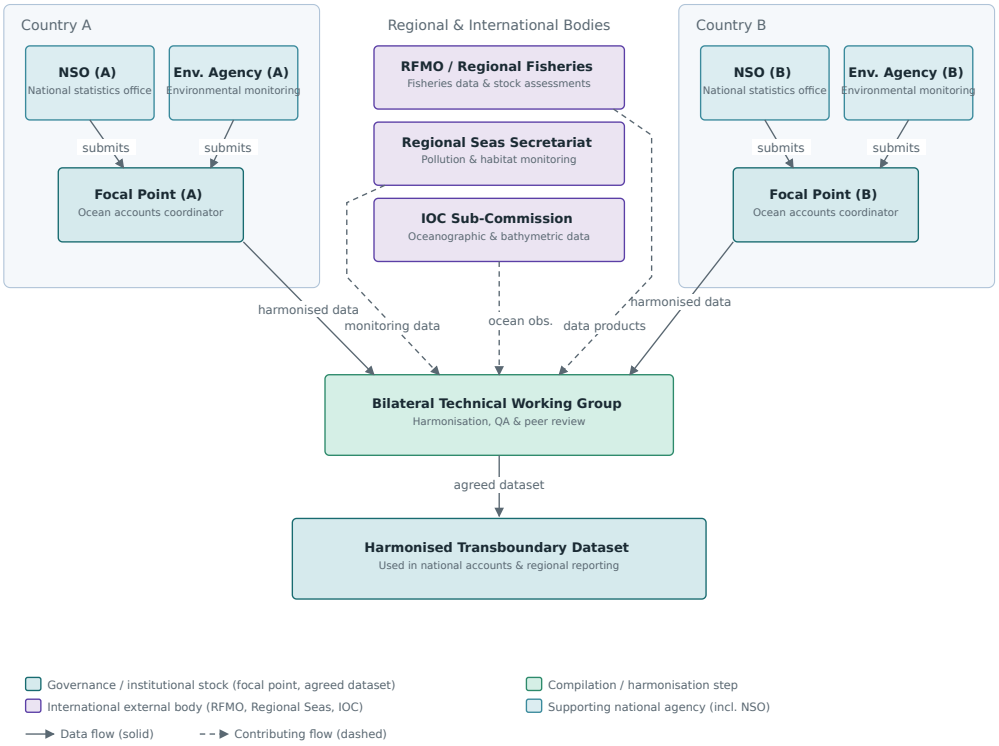


Figure 4.12.1 Two countries and three international bodies feed a bilateral TWG that produces one harmonised transboundary ocean-accounts dataset. Teal marks governance stocks; violet marks international bodies. National routes run through each Ocean Accounts Focal Point.

Source: TG-4.12 draft, §3.4 (institutional coordination mechanisms) and §3.5 (reporting and integration).

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3.5 Reporting and Integration

¶1 Data received under transboundary agreements serve three distinct reporting purposes, each with different output requirements. This section addresses all three in sequence.

¶2 **Section 3.5.1 Regional aggregation of national ocean accounts.**

¶3 Regional seas bodies and sub-regional groupings increasingly request harmonised ocean accounting data from member states for regional environmental assessments. OSPAR's Quality Status Reports, HELCOM's State of the Baltic Sea reports, the CTI-CFF Regional State of the Coral Triangle Report, and SPREP's State of the Pacific Ocean report all require country-level data that can be aggregated regionally. Countries should align the spatial boundaries, temporal reference periods, and account classifications used in their national ocean accounts with the regional reporting requirements of the bodies of which they are members.

¶4 Alignment reduces rework: where a country has designed its ocean accounts to be compatible with regional reporting requirements, the same account tables can serve both national and regional purposes. Countries should consult regional seas secretariats early in the ocean accounting design process to understand reporting templates and data submission requirements.

¶5 GOAP maintains a central data registry for member country ocean accounts. Countries with transboundary data exchange arrangements should notify the GOAP Secretariat of those arrangements so that cross-country accounting boundaries are correctly reflected in the registry and to

avoid double-counting where the same shared ecosystem is reported by two countries. GOAP reporting templates for shared ecosystem accounts should align with the partner country's national account submissions. The GOAP Secretariat provides harmonisation guidance for countries compiling accounts that overlap geographically.

¶6 **Section 3.5.2 Global frameworks.**

¶7 Three global frameworks make direct use of transboundary ocean accounting data:

- ¶8 *SDG 14 (Life Below Water)*: Indicators 14.2.1 (use of ecosystem-based approaches in managing marine areas), 14.4.1 (proportion of fish stocks within biologically sustainable levels), and 14.5.1 (coverage of protected areas) all require data that may be held by RFMO or regional monitoring systems rather than individual national agencies.[13] Countries with shared fish stocks or transboundary MPAs should use their RFMO and regional seas data exchange channels to access the indicator inputs they cannot compile from national data alone.
- ¶9 *Kunming-Montreal Global Biodiversity Framework (GBF)*: Target 3 (30x30 — 30% of areas under effective conservation by 2030) requires area-based accounting for marine protected areas that often straddle EEZ boundaries.[14] The GBF monitoring framework specifies the indicators and data requirements that countries must align with when contributing transboundary MPA data.[15] Transboundary MPA accounting should draw upon the joint monitoring programmes of regional seas conventions and IOC sub-commissions.
- ¶10 *IPBES and IPCC*: The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services and the Intergovernmental Panel on Climate Change both request national and regional ecosystem accounting data for global assessments. Transboundary data exchange that feeds national ocean accounts simultaneously enriches these global scientific processes.

¶11 **Section 3.5.3 Integration into national accounts.**

¶12 When data received under a transboundary agreement are incorporated into national ocean accounts, compilers must apply three additional steps beyond those required for domestic data:

¶13 *Harmonisation*: Apply the classification concordance and unit standardisation procedures in **TG-4.6 Data Harmonisation and Interoperability** to all received data before integration. This is particularly important for fisheries statistics, where species classification systems (FAO ASFIS, national systems), spatial aggregation units (FAO areas, ICES rectangles, national EEZ zones), and reporting periods may differ between countries.

¶14 *Lineage documentation*: Per the quality assurance requirements of **TG-0.7 Quality Assurance Principles**, all externally sourced data must be documented with: the originating country and custodian agency; the legal basis for the exchange (treaty article, MoU reference, or RFMO data access agreement); the version and vintage of the data received; any transformations applied during harmonisation; and known limitations or data quality caveats. This lineage documentation should be published as part of the national accounts metadata in accordance with the transparency requirements of the UN Fundamental Principles of Official Statistics.

¶15 *Attribution*: Published accounts should acknowledge the contributing country or regional body where data received under a transboundary agreement contributes materially to a published indicator or account table. Attribution builds trust and encourages continued data sharing (see TG-4.7 Section 3.3 on trust frameworks).

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¶16 **Worked Examples**

¶17 **TG-5.7 Thailand** and **TG-5.10 Vietnam** illustrate the institutional and technical arrangements through which two ASEAN countries aligned their fisheries accounting data for the Gulf of Thailand, including an RFMO-mediated data exchange and bilateral harmonisation of catch classification systems.

¶18 **TG-5.3 Fiji** and **TG-5.9 Vanuatu** demonstrate Pacific Island country cooperation on coral reef ecosystem accounting across shared reef systems, using the Pacific Community (SPC) as a regional data node and IOC-WESTPAC monitoring data as the primary ecosystem condition input.

¶19 Both case studies are on hold pending Section 5 content development. Compilers should consult the GOAP Secretariat for interim worked examples.

¶20 **Section 3.5.4 Requesting regional data at a resolution the account can use.**

¶21 Regional bodies publish condition information in the geometry their own assessment cycle requires, which is normally an aggregate for the convention area and its sub-regions. An ecosystem account needs the same measurements attributed to ecosystem types. The two geometries are not interchangeable, and the mismatch defeats a condition account even where the underlying monitoring is long-running and dense.

¶22 The preliminary ecosystem accounts for the OSPAR maritime area are the documented case. OSPAR holds extensive time series through ODIMS and publishes condition indicators — acidity, eutrophication, species diversity, sea surface temperature, seagrass cover, fish stock state — through its Quality Status Reports, several of them already aligned with this Technical Guidance. The condition account nonetheless could not be compiled, because the indicators were published as aggregates for the convention area and its five regions and could not be disaggregated to the ecosystem types used in the extent account. The compilers' recommendation was that regional data collection and reporting shift from a region-based to an ecosystem-based approach, and that the regional data platform carry that harmonisation on behalf of the parties[16].

¶23 Two practical consequences for a compiler requesting data from a regional body:

- ¶24 *Ask for the observations, not the indicator.* A published regional indicator is generally a terminal product: aggregated, and often not reversible to the station or grid cell it came from. Request the underlying station, survey or grid-level measurements with their coordinates and dates, and derive the ecosystem-type attribution nationally. Where only the aggregate can be released, record it as a condition indicator for the region under **TG-2.1 Biophysical Indicators** and do not enter it against an ecosystem type in the condition account.
- ¶25 *Raise reporting geometry with the secretariat, not just data access.* A data sharing agreement that secures the existing regional product still leaves the account uncompilable. The change a regional accounting programme needs is in the monitoring and reporting design, which sits with the convention's technical working groups; countries that require ecosystem-attributed condition data should carry that requirement into those groups alongside the bilateral access arrangements described in §3.2.

¶26 The same point applies in reverse to the alignment argument in §3.5.1: a country designing its national ocean accounts to serve regional reporting should confirm that the regional templates request ecosystem-attributed data, and should not assume that satisfying a region-based reporting template will produce data usable in a regional ecosystem account.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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Coral Reef Ecosystem Accounting

Provides guidance on compiling ecosystem accounts for coral reef ecosystems within the SEEA Ecosystem Accounting framework.

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on compiling ecosystem accounts for coral reef ecosystems within the SEEA Ecosystem Accounting framework. Coral reefs are among the most extensive coastal and marine ecosystem types globally.

Coral reef accounts support four priority decision contexts: MPA effectiveness monitoring (tracking condition changes inside protected areas relative to baseline); tourism carrying capacity analysis (quantifying visitor use relative to ecosystem condition); bleaching damage quantification for insurance (valuing condition losses from mass bleaching events to support parametric insurance products — the Section 3.4 subsection on reef accounts and disaster risk financing sets out the damage-formula and DHW linkage); and reef restoration return on investment (comparing restoration costs against expected service value gains). These functions connect to the policy processes in TG-1.3 OA and Marine Spatial Management.

The accounting framework here provides the foundation for TG-6.4 Kelp Forest and Temperate Reef Accounting and TG-6.5 Pelagic and Open Ocean Accounting. Valuation methods follow TG-1.9 Valuation, spatial data inputs draw on TG-4.1 Remote Sensing and Geospatial Data, and asset account structures follow TG-3.1 Asset Accounts. Biophysical indicators are addressed in TG-2.1 Biophysical Indicators.

Framework Position

This Circular owns the extent, condition, service and asset accounts for IUCN GET M1.3 photic coral reefs, and the reef-specific judgements a compiler cannot take from the generic method: the catastrophic-loss criterion for bleaching mortality, the conversion-versus-condition test, and the climate-adjusted service trajectory.

It cross-refers for the account structure and the degradation and NPV identities (TG-3.1), extent mapping (TG-4.1), condition measurement protocols (TG-4.8, TG-4.9), service classification (TG-2.4) and valuation principles (TG-1.9).

Three boundaries are easy to cross by accident. Cold-water and deep-sea coral ecosystems (M3.4, M3.5) are TG-6.6. Submerged artificial structures are M4.1 and belong to TG-6.9 Section 3.5.2, even when colonised by reef-building corals. The produced-asset side of coastal protection is TG-6.11; this Circular records the protection service flow.

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ABOUT THIS CIRCULAR

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1. Outcome

¶1 This Circular provides guidance on compiling ecosystem accounts for coral reef ecosystems within the SEEA Ecosystem Accounting framework. Coral reefs are among the most extensive coastal and marine ecosystem types globally.

¶2 Coral reef accounts support four priority decision contexts: **MPA effectiveness monitoring** (tracking condition changes inside protected areas relative to baseline); **tourism carrying capacity analysis** (quantifying visitor use relative to ecosystem condition); **bleaching damage quantification for insurance** (valuing condition losses from mass bleaching events to support parametric insurance products — the Section 3.4 subsection on reef accounts and disaster risk financing sets out the damage-formula and DHW linkage); and **reef restoration return on investment** (comparing restoration costs against expected service value gains). These functions connect to the policy processes in **TG-1.3 OA and Marine Spatial Management**.

¶3 The accounting framework here provides the foundation for **TG-6.4 Kelp Forest and Temperate Reef Accounting** and **TG-6.5 Pelagic and Open Ocean Accounting**. Valuation methods follow **TG-1.9 Valuation**, spatial data inputs draw on **TG-4.1 Remote Sensing and Geospatial Data**, and asset account structures follow **TG-3.1 Asset Accounts**. Biophysical indicators are addressed in **TG-2.1 Biophysical Indicators**.

¶4 ⓘ **Framework Position**

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¶6 It cross-refers for the account structure and the degradation and NPV identities (**TG-3.1**), extent mapping (**TG-4.1**), condition measurement protocols (**TG-4.8**, **TG-4.9**), service classification (**TG-2.4**) and valuation principles (**TG-1.9**).

¶7 Three boundaries are easy to cross by accident. Cold-water and deep-sea coral ecosystems (M3.4, M3.5) are **TG-6.6**. Submerged artificial structures are M4.1 and belong to **TG-6.9** Section 3.5.2, even when colonised by reef-building corals. The produced-asset side of coastal protection is **TG-6.11**; this Circular records the protection service flow.

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2. Requirements

¶1 This Circular requires familiarity with **TG-0.1 General Introduction to Ocean Accounts**, **TG-3.1 Asset Accounts**, **TG-1.9 Valuation**, and **TG-4.1 Remote Sensing and Geospatial Data**. Readers should also be familiar with **TG-2.1 Biophysical Indicators** (for the condition variables in Section 3.2) and **TG-2.4 Environmental Goods and Services** (for the service classification in Section 3.3).

¶2 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 Coral reef ecosystems are classified within the IUCN Global Ecosystem Typology as **M1.3 Photic coral reefs** (Marine Shelf biome, M1)[1], [2]. The SEEA EA treats coral reefs as **ecosystem assets**: contiguous areas of a specific ecosystem type delineated "based on the areas of the different ecosystem types associated with the seabed, for example, seagrass meadows, subtidal sandy bottoms and coral reefs"[3], [4].

¶2 This section examines extent accounting (Section 3.1), condition assessment (Section 3.2), ecosystem services (Section 3.3), and valuation methods (Section 3.4). Section 3.5 provides the com-

pilation procedure and Section 3.6 presents a worked example. Account linkages are illustrated in Figure 6.1.1[5].

¶3 This Circular focuses exclusively on photic (warm-water) coral reefs classified under IUCN GET M1.3. Cold-water and deep-sea coral ecosystems differ from photic reefs in their ecological characteristics, depth distributions, and data requirements. Such ecosystems include those classified under M3.5 (Deepwater biogenic beds) and those found on M3.4 (Seamounts, ridges and plateaus). Accounting for deep-sea ecosystems, including cold-water coral formations, is addressed in **TG-6.6 Deep Sea and ABNJ Accounting**.

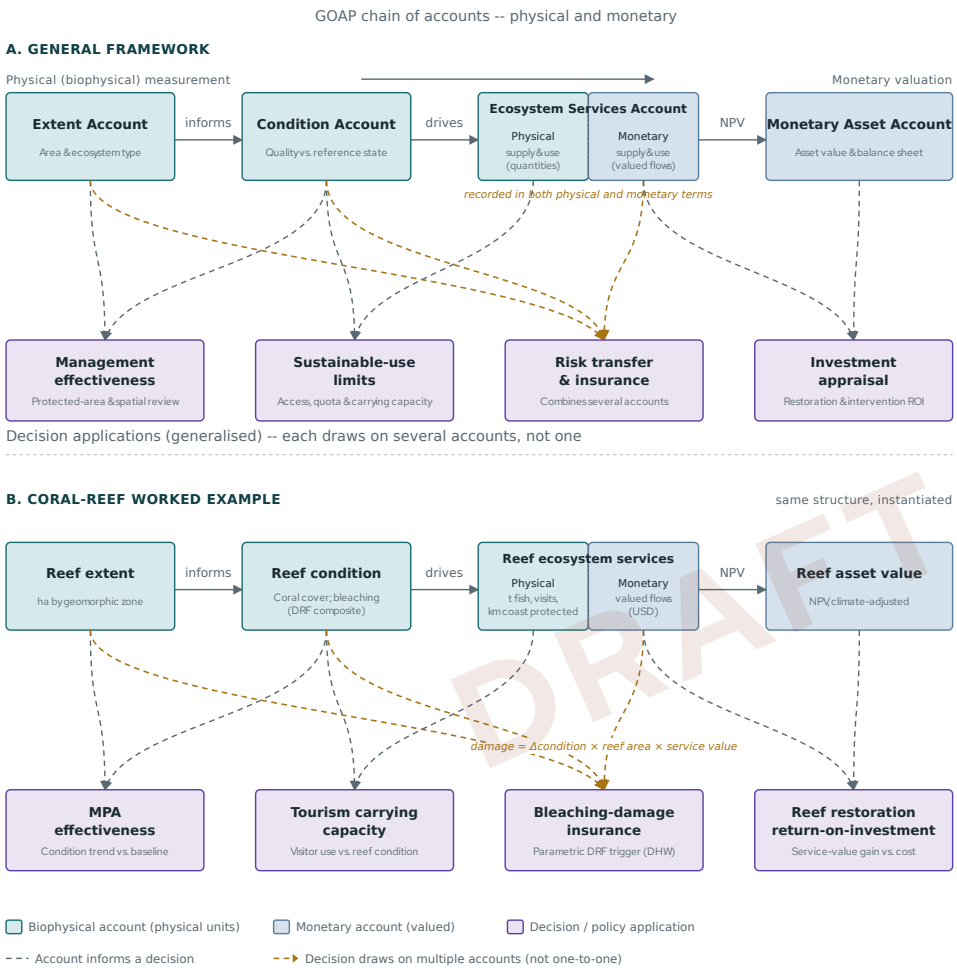


Figure 6.1.1 Two-panel GOAP account chain: Extent informs Condition, which drives Ecosystem Services into the Monetary asset account; Panel B instantiates coral reefs. Decision applications draw on several accounts, not one-to-one.

Source: TG-6.1, Section 1 (decision contexts), Sections 3.1--3.4 (account chain), 3.4 reef-accounts-and-disaster-risk-financing (damage formula), Table 3 (physical and monetary services columns); account-chain logic consistent with SEEA EA 2021, Chapter 4 (extent), Chapter 5 (condition), Chapters 6--7 (ecosystem services, physical and monetary supply-and-use), Chapters 9--10 (monetary valuation).

3.1 Extent Accounting

¶1 Ecosystem extent accounts record the total area of each ecosystem type within an ecosystem accounting area (EAA), along with additions and reductions during the accounting period[6].

For coral reefs, extent is typically measured in hectares or square kilometres of reef surface area. Accurate delineation of reef extent provides the foundation for condition assessment and services quantification.

¶2 The asset account structure presented in **TG-3.1 Asset Accounts** applies directly to coral reef ecosystem assets. The key accounting entries (opening stock, additions, reductions, and closing stock) capture changes in reef extent over the accounting period.

Mapping coral reef extent

¶1 Coral reef extent mapping combines remote sensing with in-situ validation[7]. Primary approaches: (1) **satellite imagery** – the Allen Coral Atlas (v2.0, 2022) provides standardised reef mapping at ~5 m resolution globally, whilst Landsat and Sentinel-2 provide recurring observations (see **TG-4.1 Remote Sensing and Geospatial Data** for processing guidance); (2) **aerial photography and drone surveys** – for patchy reefs and complex geomorphology (see **TG-4.2 Survey Methods**); (3) **bathymetric surveys** – acoustic and LiDAR for three-dimensional structure; (4) **in-situ surveys** – dive transects, manta tows, and drop cameras for validation. Document data sources, resolution, and temporal coverage to ensure reproducibility.

Classification within IUCN GET

¶1 Coral reefs are classified as **M1.3 Photic coral reefs** within the IUCN Global Ecosystem Typology (Marine Shelf biome, M1). For the GET realm/biome/EFG hierarchy and the national crosswalk obligation, see **TG-4.1 Remote Sensing and Geospatial Data** Section 3.2.4.[8]

¶2 For national accounting purposes, coral reef ecosystem types may be further disaggregated based on geomorphological class (fringing, barrier, atoll, patch), depth zone (reef flat, reef crest, fore-reef slope), or dominant benthic community (hard coral dominated, soft coral dominated, algal dominated)[9], following SEEA EA paragraphs 3.22-3.24[10].

Disaggregation by geomorphic zone

¶1 Where reef geomorphic zones (fringing, barrier, atoll rim, patch) face materially different pressures or provide distinct service profiles, condition and service accounts should be compiled separately for each zone. Fringing reefs typically experience higher sediment and nutrient pressures from terrestrial runoff, whilst outer barrier and patch reef positions experience greater thermal exposure and wave energy. Where land-based sediment or nutrient pressure on fringing reefs is documented in national monitoring data, separate fringing-reef condition accounts are recommended even where data for other zones are aggregated. Where data do not support zone-level compilation, a single spatially aggregated condition score is acceptable, but the aggregation approach and its implications for hiding inter-zone heterogeneity should be documented in account metadata so that downstream users can interpret the composite indicator appropriately.

What is coral-specific about the extent account

¶1 The account structure – opening extent, managed and unmanaged additions and reductions, the reclassification block, and the closing identity – is the standard one and is set out once in **TG-3.1 Asset Accounts** Section 3.5.1[11]. A worked coral reef extent account appears at Section 3.6 below. What follows is only what a compiler must decide differently for reefs.

¶2 **Additions** are primarily unmanaged (natural growth and recovery). Managed expansion (coral gardening, larval enhancement) typically represents small additions[12]. Placed artificial structures are **not** an addition to M1.3 extent, even where corals colonise them: they are a distinct ecosystem type, IUCN GET M4.1 Submerged artificial structures, and are recorded in their own extent entry under the rule in **TG-6.9 Offshore Energy Thematic Methods** Section 3.5.2, which owns the treatment of submerged artificial structures for this publication. Recording the same hectares as both M1.3 and M4.1 would double-count them. **Reductions** may be managed (coastal development, dredging, land reclamation) or unmanaged (storm damage, bleaching-induced mortality, chronic

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degradation). Climate-driven bleaching mortality is classified as an unmanaged reduction because it is not the result of a deliberate management decision[13].

¶3 Bleaching-induced mortality should be recorded as a **catastrophic loss** in the extent account, rather than a routine unmanaged reduction, when both of the following procedural criteria are satisfied: (1) the mortality is attributable to a discrete, identifiable thermal stress event, as identified by NOAA Coral Reef Watch degree heating week (DHW) alerts at Alert Level 1 or higher over the reef area; and (2) the event is documented in peer-reviewed literature or national monitoring reports as exceptional — that is, not part of routine expected annual losses. Gradual mortality that cannot be attributed to a single discrete event is classified as an unmanaged reduction. This procedural rule follows the SEEA CF definition of catastrophic losses as "large-scale, discrete and recognizable events" that are unexpected and exceptional[14]. No published standard (SEEA CF, SEEA EA, GCRMN, NOAA, IUCN) specifies a quantitative percentage mortality threshold for the classification, and the guidance here is therefore indicative.

Restoration interventions

¶1 Coral gardening, larval enhancement and substrate stabilisation produce managed additions to extent and, where successful, condition gains. Where the intervention is a nature-based solution, its counterfactual tier, survival adjustment, permanence risk and lifecycle cost are recorded in parallel under **TG-6.15 Ocean Accounting for Nature-based Solutions** Section 3.2. Reef restoration has among the lowest recorded survival rates of any marine restoration type, so the survival adjustment in that Circular's Section 3.4 does material work here and an extent entry taken at planted area will overstate the gain.

Reef conversions

¶1 Reef conversions are recorded in the reclassification block of the extent account (**TG-3.1** Section 3.5.1, Table 2b), not in a separate change matrix[15]. The transitions that matter for reefs are coral reef to algal-dominated rubble after a mortality event, coral reef to seagrass meadow, and degraded reef to recovering reef. A reef that loses live coral but retains its carbonate structure and is still classified M1.3 has changed **condition**, not type, and belongs in Section 3.2 rather than here — this is the judgement compilers most often get wrong, because the ecological loss feels like a conversion.

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3.2 Condition Assessment

¶1 Ecosystem condition accounts record the quality or health of coral reef ecosystems relative to a reference condition. The SEEA EA defines condition as "the quality of an ecosystem measured in terms of its abiotic and biotic characteristics"[16]. The principles for selecting and interpreting biophysical indicators are addressed in **TG-2.1 Biophysical Indicators**. This section applies those principles to coral reefs. The measurement protocols for the variables themselves — how each is observed, at what frequency and to what tolerance — are owned by **TG-4.8 Physical Condition Measurement** and **TG-4.9 Biological Condition Measurement**; this Section selects and interprets them for photic coral reefs.

Condition variables for coral reefs

¶1 The SEEA EA organises condition variables within the Ecosystem Condition Typology (ECT). Table 3.2.1 maps ECT classes to reef-relevant variables[17].

ECT class	Reef-relevant variables
Class A1: Physical state	Abiotic characteristics (water temperature, pH, turbidity, dissolved oxygen).
Class A2: Chemical state	Nutrient concentrations, pollutant levels, aragonite saturation state.

ECT class	Reef-relevant variables
Class B1: Compositional state	Species composition, functional diversity, presence of indicator species.
Class B2: Structural state	Coral cover, rugosity, reef accretion rates.
Class B3: Functional state	Primary productivity, nutrient cycling, bioerosion rates.
Class C1: Landscape and seascape characteristics	Connectivity, patch size, fragmentation.

¶2 The following variables are recommended for coral reef condition assessment[18]. Reference levels are indicative, and compilers should adapt them to regional baselines (Caribbean, Indo-Pacific, Red Sea conditions differ substantially).

¶3 Table 2 includes a **Direction** column flagging whether each variable is "standard" (higher value = higher condition) or "inverse" (higher value = lower condition). Both normalisation formulas are defined in **TG-2.1** Section 3.4.1. Compilers must check the Direction column before applying the formula.

Condition variable	ECT class	Direction	Measurement approach	Reference level guidance
Live hard coral cover (%)	B2 Structural	Standard	Transect surveys, remote sensing	Upper: historical baseline (preferred) or 40% (default); Lower: 5%
Coral species richness	B1 Compositional	Standard	Species inventories	Reference site diversity
Fish species richness	B1 Compositional	Standard	Visual census surveys	Reference site diversity
Herbivore fish biomass (kg/ha)	B2 Structural	Standard	Underwater visual census	Upper: 50 kg/ha; Lower: 5 kg/ha
Macroalgae cover (%)	B2 Structural	Inverse	Transect surveys	Upper (good): 5%; Lower (poor): 40%
Coral recruitment density	B3 Functional	Standard	Settlement tile surveys	Regional norms
Reef rugosity index	B2 Structural	Standard	Chain intercept, 3D photogrammetry	Upper: 2.0; Lower: 1.2
Bleaching prevalence (%)	A1 Physical state	Inverse	Bleaching surveys	Upper (good): 0%; Lower (poor): 50%
Water quality index	A2 Chemical	Standard	Water sampling	Jurisdiction standards
Aragonite saturation state	A2 Chemical	Standard	Carbonate chemistry	Upper: 4.0; Lower: 3.0

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¶4 *Table 2: Condition variables for coral reef ecosystems. The Direction column indicates whether the standard or inverse normalisation formula (defined in **TG-2.1** Section 3.4.1) should be applied.*

Reference levels and condition indicators

¶1 For coral reefs, reference conditions may be established based on the four options summarised in Table 3.2.2 below.

¶2 **Table 3.2.2: Reference condition options for coral reef ecosystems**

Reference type	Description
Historical baselines	Documented reef condition from historical records, photographs, or palaeoecological evidence (e.g., pre-1950 baseline).
Contemporary reference sites	Condition observed at minimally impacted reference reefs within the same biogeographic region.

Reference type	Description
Scientific thresholds	Ecologically meaningful boundaries such as the 30% coral cover threshold commonly associated with reef functionality and ecosystem service provision.
Policy targets	Condition levels consistent with management objectives (e.g., national marine park standards).

¶3 Regional variation requires context-specific reference level selection [19]. For live hard coral cover, a site-specific historical baseline is the preferred upper reference where pre-disturbance data exist. The default 40% applies when no historical data are available. Document the data source, survey year, and spatial coverage in account metadata.

Aggregation and weighting of condition indicators

¶1 Indicator-level scores are combined into a composite condition index following the principles described in SEEA EA paragraphs 5.77–5.88, which discuss weighted averaging and other combination methods [20]. For coral reefs specifically, peer-reviewed literature treats live hard coral cover (B2 Structural) as the primary structural indicator of reef condition [21]. Where expert ecological judgement is available, live hard coral cover should be assigned the largest single weight in the composite index, indicatively at least 0.30, with the remaining weight distributed across compositional, functional, and other structural indicators according to local management priorities. Where expert weighting is not feasible, equal weighting is acceptable as a documented default. The weighting approach (whether expert-derived, equal, or PCA-derived) is a methodological choice that materially affects the composite score, and should be documented in account metadata alongside the rationale for any departure from equal weights.

¶2 **Two-composite framing for routine reporting versus disaster risk financing.** Compilers should maintain two composite variants where reef accounts are used to support disaster risk financing (DRF) applications. The **routine composite** (live hard coral cover, herbivore fish biomass, macroalgae cover, and reef rugosity, with the weights described above) is appropriate for general reporting on reef condition. It excludes bleaching prevalence. A composite score derived under routine weights therefore will not respond to a bleaching event, and is not suitable for any application that uses the damage formula Damage = (Condition_pre − Condition_post) x area x unit service value (see the Section 3.4 subsection on reef accounts and disaster risk financing). For DRF applications, a **DRF-composite** that includes bleaching prevalence (or post-bleaching mortality) alongside the four routine variables must be used. Indicative weights for the DRF-composite are: live hard coral cover 0.30, bleaching prevalence 0.20, and the three remaining variables (herbivore fish biomass, macroalgae cover, reef rugosity) 0.167 each, summing to 1.000 (0.30 + 0.20 + 3 x 0.167 = 1.001, with one of the 0.167 terms rounded down to 0.166 so the displayed weights sum to exactly 1.000). Compilers may adjust these weights provided live hard coral cover retains the primary weight and bleaching prevalence carries a non-trivial weight, so that the composite index responds materially to bleaching events.

Bleaching as a condition indicator

¶1 Coral bleaching is the expulsion of symbiotic zooxanthellae in response to thermal stress, and is a primary condition indicator for reefs [22], [23]. Bleaching may be recorded using any of the four metrics in Table 3.2.3.

Metric	Description
Bleaching prevalence	Percentage of colonies affected.
Bleaching severity	Degree of tissue colour loss using standardised colour charts.
Post-bleaching mortality	Percentage of colonies that died following bleaching.
Recovery status	Return to baseline coloration following bleaching.

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¶2 NOAA Coral Reef Watch provides satellite-derived bleaching alerts and degree heating week (DHW) products that can be integrated with in-situ monitoring data [24].

¶3 Where bleaching leads to substantial mortality, it may also be recorded as a **catastrophic loss** in extent accounts following the two-criterion procedural rule in Section 3.1 [25].

Structure of condition accounts

¶1 Condition accounts may be presented at the three levels of aggregation summarised in Table 3.2.4 below [26].

Account level	Description
Variable accounts	Tracking individual condition variables over time (SEEA EA Table 5.3).
Indicator accounts	Presenting normalised indicators derived from variables (SEEA EA Table 5.4).
Index accounts	Aggregating indicators into composite condition indices (SEEA EA Table 5.5).

¶2 The aggregation approach should follow the weighting guidance above and the principles in SEEA EA paragraphs 5.77–5.88.

3.3 Ecosystem Services

¶1 Ecosystem services accounts record flows from coral reef ecosystems to economic units and households [27]. The methodology for identifying and measuring services is in **TG-2.4 Environmental Goods and Services**.

¶2 ⓘ **Recording rule — coastal protection service**

¶3 This Circular is the recording point for the coastal protection service supplied by coral reefs. **TG-6.11 Coastal Infrastructure Accounting** Section 3.3.2 records the produced-asset side — the capital cost and depreciation of engineered and hybrid works — and cross-refers here for the service; it does not estimate a second protection value for the same area. **TG-6.15** Section 3.8 supplies the method for comparing the two.

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Provisioning services

¶1 **Fisheries provisioning** — Coral reefs support fisheries for reef fish, invertebrates (lobster, sea cucumber, trochus), and associated pelagic species [28]. The ecosystem service is the reef's contribution to fish production, distinct from human inputs (fishing effort, gear, vessels). Key physical metrics: fish biomass on reefs (kg/ha), sustainable yield estimates (tonnes/year), actual retained catch (tonnes), and species composition. For fisheries accounting detail, see **TG-6.7 Fisheries Accounting: Integrating Stock Assessment**.

¶2 **Genetic and biochemical resources** — Coral reef organisms provide sources of pharmaceuticals, cosmetics, and other biochemical products. Whilst difficult to quantify, these potential services represent option value for future applications.

¶3 **Ornamental resources** — Live coral, reef fish, and other organisms collected for the aquarium trade represent a distinct provisioning service flow. Physical units should follow CITES trade database conventions (see Section 3.3 services account, Table 3): live ornamental fish in number of specimens, and live ornamental corals and invertebrates in number of colonies or kg.

Regulating services

¶1 **Coastal protection** — Coral reefs attenuate wave energy, reducing coastal erosion and flood risk [29], [30]. The value of this service depends on reef extent, condition, and the exposure of coastal assets. Degraded reefs provide less wave attenuation than healthy reefs [31]. Physical metrics: wave energy attenuation (% reduction in wave height), avoided damage costs (currency/year), length of coastline protected (km), and population in protected zones.

¶2 **Water quality regulation** — Reef ecosystems contribute to water quality regulation through several distinct biological and physical mechanisms, which should be disaggregated in Table 3 rather than reported under an ambiguous single "volume filtered" entry:

1. ¶3 **Sponge-mediated biofiltration** — Reef sponges actively pump and filter water, and remove dissolved and particulate organic matter through the "sponge loop". Quantification follows the indicative metric "sponge biofiltration rate (L/h/m²) x reef area". The metric draws on per-individual pumping-rate measurements scaled by sponge density from benthic surveys. No internationally standardised reef-area-normalised protocol is currently published, so this metric should be reported as indicative and the underlying density and pumping-rate sources documented in account metadata.
2. ¶4 **Turbidity reduction** — Wave attenuation and particle trapping in reef structures reduce water-column turbidity over the reef and adjacent seagrass beds. This sub-service is quantifiable as the difference in nephelometric turbidity units (NTU) across a reef cross-section.
3. ¶5 **Nutrient uptake** — Coral symbionts and other reef autotrophs assimilate dissolved nutrients, with quantification through mass-balance approaches.

¶6 Compilers should select the sub-service(s) that match available monitoring data and avoid the unqualified "volume filtered" unit, which is more appropriate to oyster and seagrass systems than to coral reefs [32].

¶7 **Carbon cycling** — Coral reefs are widely considered net carbon sources at the ecosystem scale because calcification releases CO2, even though photosynthesis by zooxanthellae, associated seagrass beds, and algal turf can sequester carbon over short timescales [33], [34]. There is no default presumption of net sequestration for coral reefs, and net flux entries implying net uptake require site-specific evidence. Compilers should not transfer the blue-carbon sequestration presumption from mangrove/seagrass systems (see TG-6.2 Mangrove and Coastal Wetland Accounting) to reef accounts.

¶8 For accounting purposes, compilers should avoid combining reef carbon into a single ambiguous figure and should instead record it as **two distinct entries**:

- ¶9 A **stock** entry: carbon stored in the reef framework structure (tC), recorded in the asset/balance sheet at opening and closing of the accounting period.
- ¶10 A **flow** entry: net annual carbon flux (tC/year) attributable to the combined effects of calcification (release) and net photosynthetic production (uptake), reported with an explicit sign convention (positive = net uptake by the reef, negative = net release to the atmosphere).

¶11 Where the net annual flux is negative (the reef is a net CO2 source over the period), the negative value must be recorded as a negative service flow rather than suppressed or reset to zero, so that monetary valuation does not systematically overstate reef carbon services. The monetary value applied to the flux entry uses an explicit carbon price source, typically the domestic emissions trading scheme price where one exists, or the national social cost of carbon. That price source must be documented alongside the entry.

Cultural services

¶1 **Recreation and tourism** — Coral reefs support diving, snorkelling, and coastal tourism [35], [36]. Physical metrics: visitor numbers (annual person-visits), trip expenditure attributable to reef access, consumer surplus, and recreation days. See valuation in Section 3.4 (simulated exchange value method) [37].

¶2 **Cultural heritage and spiritual values** — Traditional fishing grounds, spiritual sites, and elements of cultural identity are recorded qualitatively or through participatory valuation.

¶3 **Education and research** — Research expenditure and educational outcomes attributable to reef access.

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Structure of services accounts

¶1 Ecosystem services flow accounts record the quantity and, where feasible, the monetary value of services provided during the accounting period [38]:

Ecosystem service	Physical quantity	Physical units	Monetary value (USD thousand)
Provisioning services			
– Reef fisheries	750	tonnes	2,250
– Ornamental fish (live trade)	11,500	number of specimens	60
– Ornamental corals and invertebrates (live trade)	1,200	kg (or number of colonies)	25
– Genetic resources	(qualitative)	(qualitative)	(not valued)
Regulating services			
– Coastal protection	42	km protected	8,200
– Water quality regulation: sponge biofiltration	1,200	sponge biofiltration rate (L/h/m²) x reef area, ML/yr equivalent	120
– Water quality regulation: turbidity reduction	8	NTU reduction across cross-section	40
– Water quality regulation: nutrient uptake	18	tN/yr	20
– Carbon cycling: stock (reef framework)	32,400	tC stored (balance sheet entry)	(stock, not flow)
– Carbon cycling: net annual flux	-150	tC/yr (positive = net uptake; negative = net release) [39]	-8
Cultural services			
– Recreation and tourism	115,000	person-visits	4,950
– Cultural and spiritual	(qualitative)	(qualitative)	(not valued)
– Education and research	(qualitative)	(qualitative)	(not valued)
Total valued service flows			**15,657**

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¶2 *Table 3: Structure of ecosystem services flow account for coral reefs with illustrative synthetic values (adapted from SEEA EA Table 7.1). Ornamental species are reported in two sub-rows aligned with CITES trade database conventions [40]. Carbon cycling is split between a stock balance-sheet entry and an annual flux flow entry, with negative flux values retained rather than suppressed.*

3.4 Valuation Methods

¶1 Monetary valuation follows the exchange-value preference hierarchy in **TG-2.4 Environmental (including Ecosystem) Goods and Services** Section 3.10 and **TG-3.2 Flows from Environment to Economy** [41], [42]. The applicable methods for coral reef services are summarised below.

Valuation of ecosystem services

¶1 **Fisheries services** – Resource rent (gross revenue minus costs of labour, capital, and other inputs) [43]. For the worked example derivation, see Section 3.6 Step 3. For small-scale fisheries where the input-subtraction method yields near-zero or negative resource rent, apply the net price method (SEEA EA para. 9.42) and document the comparator source. See **TG-6.7 Fisheries Accounting** for the fisheries-specific application.

¶2 **Tourism and recreation** – The tourism expenditure this draws on is compiled as an industry segment in **TG-6.14 Marine and Coastal Tourism Accounting**; a compiler running both should take the

reef-attributable expenditure from that segment rather than estimating it twice. For accounting purposes, methods yielding exchange values consistent with SNA principles are preferred [44], [45]. Applicable approaches: market-based methods (tourism expenditure and producer margins), travel cost methods, contingent valuation, and simulated exchange values.

¶3 **Simulated exchange value for reef tourism.** "Simulated exchange value" as used in reef tourism accounting refers to a specific construct from SEEA EA Chapter 9. It equals the tourism-related expenditure attributable to reef access multiplied by the reef ecosystem share of the tourist experience:

> *Simulated exchange value = (Tourism expenditure attributable to reef access) x (Reef ecosystem share)*

¶4 The **reef ecosystem share** is estimated by subtracting the value of human-provided services to reef tourists (accommodation, transport, guiding services, gear hire) from total reef-related tourist expenditure and attributing the residual to the ecosystem. This residual approach ensures that the recorded value reflects only the ecosystem's contribution rather than the gross tourism turnover. The simulated exchange value derivation is set out in SEEA EA paras. 9.52–9.59 [46]. Compilers unfamiliar with this construct should not substitute gross visitor expenditure (which overstates the ecosystem contribution) or consumer surplus (which is a welfare measure not consistent with the exchange-value basis of the accounts).

¶5 **Coastal protection** — Avoided damage cost methods compare expected damages with and without the reef [47]. These methods require hazard modelling, exposure mapping, vulnerability assessment, and scenario comparison. Alternative approaches: replacement cost (engineered equivalents such as seawalls) and hedonic pricing (property value premiums).

¶6 **Non-use values** — Non-use values (existence, bequest, option) fall outside the exchange-value scope of the SEEA EA [48] but may be compiled as complementary welfare estimates (stated preference methods) in supplementary tables, clearly distinguished from core account entries. See **TG-1.9 Valuation** for the exchange-value/welfare-value distinction.

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Valuation of ecosystem assets

¶1 The NPV method for ecosystem assets, the discount-rate choice, the perpetuity-or-finite-horizon decision, the rule that the condition adjustment is applied **once** at the service-flow step, and the degradation identity are all set out in **TG-3.1 Asset Accounts** Section 3.5.3, and are not restated here [49], [50], [51]. Restoration cost as a complement to NPV is covered in the same place [52], [53].

¶2 What is reef-specific is the **service trajectory**. A stable-flow NPV that assumes service flows continue at the opening-period level for the whole projection horizon will substantially overstate the asset value of reefs facing documented bleaching risk under IPCC AR6 warming scenarios: reefs are among the few ecosystem assets for which a published, quantified condition decline is already available at national scale. Where a bleaching risk assessment exists — NOAA Coral Reef Watch projections, national climate scenarios, regional downscaled models — use it to project the condition trajectory forward and derive a declining service flow, rather than applying a perpetuity to the opening-period flow.

¶3 Two consequences follow. Present the climate-adjusted NPV **and** the stable-flow baseline, the latter as a sensitivity scenario, noting that the climate-adjusted estimate is a prudent lower bound for accounting purposes. And record the condition trajectory used, its source and the projection horizon in account metadata, because the trajectory is doing more work in the reef asset value than the discount rate is.

Reef accounts and disaster risk financing

¶1 Reef accounts directly support **parametric insurance** and other disaster risk financing instruments for bleaching damage, an application identified in the Outcome section. The monetary damage from a discrete bleaching event is calculated by combining the condition account with the services account:

> *Damage = (Condition_pre − Condition_post) x Reef area x Annual service value per unit area*

¶2 where Condition_pre and Condition_post are the composite condition index scores immediately before and after the bleaching event, Reef area is the affected extent (ha), and Annual service value per unit area is drawn from the services account in Section 3.3. This damage estimate can serve as the indemnity in parametric insurance products where NOAA Coral Reef Watch **degree heating week (DHW)** thresholds are used as the trigger: for example, Alert Level 1 (4 DHW) for moderate bleaching and Alert Level 2 (8 DHW) for severe bleaching with widespread mortality risk[54]. Compilers intending to use reef accounts for insurance purposes should align the bleaching prevalence condition variable in Table 2 with the DHW trigger levels used in the relevant insurance product, so that the condition-based damage estimate and the parametric trigger refer to the same underlying ecological event. Existing reef insurance products (e.g., the Quintana Roo Coastal Zone Management Trust) demonstrate the operational feasibility of this approach[55].

¶3 The Condition_pre and Condition_post values used in the damage formula must be drawn from the **DRF-composite** introduced in Section 3.2 (which includes bleaching prevalence or post-bleaching mortality), not the routine four-variable composite used for general condition reporting. A routine composite that omits bleaching will not respond to a bleaching event, so substituting it into the damage formula would yield Condition_pre approximately equal to Condition_post and an indemnity of zero regardless of the severity of the underlying ecological loss. Use of the DRF-composite for any insurance, parametric trigger, or disaster risk financing calculation is therefore mandatory, whilst the routine composite remains acceptable for general reporting.

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3.5 Compilation Procedure

Step 1: Data collection and source identification

¶1 Primary data sources include:

¶2 **Extent data**:

- ¶3 Satellite imagery (Sentinel-2, Landsat, Planet) for reef extent classification
- ¶4 Allen Coral Atlas v2.0 for standardised reef mapping
- ¶5 National benthic habitat mapping programmes
- ¶6 Historical reef extent records for baseline establishment

¶7 **Condition data**:

- ¶8 Field survey data from reef monitoring programmes (transects, manta tows, photo quadrats)
- ¶9 NOAA Coral Reef Watch for thermal stress and bleaching alerts
- ¶10 GCRMN regional reports for comparative condition benchmarks
- ¶11 Water quality monitoring data from coastal stations

¶12 **Services data**:

- ¶13 Fisheries catch statistics from national agencies
- ¶14 Tourism visitation data from protected area authorities
- ¶15 Coastal infrastructure inventories for protection service valuation
- ¶16 Expenditure surveys for recreation service measurement

¶17 Data quality should be assessed following **TG-0.7 Quality Assurance**, with attention to temporal consistency, spatial coverage, and measurement uncertainty.

Step 2: Reef extent classification and mapping

¶1 Classify reef extent using IUCN GET M1.3, with optional sub-classification by geomorphology (fringing, barrier, atoll, patch) or depth zone (reef flat, crest, slope). Validate remote sensing classifications using field survey data. See **TG-4.1 Remote Sensing and Geospatial Data** for classification workflows.

Step 3: Condition variable measurement

¶1 Measure condition variables from Table 2 for each reef ecosystem asset (or spatially aggregated unit), calculating area-weighted averages at opening and closing periods. The SEEA EA recommends at least one variable per ECT class [56].

Step 4: Reference condition establishment and indicator derivation

¶1 Establish reference levels from historical baselines, reference sites, or scientific thresholds. Derive indicators using the standard and inverse normalisation formulas (Direction column of Table 2, with the formulas defined in **TG-2.1** Section 3.4.1). Aggregate into a composite index following the weighting guidance in Section 3.2 (live hard coral cover indicatively weighted at least 0.30; equal weighting as a documented default). Document reference level rationale, including data source, year, and spatial coverage where a site-specific historical baseline is used.

Step 5: Ecosystem service quantification

¶1 Quantify service flows in physical units using the classification in Table 3: harvest statistics for provisioning services, and biophysical models and survey methods for regulating and cultural services. Include the disaggregated water-quality sub-services and the split carbon stock/flow entries (Section 3.3). Link service flows to extent and condition, and validate against administrative data.

Step 6: Monetary valuation

¶1 Estimate monetary values using the methods in Section 3.4 and **TG-2.4 Environmental (including Ecosystem) Goods and Services** Section 3.10, applying resource-rent decomposition for fisheries and the simulated exchange value construct for tourism. Calculate NPV asset values at opening and closing periods, presenting both climate-adjusted and stable-flow scenarios where bleaching risk is documented.

Step 7: Account integration and balance sheet compilation

¶1 Compile extent, condition, services, and monetary asset accounts into the standard SEEA EA formats (Sections 3.1–3.4). Verify accounting identities (closing = opening + additions - reductions), cross-check physical and monetary consistency, and integrate reef accounts with national ocean accounts.

3.6 Worked Example

¶1 This worked example demonstrates the compilation of coral reef ecosystem accounts for a hypothetical atoll system representative of a Pacific small island developing state. The example follows the extent-condition-services-valuation sequence and illustrates the key accounting entries and calculations.

¶2 **Setting:** A national EAA containing an atoll with 4,850 hectares of coral reef ecosystem classified as M1.3 Photic coral reefs. The reef system includes fringing reefs (2,900 ha), patch reefs (1,200 ha), and barrier reef sections (750 ha). National monitoring data document persistent sediment and nutrient pressure on the fringing reef component from terrestrial runoff. Consistent with the guidance in Section 3.1, a separate fringing-reef condition account is compiled alongside the

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spatially aggregated atoll-wide account presented below, with both reported in the published account metadata.

Step 1: Extent account (year t to t+1)

Accounting entry	Coral reef extent (hectares)
Opening extent (year t)	4,850
Additions to extent	
– Managed expansion (restoration)	15
– Unmanaged expansion (natural recovery)	20
Total additions	35
Reductions in extent	
– Managed reduction (port development)	25
– Unmanaged reduction (cyclone damage + bleaching mortality)	65
Total reductions	90
Closing extent (year t+1)	4,795

¶1 *Net loss: 55 ha (1.1%). The bleaching component of the 65 ha unmanaged reduction satisfies both criteria for catastrophic loss classification (Section 3.1) and is recorded under the catastrophic-loss line item in the account workbook.*

Step 2: Condition account

¶1 Condition indicators are derived from field survey data using the reference levels and direction conventions in Table 2:

Condition variable	Direction	Observed value	VH	VL	Formula	Indicator score
Live hard coral cover	Standard	32%	40%	5%	(V–VL)/(VH–VL)	0.77
Herbivore fish biomass	Standard	38 kg/ha	50	5	(V–VL)/(VH–VL)	0.73
Macroalgae cover	Inverse	12%	5%	40%	(VL–V)/(VL–VH)	0.80
Reef rugosity index	Standard	1.72	2.0	1.2	(V–VL)/(VH–VL)	0.65

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¶2 Composite condition index (live hard coral cover weighted 0.30 as the primary structural indicator, with the remaining weight of 0.70 distributed equally across three variables at 7/30 ≈ 0.2333 recurring each, so that weights sum to exactly 1.000):

> *Composite = 0.30 x 0.77 + 0.2333 x 0.73 + 0.2333 x 0.80 + 0.2334 x 0.65 = 0.231 + 0.170 + 0.187 + 0.152 =* ***0.74***

¶3 For comparison, an equal-weighted composite (0.25 each) yields (0.77 + 0.73 + 0.80 + 0.65) / 4 = 0.74. For this dataset, the weighting choice does not materially shift the headline composite, but the weighting choice and its rationale are nevertheless documented in account metadata.

¶4 **DRF-composite (alongside the routine composite above).** Where the reef accounts are used to support parametric insurance or other disaster risk financing instruments, the bleaching-inclusive DRF-composite introduced in Section 3.2 is computed in parallel. The worked example uses an

illustrative bleaching prevalence observation of 8% with VH = 0% (good) and VL = 50% (poor). These reference values give an inverse-direction indicator of (50 – 8) / (50 – 0) = 0.84:

Condition variable	Direction	Indicator score	DRF weight
Live hard coral cover	Standard	0.77	0.30
Bleaching prevalence	Inverse	0.84	0.20
Herbivore fish biomass	Standard	0.73	0.167
Macroalgae cover	Inverse	0.80	0.167
Reef rugosity index	Standard	0.65	0.166

> *DRF-composite = 0.30 x 0.77 + 0.20 x 0.84 + 0.167 x 0.73 + 0.167 x 0.80 + 0.166 x 0.65 = 0.231 + 0.168 + 0.122 + 0.134 + 0.108 =* **0.76**

¶5 The DRF-composite (0.76) is marginally higher than the routine composite (0.74) for this worked example because the illustrative bleaching prevalence is low (8%, well below the VL of 50%). Under a discrete bleaching event raising prevalence post-event to, say, 40%, the bleaching indicator would fall to (50 – 40) / 50 = 0.20, and, with the other four indicators held constant, the DRF-composite would fall to 0.30 x 0.77 + 0.20 x 0.20 + 0.167 x 0.73 + 0.167 x 0.80 + 0.166 x 0.65 = 0.2310 + 0.0400 + 0.1219 + 0.1336 + 0.1079 = 0.63. This Condition_pre = 0.76 to Condition_post = 0.63 change (– 0.13) drives the damage formula in the Section 3.4 subsection on reef accounts and disaster risk financing. The routine composite, which excludes bleaching prevalence, would remain at 0.74 across the same event and would yield zero damage.

¶6 *Composite condition: 0.74. Rugosity is the limiting factor, indicating historical loss of three-dimensional reef architecture.*

Step 3: Ecosystem services (annual flows)

Service	Physical quantity	Monetary value (USD)
Reef fisheries	750 tonnes	2,250,000 (resource rent: see derivation below)
Coastal protection	42 km coastline	8,200,000 (avoided damage)
Recreation and tourism	115,000 person-visits	4,950,000 (simulated exchange value)
Total valued services (3 major)		**15,400,000**

¶1 **Resource rent sub-calculation for reef fisheries:**

Line item	Value (USD)
Gross revenue (750 t at USD 5,000/t)	3,750,000
less: Vessel operating costs	(600,000)
less: Labour costs	(700,000)
less: Capital consumption	(200,000)
Resource rent	**2,250,000**

¶2 **Simulated exchange value sub-calculation for tourism:**

Line item	Value (USD)
Total reef-related tourist expenditure (115,000 visits x USD 110 average)	12,650,000
less: Accommodation, transport, guiding (human-provided services)	(7,700,000)
Reef ecosystem share (simulated exchange value)	**4,950,000**

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¶3 **Coastal-protection avoided-damage sub-derivation.** Coastal protection is the largest single service in this worked example (USD 8.2 million, 53% of the headline value) and is derived as the sum of a storm-avoidance component and chronic erosion- and flood-risk-avoidance components, both scaled by a reef-condition multiplier consistent with Ferrario and others (2014)[57].

Line item	Value (USD)
Storm component (1-in-50-year design event)	
Coastal capital at risk in the affected zone	410,000,000
Loss share without reef attenuation (12%)	49,200,000
Annualised over 50-year recurrence interval (EAD_no-reef)	984,000
Loss share with reef attenuation at condition 0.74 (2.2%, per Ferrario 2014 wave-attenuation parameters)	9,020,000
Annualised over 50-year recurrence interval (EAD_with-reef)	180,000
Storm avoided-damage component (EAD_no-reef − EAD_with-reef)	*804,000*
Chronic erosion- and flood-risk-avoidance components	
Avoided chronic shoreline erosion and recurrent nuisance-flood damages referenced to the national coastal-asset register	7,400,000
Total coastal protection (storm + chronic, at condition 0.74)	**8,204,000**
Rounded value reported in the headline services table	**8,200,000**

¶4 The value scales linearly with reef condition via the multiplier (Condition / 0.74): a reef condition of 0.50 would reduce the coastal-protection service to USD 8,200,000 x (0.50 / 0.74) = USD 5,540,000, and a fully degraded reef (Condition = 0) would reduce it to zero. The chronic erosion and recurrent flood components are referenced to the national coastal-asset register, and the loss-share parameters follow Ferrario and others (2014)[57].

¶5 Additional services from Table 3, including ornamental fish/corals (USD 85,000), water-quality sub-services (USD 180,000), and net carbon flux (USD −8,000), are excluded from the headline asset valuation for simplicity but appear in the full services account in Section 3.3.

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Step 4: Asset valuation — stable-flow and climate-adjusted scenarios

¶1 Applying a 4% social discount rate over a 25-year projection horizon:

¶2 **Stable-flow baseline (Service_t = USD 15,400,000 for all t):**

> *Asset value = 15,400,000 x present value annuity factor (4%, 25 years) Asset value = 15,400,000 x 15.62 =* ***USD 240,550,000***

¶3 **Climate-adjusted scenario.** NOAA Coral Reef Watch and national climate scenarios for this atoll project a decline in composite condition from 0.74 at t = 0 to approximately 0.55 at t = 25 under a SSP2-4.5 trajectory, with a roughly linear interpolation in intervening years. Applying Service_t = 15,400,000 x (Condition_t / 0.74) and discounting at 4%:

> *Climate-adjusted asset value ~* ***USD 211–216 million***

¶4 The derivation: Condition_t declines linearly from 0.74 at t = 0 to 0.55 at t = 25, giving Condition_t / 0.74 values from 1.000 (year 0) down to 0.743 (year 25). Service_t = 15,400,000 x (Condition_t / 0.74) is summed as a discounted annuity at 4% over 25 years. The midpoint of the trajectory gives a discounted service sum of approximately USD 213 million. The +/- 3 million range reflects alternative endpoint assumptions: USD 211 million uses Condition_25 = 0.53 (lower bound

of the national scenario range) and USD 216 million uses Condition_25 = 0.57 (upper bound). Only one trajectory shape (linear decline) is modelled. Compilers with non-linear condition projections should substitute the appropriate Condition_t path.

¶5 Both values are recorded in the asset account, with the climate-adjusted figure flagged as the prudent lower bound. The Condition_t trajectory source and projection horizon are documented in metadata.

¶6 *The ~10–15% reduction under the climate-adjusted scenario reflects projected service-capacity decline. The reef carbon stock of 32,400 tC (Table 3 balance-sheet entry) is not included in the NPV, which captures annual service flows only. Including the carbon stock would double-count against approaches that draw on that figure separately.*

Step 5: Integration with national accounts

- ¶1 Extent decline (1.1%) and condition index (0.74) feed into **TG-2.1 Biophysical Indicators** as headline reef health metrics.
- ¶2 Annual service flow (USD 15.4 million) contributes to **TG-2.4 Ecosystem Goods and Services**.
- ¶3 Protected coastline (42 km) links to **TG-1.3 OA and Marine Spatial Management** for MPA effectiveness analysis.
- ¶4 The bleaching-damage formula (Section 3.4) connects condition and service accounts to disaster risk financing.
- ¶5 Reef fisheries (750 tonnes) cross-references **TG-6.7 Fisheries Accounting**.
- ¶6 Extent data sourced from Sentinel-2 imagery (**TG-4.1**), and condition variables from 35 monitoring site transects (**TG-4.2 Survey Methods**).

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4. Supplementary Materials

4.1 Data Sources

¶1 Key data sources for coral reef ecosystem accounting include:

- ¶2 **Allen Coral Atlas** (allencoralatlas.org) — global reef extent and geomorphic mapping at approximately 5-metre resolution derived from Planet satellite imagery, version 2.0 released 2022
- ¶3 **Global Coral Reef Monitoring Network (GCRMN)** — standardised reef condition monitoring protocols and regional reports, sixth global status report published 2021
- ¶4 **NOAA Coral Reef Watch** (coralreefwatch.noaa.gov) — satellite-derived bleaching alerts, sea surface temperature, and degree heating weeks, updated daily
- ¶5 **Reef Check** — volunteer reef monitoring data using standardised protocols
- ¶6 **World Resources Institute Reefs at Risk** — global threat and value assessments
- ¶7 **National reef monitoring programmes** — country-specific monitoring systems (e.g., Australian Institute of Marine Science Long-Term Monitoring Program)
- ¶8 **FAO fisheries statistics** — reef-associated catch data
- ¶9 **CITES Trade Database** (managed by UNEP-WCMC) — international trade data for live corals (kg) and ornamental fish (number of specimens) consistent with the Table 3 ornamental species units

5. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

6. References

¶1 See the SEEA Ecosystem Accounting framework (2021) and related technical guidance for detailed methodological specifications. Key references include:

- ¶2 United Nations and others (2021). *System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA)*.
- ¶3 NCAVES and MAIA (2022). *Monetary valuation of ecosystem services and ecosystem assets for ecosystem accounting: Interim Version 1st edition*.
- ¶4 Keith, D.A. and others (2020). *IUCN Global Ecosystem Typology 2.0: Descriptive profiles for biomes and ecosystem functional groups*.
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- ¶6 Ferrario, F., Beck, M.W., Storlazzi, C.D., Micheli, F., Shepard, C.C. and Airoldi, L. (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications*, 5, 3794.
- ¶7 GCRMN (2021). *Status of Coral Reefs of the World: 2020*. Global Coral Reef Monitoring Network/International Coral Reef Initiative.
- ¶8 Allen Coral Atlas (2022). *Allen Coral Atlas v2.0*. Vulcan Inc./Arizona State University. Available at allencoralatlas.org.
- ¶9 Hughes, T.P. and others (2017). Coral reefs in the Anthropocene. *Nature*, 546, 82–90.
- ¶10 Beck, M.W. and others (2018). The global flood protection savings provided by coral reefs. *Nature Communications*, 9, 2186.
- ¶11 de Goeij, J.M. and others (2013). Surviving in a marine desert: the sponge loop retains resources within coral reefs. *Science*, 342, 108–110.

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FOOTNOTES

1. ¶1 IUCN GET M1.3 Photic coral reefs describes coral reefs as ecosystems "found in warm, shallow (rarely >60 m deep), clear, relatively nutrient-poor, open coastal waters" where temperatures vary between 17-34 degrees C. See Keith, D.A. and others (2020), *IUCN Global Ecosystem Typology 2.0*.
2. ¶2 SEEA EA para. 3.12 and Appendix A3.2 recognise the alignment between SEEA ecosystem type classification and the IUCN Global Ecosystem Typology.
3. ¶3 SEEA EA para. 3.5 defines ecosystem assets as "contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions."
4. ¶4 SEEA EA para. 3.12.
5. ¶5 This figure illustrates the conceptual linkages between the four account types compiled for coral reef ecosystems, following the accounting sequence described in SEEA EA Chapters 3, 4, 5, and 7-8.
6. ¶6 SEEA EA Chapter 4 (paras. 4.1-4.30) provides the methodology for ecosystem extent accounts.
7. ¶7 For remote sensing methods applicable to coral reef mapping, see **TG-4.1 Remote Sensing and Geospatial Data** and SEEA EA para. 4.10 on the use of Earth observation data.
8. ¶8 IUCN GET M1.3 and SEEA EA Table 3.2.
9. ¶9 SEEA EA para. 3.22-3.24 discusses national adaptation of ecosystem type classifications, including zone- or community-based sub-classifications applicable to coral reefs.
0. ¶10 SEEA EA paras. 3.22-3.24.
1. ¶11 SEEA EA Table 4.1 presents the standard ecosystem extent account format.
2. ¶12 SEEA EA para. 4.14-4.17 distinguishes managed and unmanaged additions and reductions.
3. ¶13 SEEA EA para. 4.17. The classification of climate-driven bleaching mortality as an unmanaged reduction follows the SEEA EA distinction between managed changes (resulting from deliberate decisions) and unmanaged changes (associated with natural processes, including those influenced by anthropogenic pressures).
4. ¶14 SEEA CF para. 5.49 and Chapter V define catastrophic losses procedurally as "large-scale, discrete and recognizable events" that are unexpected and exceptional; no quantitative mortality percentage is specified in SEEA CF, SEEA EA, GCRMN, NOAA, or IUCN guidance.
5. ¶15 SEEA EA Table 4.2 and paras. 4.20-4.28 present the ecosystem type change matrix format and methodology.
6. ¶16 SEEA EA para. 2.26 and 5.3.
7. ¶17 SEEA EA para. 5.29-5.40 and Table 5.2 present the Ecosystem Condition Typology (ECT).
8. ¶18 Adapted from SEEA EA Table 5.7 examples for marine ecosystems. Reference levels are indicative and should be calibrated to regional baselines.
9. ¶19 SEEA EA para. 5.68.

0. ¶20 SEEA EA paras. 5.77-5.88.
1. ¶21 Live hard coral cover is treated as the primary structural indicator of reef condition in the peer-reviewed literature; see Hughes, T.P. and others (2017), "Coral reefs in the Anthropocene", *Nature*, 546, 82–90. The indicative minimum weight of 0.30 is an editorial recommendation and a methodological choice that compilers must document; it is not prescribed in SEEA EA paras. 5.77–5.88 or any specific weighting study.
2. ¶22 Coral bleaching is a well-documented indicator of thermal stress; see Sheppard, C., Davy, S., Pilling, G. and Graham, N. (2018), *The Biology of Coral Reefs*, Oxford University Press.
3. ¶23 IUCN GET M1.3 Photic coral reefs.
4. ¶24 NOAA Coral Reef Watch provides satellite coral bleaching monitoring products at coralreefwatch.noaa.gov.
5. ¶25 SEEA CF Chapter V, section on catastrophic losses (para. 5.49), describing "exceptional and significant reductions in the natural resource due to discrete events". See footnote 14a.
6. ¶26 SEEA EA Tables 5.3, 5.4, and 5.5 present variable, indicator, and index account formats.
7. ¶27 SEEA EA Chapter 6-7 (paras. 6.1-7.46) provide the methodology for ecosystem services accounts.
8. ¶28 SEEA EA para. 6.43-6.52 addresses provisioning services.
9. ¶29 SEEA EA para. 6.73-6.81 discusses regulating services for coastal protection.
0. ¶30 SEEA EA Table 6.3 lists coastal protection among regulating ecosystem services.
1. ¶31 The relationship between reef condition and coastal protection capacity is documented in the scientific literature; see Ferrario et al. (2014) "The effectiveness of coral reefs for coastal hazard risk reduction and adaptation", *Nature Communications*.
2. ¶32 Sponge biofiltration on coral reefs is documented by de Goeij, J.M. and others (2013), "Surviving in a marine desert: the sponge loop retains resources within coral reefs", *Science*, 342, 108–110. Reef-area-normalised sponge biofiltration rates are not yet standardised in published GCRMN, AIMS, or equivalent monitoring protocols; the metric "sponge biofiltration rate (L/h/m²) x reef area" should therefore be reported as indicative, with the underlying sponge density and per-individual pumping-rate sources documented. SEEA EA paras. 6.73–6.81 cover regulating services.
3. ¶33 SEEA EA Chapter 13 and Table 13.4 identify core ocean statistics for biogeochemical cycling by ecosystem type.
4. ¶34 Ware, J.R., Smith, S.V. and Reaka-Kudla, M.L. (1992). Coral reefs: sources or sinks of atmospheric CO2? *Coral Reefs*, 11(3), 127-130. See also SEEA EA para. 6.82-6.90 on global climate regulation services and the distinction between carbon storage stocks and carbon sequestration flows.
5. ¶35 SEEA EA para. 6.91-6.105 addresses cultural services including recreation.
6. ¶36 SEEA EA para. 13.81.
7. ¶37 SEEA EEA Technical Recommendations para. 4.103.
8. ¶38 SEEA EA Table 7.1 presents the standard ecosystem services supply and use account format.
9. ¶39 The negative net annual carbon flux is retained as a negative service flow rather than suppressed, so that monetary valuation does not systematically overstate reef carbon services. The carbon price applied is the domestic emissions trading scheme price where one exists, or the national social cost of carbon reference value, and is documented in account metadata.
0. ¶40 CITES Trade Database (managed by UNEP-WCMC) records live corals in kilograms and ornamental fish in number of specimens; these conventions are applied to the Table 3 ornamental species sub-rows to ensure inter-country comparability.
1. ¶41 SEEA EA Chapter 9-10 and the NCAVES/MAIA Valuation Guidance provide detailed valuation methodology.
2. ¶42 SEEA EA para. 9.14.
3. ¶43 SEEA EA para. 9.37-9.45 discusses resource rent approaches. The net price method for small-scale fisheries with near-zero or negative input-subtraction resource rent follows SEEA EA para. 9.42.
4. ¶44 SEEA EA para. 9.52-9.60 addresses valuation of cultural services.
5. ¶45 SEEA EEA Technical Recommendations para. 5.41.
6. ¶46 SEEA EA paras. 9.52–9.59 (verify exact paragraph numbering against the SEEA EA 2021 PDF before final publication). The simulated exchange value construct for recreation/tourism is corroborated in the applied valuation literature; see Hein and others (2015), *Ecological Economics*, 139, 140–149, and Remme and others (2022), *Ecosystem Services*, 54.
7. ¶47 SEEA EA para. 9.62-9.70 discusses avoided damage cost and related approaches.
8. ¶48 SEEA EA para. 2.53.
9. ¶49 SEEA EA para. 10.17-10.35 presents the net present value approach for ecosystem asset valuation.
0. ¶50 SEEA CF para. 5.137 on the discount factor.
1. ¶51 SEEA EA para. 10.71-10.80 addresses the measurement of ecosystem degradation (paragraph range to be verified against the SEEA EA 2021 PDF before publication).
2. ¶52 SEEA EA para. 10.45-10.52 discusses restoration cost approaches.
3. ¶53 SEEA EA para. 10.46.
4. ¶54 NOAA Coral Reef Watch degree heating week (DHW) products and alert level thresholds are documented at coralreefwatch.noaa.gov. Alert Level 1 (4 DHW) is associated with significant bleaching risk; Alert Level 2 (8 DHW) with widespread bleaching and mortality risk.
5. ¶55 Beck, M.W. and others (2018). The global flood protection savings provided by coral reefs. *Nature Communications*, 9, 2186 (DOI: 10.1038/s41467-018-04568-z). The Quintana Roo Coastal Zone Management Trust (Mexico) provides an operational example of parametric reef insurance triggered on wind speed and reef condition.

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6. ¶56 SEEA EA para. 5.46. "Ideally, the compilation of ecosystem condition accounts should ensure that for each ecosystem type, at least one variable is selected for each of the six ECT classes."
7. ¶57 Ferrario, F., Beck, M.W., Storlazzi, C.D., Micheli, F., Shepard, C.C. and Airoldi, L. (2014). "The effectiveness of coral reefs for coastal hazard risk reduction and adaptation", *Nature Communications*, 5, 3794. The 2.2% reef-attenuated loss share applied at condition 0.74 is an illustrative figure consistent with the wave-energy and wave-height attenuation parameters reported in that paper; compilers should derive country-specific values from their national coastal hazard modelling using the Ferrario parameter ranges as a guide.

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Mangrove and Coastal Wetland Accounting

Provides guidance on compiling ecosystem accounts for mangroves and coastal wetlands.

Version 0.8.2 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on compiling ecosystem accounts for mangroves and coastal wetlands. The accounts support four policy applications: blue carbon credit verification for voluntary and compliance carbon markets; coastal protection valuation for infrastructure planning; mangrove restoration prioritisation for climate adaptation; and REDD+ coastal extension for nationally determined contributions under the Paris Agreement.

This Circular connects to TG-2.8 Climate Change Indicators, which draws on blue carbon sequestration rates compiled here; TG-2.9 Disaster Risk Indicators, which uses coastal protection measurements from Section 3.4; and TG-1.8 OA and Project-Level Finance, which applies carbon accounts and service valuations to blue bonds, debt-for-nature swaps, and payments for ecosystem services.

This Circular is one of four thematic ecosystem circulars — alongside TG-6.1 Coral Reef Accounting, TG-6.3 Seagrass Ecosystem Accounting and TG-6.4 Kelp Forest and Temperate Reef Accounting — that apply the generic ecosystem asset method in TG-3.1 Asset Accounts, the extent methods in TG-4.1 and the condition methods in TG-4.8 and TG-4.9 to one coastal ecosystem type each. The four are peers: none is a prerequisite for another, and each is compiled independently. Estuarine and deltaic assets influenced by catchment inputs are carried forward in TG-6.13 Freshwater-Marine Interaction Accounting.

Framework Position

This Circular owns the extent, condition, service and asset accounts for IUCN GET MFT1.1 coastal river deltas, MFT1.2 mangroves and MFT1.3 coastal saltmarshes and reedbeds. It also owns the blue carbon pricing rule for the publication (Section 3.6): the SEEA EA two-component model, applied identically across all blue carbon ecosystems.

It cross-refers for the account structure (TG-3.1), extent and condition measurement (TG-4.1, TG-4.8, TG-4.9) and valuation principles (TG-1.9).

Seagrass is TG-6.3, not this Circular, despite the shared blue carbon method. Catchment-borne nutrient and sediment inputs to these systems are TG-6.13. The fisheries production that nursery habitat supports is recorded once, as an intermediate service here and as landed catch in TG-6.7.

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ABOUT THIS CIRCULAR

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1. Outcome

¶1 This Circular provides guidance on compiling ecosystem accounts for mangroves and coastal wetlands. The accounts support four policy applications: **blue carbon credit verification** for voluntary and compliance carbon markets; **coastal protection valuation** for infrastructure planning; **mangrove restoration prioritisation** for climate adaptation; and **REDD+ coastal extension** for nationally determined contributions under the Paris Agreement.

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2. Requirements

- ¶1 **TG-0.1 General Introduction to Ocean Accounts**
- ¶2 **TG-3.1 Asset Accounts** — in particular Section 3.4 on ecosystem asset accounts.
- ¶3 **TG-1.9 Valuation** — foundational valuation concepts are not repeated here.
- ¶4 **TG-4.1 Ecosystem Extent** — general extent accounting, spatial data requirements, and change detection.

¶5 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 Mangroves and coastal wetlands occupy the transitional zone between terrestrial and marine environments, classified within the MFT1 Brackish Tidal Systems biome of the IUCN Global Ecosystem Typology (GET)[1]. For the GET realm/biome/EFG hierarchy and the national crosswalk obligation, see **TG-4.1** Section 3.2.4.[2] Key ecosystem functional groups are summarised in Table 3.0.1 below[3].

Functional group	Description
MFT1.2 Intertidal forests and shrublands (mangroves)	Characterised by salt-tolerant trees and shrubs with specialised adaptations including pneumatophores, salt excretion glands, and vivipary.
MFT1.3 Coastal saltmarshes and reedbeds	Dominated by salt-tolerant herbaceous plants and grasses in the upper intertidal zone.
MFT1.1 Coastal river deltas	Complex mosaics incorporating mangroves, saltmarshes, and other transitional ecosystem types.

¶2 Sections 3.1–3.6 cover ecosystem extent, condition, blue carbon services, coastal protection, nursery habitat services, and valuation [4]. Compilers should also consult **TG-3.8 Combined Presentations** for the bridge to the SEEA-CF Thematic Carbon Stock Account referenced in Section 3.3. Section 3.7 presents a step-by-step compilation procedure and Section 3.8 provides a worked example.

3.1 Extent Accounting

¶1 Ecosystem extent accounts record mangrove and coastal wetland area within an ecosystem accounting area (EAA), typically in hectares [5]. Extent accounts provide the spatial foundation for all subsequent condition and service accounts. For satellite sensor selection, cloud-cover management, tidal timing, and general accuracy assessment, see **TG-4.1 Ecosystem Extent**. Mangrove-specific considerations are noted below.

Ecosystem type classification

¶1 Mangroves and coastal wetlands should be classified at the ecosystem functional group (EFG) level or finer national classifications [6]:

IUCN GET Code	Ecosystem Functional Group	Description
MFT1.2	Intertidal forests and shrublands	Mangrove forests and related tidal woody vegetation
MFT1.3	Coastal saltmarshes and reedbeds	Herbaceous tidal wetlands including salt marshes
MFT1.1	Coastal river deltas	Complex deltaic mosaics with multiple ecosystem types

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¶2 National classifications may disaggregate further by dominant species (e.g., Rhizophora-dominated vs. Avicennia-dominated) or structural characteristics [7]. Temperate compilers should identify the most appropriate GET functional groups for their national context and document classification decisions transparently.

Remote sensing and accuracy assessment

¶1 Remote sensing provides the primary data source for extent mapping [8], [9]. Mangrove-specific considerations supplementing **TG-4.1 §3.3** are:

- ¶2 L-band SAR (Sentinel-1, ALOS-2 PALSAR-2) for canopy height retrieval under cloud cover [10]
- ¶3 NDVI thresholds for mangrove vs saltmarsh discrimination
- ¶4 Imagery acquired within ±2 hours of low tide for intertidal fringe mapping

¶5 **Saltmarsh-specific:** Saltmarsh mapping requires high-resolution optical imagery (0.5–2 m) and LiDAR-derived elevation models to separate saltmarsh from adjacent upland vegetation. Multi-temporal classification exploiting phenological contrasts improves discrimination.

¶6 **Global datasets:** Global Mangrove Watch provides annual mangrove extent maps from 1996 at 25-metre resolution [11]. The Global Tidal Wetland Change Dataset tracks saltmarsh, mangrove, and tidal flat changes globally [12].

¶7 Accuracy documentation must include: accuracy assessment method (area-based probability sampling); reference data source and collection date; overall, producer, and user accuracy by class; confusion matrix; and imagery source, acquisition date, resolution, and cloud cover or tidal stage. For national GHG inventory reporting, minimum overall accuracy of 85% is a widely applied convention (IPCC Good Practice Guidance)[13]. For carbon credit accounting under voluntary standards (e.g., Verra VM0033), methodology-specific requirements apply.

Change detection

¶1 The extent account records changes between opening and closing periods using four categories[14]:

Change category	Description
Managed expansions	Increases due to restoration, afforestation, or coastal management.
Unmanaged expansions	Natural colonisation and succession.
Managed reductions	Conversion for aquaculture, agriculture, or urban development.
Unmanaged reductions	Natural losses from erosion, sea-level rise, or catastrophic events.

¶2 Temporary losses from storm damage followed by regeneration should be treated as condition changes rather than extent changes[15].

¶3 **Restored vs. naturally regenerated additions.** Managed expansions should be disaggregated into two sub-categories in account metadata:

- ¶4 *Restored (planted)* — counted as gained extent only after a **survival check at year 3 post-planting** to filter typical 30–60% three-year mortality. The threshold for entry into the extent account is canopy closure or the specified national cover percentage, whichever is reached first.
- ¶5 *Naturally regenerated* — areas colonised by unassisted propagule recruitment, typically reaching the SEEA EA extent threshold at year 10–15.

¶6 Carbon accumulation trajectories differ between sub-categories: planted monocultures accrue above-ground biomass faster initially but commonly reach lower long-term equilibrium carbon stocks than mixed naturally recruited stands. Compilers should document sub-category membership as this distinction is material for downstream carbon accounting and additionality analyses.

Extent account structure

¶1 The extent account structure is set out in **TG-3.1 Asset Accounts** Section 3.5.1 (Tables 2a and 2b) and is not restated here[16], [17]; Section 3.5.3 of the same circular governs how extent entries flow into the asset balance sheet. Compile one column per ecosystem functional group present — mangroves (MFT1.2), saltmarshes (MFT1.3) and coastal river deltas (MFT1.1) — and a worked account appears at Section 3.8 below.

¶2 Managed expansion arising from a **restoration intervention** carries a second set of entries — counterfactual, survival, permanence and lifecycle cost — recorded in parallel under **TG-6.15 Ocean Accounting for Nature-based Solutions** Section 3.2. The extent entry here and the NbS ledger there describe the same planting from different sides and are not alternatives.

¶3 Two entries need care in wetlands. **Landward migration** under sea-level rise is a reclassification and not an addition: the mangrove belt gains area from terrestrial ecosystem types and loses it seaward, and both legs belong in the reclassification block so the accounting area still balances. **Planted restoration** is a managed addition only once the stand meets the national classification threshold for the functional group; seedlings planted and not yet established are restoration expenditure with no extent entry, and recording them early is the most common source of overstated mangrove gain.

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3.2 Condition Assessment

¶1 Ecosystem condition accounts record ecosystem quality through variables reflecting composition, structure, and function[18], [19], [20]. For the general ECT framework and condition variable selection, see **TG-4.8 Physical Condition Measurement §3.1** and **TG-4.9 Biological Condition Measurement §3.1**. The variables below are mangrove- and wetland-specific applications of ECT classes, with an indication of whether each is estimable from remote sensing (*RS*) or field sampling (*FS*)[21].

¶2 **Physical state (A1):** Tidal inundation regime (*FS*); sediment accretion/erosion rate (*FS*); groundwater level (*FS*).

¶3 **Chemical state (A2):** Water salinity (*FS*); nutrient concentrations (*FS*); dissolved oxygen (*FS*).

¶4 **Compositional state (B1):** Species richness (*FS*); community composition (*FS*); presence of key species (*FS*).

¶5 **Structural state (B2):** Canopy cover (*RS*); canopy height (*RS* via LiDAR); above-ground biomass (*RS* via SAR/allometry); tree density (*FS*).

¶6 **Functional state (B3):** Net Primary Productivity (*RS* via MODIS/Sentinel); litterfall rate (*FS*); regeneration success (*FS*).

¶7 **Landscape/seascape (C1):** Hydrological connectivity (*RS*+*FS*); fragmentation (*RS*); edge effects (*RS*).

Key condition indicators

¶1 **Canopy cover** is a primary structural indicator measurable through remote sensing, and describes forest density and intactness[22].

¶2 **Species composition** reflects ecological integrity. Presence of climax species (e.g., Rhizophora in many tropical settings) indicates mature, stable ecosystems[23].

¶3 **Hydrological connectivity** governs coastal wetland function, affecting sediment supply, nutrient exchange, and biotic recruitment[24]. Disruption through road construction, aquaculture bunds, or drainage infrastructure is a major cause of degradation. Assess through tidal range comparison (observed vs. reference), distance to tidal inlet, and presence of flow barriers.

¶4 **Sediment elevation change** indicates whether wetlands are maintaining pace with sea-level rise[25]. Surface Elevation Tables (SETs) provide direct measurements. Treat as a core indicator where relative sea-level rise exceeds 2 mm/yr, and as optional but recommended elsewhere. This indicator supports climate adaptation planning.

Reference conditions

¶1 Reference conditions are required against which to assess current state, following SEEA EA Section 5.3[26]:

Reference approach	Description
Historical baselines	Pre-disturbance condition documented through historical records, early imagery, or sediment core analysis.
Minimally disturbed reference sites	Protected or relatively undisturbed examples of the same ecosystem type in the national territory or ecoregion.
Expert-defined targets	Expert assessment where historical data and reference sites are unavailable.

¶2 **Decision rule:** Prefer (i) **minimally disturbed contemporary reference sites** in the same biogeographic region; fall back to (ii) **historical baselines** with documented source and date; fall back to (iii) **expert-defined targets** only where neither alternative exists.

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¶3 This ordering is specific to mangrove and differs from the one in **TG-6.1 Coral Reef Ecosystem Accounting** Section 3.2, which prefers a site-specific historical baseline. The difference is a property of the evidence available for each ecosystem, not an inconsistency: minimally disturbed mangrove stands are commonly present within a biogeographic region whilst pre-disturbance mangrove records are commonly not, and for Caribbean reef the reverse holds — there is a strong palaeoecological and historical record and no minimally disturbed contemporary analogue. Compilers should apply the ordering given for the ecosystem they are accounting for, and document which reference condition and estimation method were used (**TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.2).

¶4 Condition variables are normalised using the formula defined in **TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.1. Each variable must be tagged as **standard** or **inverse** direction.

Sampling design for condition assessment

¶1 SEEA EA does not prescribe minimum plot density. Required documentation: number of sampling units; spatial distribution and stratification; plot dimensions; extrapolation method; and data source and collection date [27].

¶2 Appropriate stratification variables include: ecosystem type and species composition; hydrological zone and inundation frequency; condition class; geomorphic setting (fringe vs. basin vs. riverine mangrove); and remote sensing-derived indicators (canopy cover, NDVI).

¶3 Tier-appropriate guidance:

- ¶4 **Tier 1:** Single composite estimate from published global or regional defaults; document source, year, and ecological match to accounting area.
- ¶5 **Tier 2:** 2–4 satellite-derived strata, at least 3 field plots per stratum; area-weight stratum means by area.
- ¶6 **Tier 3:** Howard et al. (2014) plot-level protocols with stratified random placement and replicated sediment cores. Minimum quadrat sizes: 7 m x 7 m for mangroves, 0.5 m x 0.5 m for saltmarsh.

¶7 For seagrass condition assessment, see **TG-6.3 Seagrass Ecosystem Accounting**.

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Carbon stock estimation — key distinction

¶1 Carbon stocks in the condition account are derived by measuring each pool independently (above-ground biomass, below-ground biomass, soil organic carbon) in tC/ha. The normalised condition indicator (scaled 0–1) is a descriptor for tracking and communication. It is not a multiplier against a reference stock value. A degraded ecosystem with measured SOC of 200 tC/ha against a reference of 471 tC/ha has a condition indicator of approximately 0.42, but the carbon stock entered into the account is 200 tC/ha multiplied by ecosystem area. SOC in particular degrades non-proportionally with above-ground condition: deep sediment SOC may remain largely intact even after surface biomass removal [28].

Condition account structure

¶1 The table below follows the SEEA EA condition variable account structure [29].

SEEA ECT Class	Variable	Unit	Reference Level	Opening Value	Closing Value	Change
Physical state	Tidal range ratio	% of reference	100%			
Chemical state	Porewater salinity	ppt	Site-specific			

SEEA ECT Class	Variable	Unit	Reference Level	Opening Value	Closing Value	Change
Compositional state	Species richness	count	Pre-disturbance			
Structural state	Canopy cover	%	Reference site			
Structural state	Above-ground biomass	t C/ha	Reference site			
Functional state	Net Primary Productivity	t C/ha/yr	Historical mean			
Landscape	Hydrological connectiv-ity index	0-1	1.0 (fully connected)			

3.3 Blue Carbon Services

¶1 Figure 6.2.1 maps three mangrove carbon pools to SEEA EA accounting destinations: biomass pools enter condition attributes; annual sequestration (Cseq) enters the regulating service account; carbon storage (Cstor) enters a condition attribute with a balance-sheet footnote (not yet standardised).

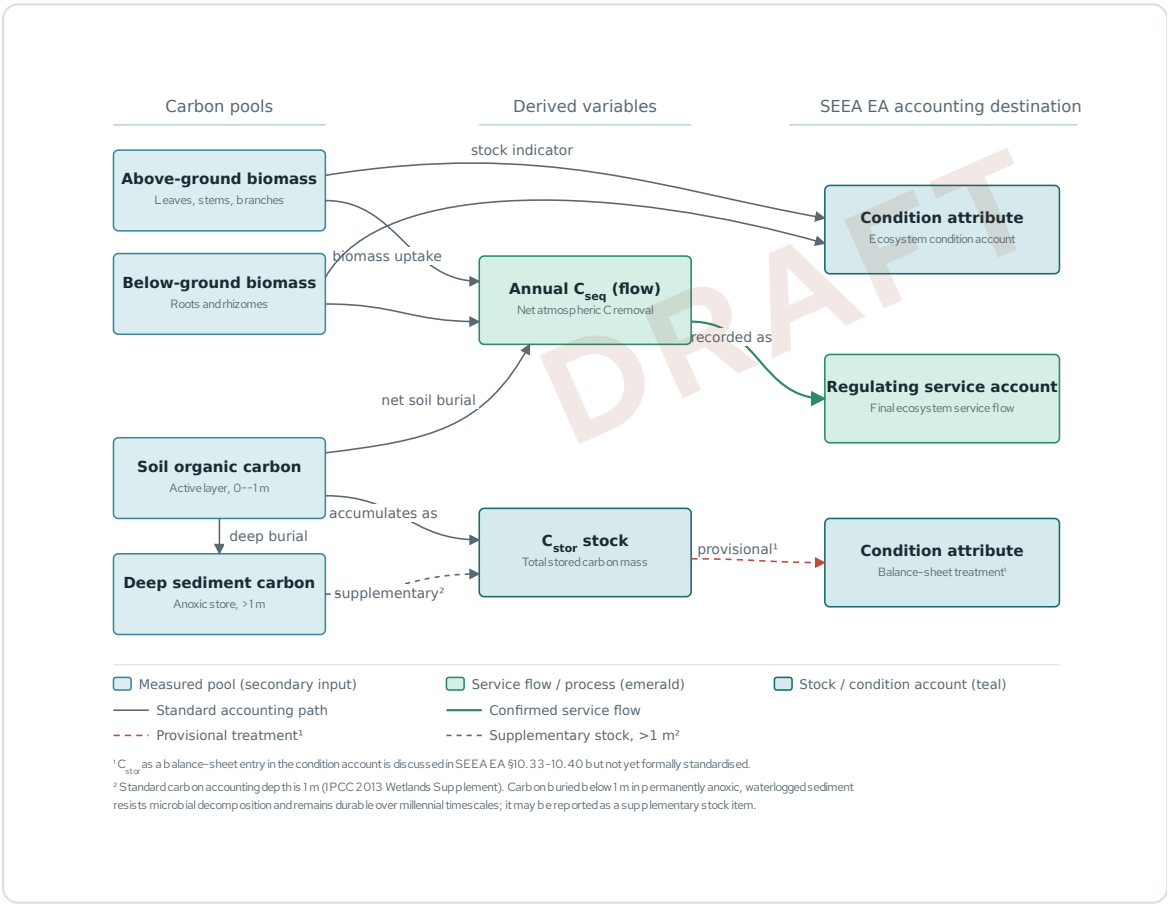


Figure 6.2.1 Blue-carbon pools map to SEEA EA destinations: biomass and soil burial feed Cseq; Cstor is a condition attribute; deep sediment is supplementary. Dashed paths mark non-standardised Cstor-to-condition link and >1 m durable store.

Source: SEEA EA 2024, §§10.20–10.40 (ecosystem condition accounting); TG-6.2 draft, Section 3.3 (Blue Carbon Services) and the net sequestration identity (NECB = biomass increment + net soil burial).

Adapted from: SEEA EA 2024 Figure 10.1 (ecosystem condition account structure), with GOAP extensions for blue carbon pool disaggregation, Cseq/Cstor derivation paths, soil burial routing, and the >1 m durable-store supplementary item.

Conceptual distinction: carbon stocks and carbon flows

¶1 A *carbon stock* is the mass of carbon held in an ecosystem at a point in time (tC or tCO2e), a state variable in the condition account. A *carbon flow* is the rate of carbon movement between ecosystem and atmosphere over a defined period (tCO2e/yr), a change variable in the ecosystem services flow account. Conflating stock and flow produces results that cannot be compared across countries or time periods [30].

¶2 Physical accounts must be compiled before monetary accounts. The recommended sequence is: (1) extent account; (2) condition account (carbon stocks per pool); (3) services flow account, physical; (4) services flow account, monetary.

IPCC Wetlands Supplement tier framework

¶1 The primary reference for blue carbon accounting is the *2013 Supplement to the 2006 IPCC Guidelines: Wetlands*, Chapter 4. Coverage by ecosystem type: mangroves (full Tier 1 across all carbon pools); tidal marshes and saltmarsh (partial Tier 1; biomass carbon stock changes require Tier 2+; soil carbon estimates carry ±50–90% uncertainty at Tier 1); seagrass (out of scope — see **TG-6.3**); tidal flats (not covered by the Wetlands Supplement) [31].

¶2 Kelp, sargassum, and other macroalgae are out of scope. Their attribution as carbon sinks remains scientifically unresolved, and no agreed IPCC accounting boundary exists.

¶3 Minimum recommended tiers by use case:

Use case	Minimum tier	Rationale
National GHG inventory (UNFCCC reporting only)	Tier 1 acceptable as starting point	Permitted where coastal wetlands are not a key category
NDC contribution / REDD+ / Warsaw Framework	Tier 2	Country-specific emission factors required
Ocean account for policy planning	Tier 2	Physical precision required for spatial planning
Carbon project accreditation (VCS/Gold Standard)	Tier 3	VM0033 sets this threshold explicitly
Blue carbon credit issuance / financial instruments	Tier 3	Additionality, permanence, and leakage require site-specific baselines
High-precision ecosystem service valuation	Tier 3	Monetary reliability depends on physical account precision

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¶4 Countries should not remain at Tier 1 for key categories. Where blue carbon ecosystems make a material contribution to national GHG balances (e.g., Indonesia, Philippines, Madagascar, Australia), Tier 2 should be the minimum for NDC and national communications submissions [32].

Scope boundary: aquaculture carbon claims

> *Note on scope*
> *Bivalve aquaculture (oysters, mussels, clams) is outside scope. Animals are heterotrophs, and bivalve shell calcification ($Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$) produces CO_2 as a by-product. Net atmospheric effects are contested. Shell formation is a metabolic process, not an ecosystem service delivered by a coastal ecosystem asset.*
> *Seaweed farming is generally outside scope. In most operations, harvested biomass is consumed within months to years without durable long-term sequestration (SEEA EA para. 6.114). Emerging applications (deep-ocean sinking, biochar conversion) should be treated as experimental pending IPCC guidance [33].*

Carbon stock accounting

¶1 Mangroves and coastal wetlands store carbon in five pools requiring separate accounting [34]:

Carbon Pool	Measurement Method	Typical Range	Accounting Treatment
Above-ground biomass	Allometric equations	50-250 tC/ha	Condition account (stock)
Below-ground biomass	Root:shoot ratios or allometry	30-150 tC/ha	Condition account (stock)
Dead wood	Field measurement (volume x density)	1-20 tC/ha (locally significant in disturbed forests)	Condition account (stock)
Litter	Quadrat harvest	0.5-5 tC/ha (minor)	Condition account (stock)
Soil organic carbon (0-1m)	Core sampling	200-1000 tC/ha	Condition account (stock)

¶2 **Above-ground biomass:** Carbon content typically estimated at 45–50% of dry biomass weight [35].

¶3 **Below-ground biomass:** Root:shoot ratios of 0.5–1.5 commonly applied. For mangroves with extensive stilt root systems, below-ground biomass may equal or exceed above-ground biomass [36].

¶4 **Dead wood and litter:** Minor pools in most intact systems but locally significant in disturbed forests. Enumerate following IPCC Wetlands Supplement Chapter 4 protocols.

¶5 **Sediment organic carbon (SOC):** The largest pool in most coastal wetlands, typically 70–95% of total ecosystem carbon. Representative ranges: mangrove SOC 500–1,500 tCO2e/ha to 1-metre depth (potentially exceeding 3,000 tCO2e/ha in Southeast Asian deep peat soils); saltmarsh SOC 200–700 tCO2e/ha. Methods that neglect soil cores will underestimate total ecosystem carbon.

¶6 The standard accounting depth is 1 metre (IPCC 2013 Wetlands Supplement). For mangrove systems with deep peat soils, compilers may additionally report carbon stocks to bedrock or depth of organic accumulation as a supplementary item, clearly distinguishing these from the 1-metre figures [37].

¶7 **Carbon market deeper-deposit requirement:** Verra VM0033 requires sampling to refusal or 3 m (whichever is shallower) for credit issuance. Where the account supports both SEEA reporting and credit issuance, report (a) 0–1 m stock for SEEA/inventory comparability and (b) full-depth stock to refusal or 3 m as a supplementary item.

¶8 **Soil-carbon sampling and laboratory protocol** (Kauffman & Donato 2012, CIFOR WP86 Sections 4–5; Howard et al. 2014 Chapter 4):

- ¶9 *Core count and depth intervals:* minimum 6 cores per plot at 0–15, 15–30, 30–50, and 50–100 cm intervals (plus deeper intervals where the deeper-deposit protocol applies).
- ¶10 *Compaction correction:* record extruded core length against cored interval length; apply ratio as depth-correction factor. Sediment compression of 20–40% during coring is common.
- ¶11 *Laboratory method:* dry combustion using an elemental analyser preferred. Where Walkley-Black wet oxidation is used, apply a recovery factor of 1.30 unless site-specific calibration exists.
- ¶12 *Loss-on-ignition:* requires site- or species-specific calibration against dry combustion before use for accounting purposes.

¶13 The three-tier hierarchy for blue carbon stock measurement maps to the IPCC Wetlands Supplement tier framework (see use-case table above). Murdiyarso et al. (2023) provide a national-scale worked example of the Tier 1 to Tier 2 transition for Indonesian mangroves [38].

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Allometric equations and uncertainty

¶1 Selection rule — use the most specific equation available, in order:

1. ¶2 **Species-specific local equation** from destructive sampling within the accounting area.
2. ¶3 **Regional species-specific substitute** from the same species in a climatically analogous region. Price et al. (2024) confirmed common allometric equations hold for three transatlantic mangrove species across wide climate gradients.
3. ¶4 **Pantropical equation with measured wood density:** Komiyama et al. (2005): AGB (kg) = 0.251 x rho x D^2.46; BGB (kg) = 0.199 x rho^0.899 x D^2.22, where rho is wood density (g/cm³) and D is DBH (cm).
4. ¶5 **Pantropical default without measured wood density** — lowest confidence; document as a limitation [39].

¶6 For saltmarsh, Butler et al. (2025) demonstrated models explaining up to 89.3% of biomass variance for Southeast Australian species. Destructive harvest protocols from Howard et al. (2014) remain the standard fallback: 0.25 m² quadrats and a 0.42–0.45 carbon content factor.

¶7 **Equation applicability ranges:**

Equation	Predictors	Calibrated on	DBH range (cm)	Reported error	Recommended use
Komiyama et al. (2005) pantropical	DBH, wood density	Mixed species (Thailand, Indonesia, Panama)	5–49	RSE approx. 12%	Default; flag extrapolation outside DBH range
Komiyama et al. (2008) species-specific	DBH (species-specific coefficients)	Multiple Rhizophora, Avicennia, Bruguiera, Sonneratia	Varies 2–40	Species-dependent	Preferred where species represented and stand analogous
Kauffman & Donato (2012) / Kauffman et al. (2016)	DBH	Mixed neotropical and Indo-Pacific	2–50	Reported in source	Standard for protocol-level consistency
Butler et al. (2025) saltmarsh	Canopy diameter, height	SE Australian saltmarsh species	n/a	R^2 up to 0.893	Saltmarsh AGB where species and structure analogous

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¶8 Compilers must: (a) confirm species and DBH range fall within the calibration domain; (b) flag extrapolation as documented uncertainty; and (c) record the equation reference in account metadata.

¶9 **DBH measurement conventions (Kauffman & Donato 2012 Section 3.2; Howard et al. 2014 Chapter 3):**

- ¶10 *Rhizophora* spp. — 1.3 m above the highest prop root.
- ¶11 *Avicennia* spp. — 1.3 m above substrate; pneumatophores not measured as stems.
- ¶12 *Sonneratia* spp. — 1.3 m above substrate; multi-stemmed individuals reported as sum of basal area.
- ¶13 *Bruguiera* spp. — 1.3 m above substrate.
- ¶14 *Excoecaria agallocha*, *Heritiera* spp. — measure immediately above buttress where buttresses exceed 1.3 m.
- ¶15 Coppicing/multi-stemmed — record each stem >5 cm DBH separately; sum basal area for biomass.

¶16 **Uncertainty quantification:** Allometric equation uncertainty typically constitutes 30–75% of total biomass estimation uncertainty [40]. Where Monte Carlo simulation is feasible, sample from

each parameter's error distribution across 1,000+ iterations and report mean and 95% confidence interval. Where not feasible, report known confidence intervals from the equation's published validation. Uncertainty is documented in the technical annex, not embedded in account tables.

Carbon sequestration measurement

¶1 Carbon sequestration is the ongoing removal of CO2 from the atmosphere, distinct from carbon storage [41]. For mangroves and coastal wetlands, it occurs through biomass accumulation (net growth of vegetation) and sediment burial (organic matter incorporation into accreting sediments) [42].

¶2 Global average sequestration rates: mangroves approximately 1.5–2.5 tC/ha/yr; saltmarshes approximately 0.5–2.0 tC/ha/yr [43], [44].

¶3 **Net sequestration identity (operational rule for the flow account):**

> *Net carbon sequestration (period t) = Gross biomass increment + Net soil C accumulation − Mortality and respiration losses − Conversion and degradation emissions*

¶4 The retention (stock) service is recorded in the condition account [45]. The sequestration (flow) service is recorded in the services flow account using the net identity above [46]. Reporting stock change and additionally applying a sequestration rate per hectare constitutes double counting.

Approach	Description
Biomass change methods	Repeated measurements of vegetation structure with allometric equations applied to compute net biomass increment between censuses.
Sediment carbon burial rate	Radioisotope dating (210Pb CRS, optionally cross-validated with 137Cs) to establish sediment accumulation rates.
Eddy covariance	Direct measurement of net ecosystem CO2 exchange (NEE) for intensive sites. NEE captures gas-phase flux only; do not substitute NEE for burial or vice versa. NEE and burial together approximate Net Ecosystem Carbon Balance (NECB) when combined with lateral flux and harvest terms (Chapin et al. 2006).

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Sediment carbon burial rate measurement

¶1 The sediment carbon burial rate, also termed the organic carbon accumulation rate (CAR), measures carbon passing below the zone of active decomposition into stable, anoxic long-term storage. It is distinct from standing stock and from short-term surface accumulation.

¶2 **Lead-210 (210Pb) CRS model — primary method:** The Constant Rate of Supply (CRS) model is recommended for vegetated coastal sediments, as it allows sedimentation rates to vary, which is appropriate for blue carbon systems. The carbon accumulation rate is:

¶3 **CAR (g C/cm²/yr) = SAR x DBD x %OC**

¶4 where SAR is sediment accumulation rate (cm/yr); DBD is dry bulk density (g/cm³); %OC is organic carbon content. To convert: 1 g C/cm²/yr = 100 tC/ha/yr.

¶5 Published global mean rates (Arias-Ortiz et al. 2018): mangroves approximately 1.74 tC/ha/yr (range 0.08–4.26); saltmarshes approximately 2.10 tC/ha/yr [47].

¶6 **Methodological note — mixed layer correction:** Calculate CAR from accumulation rates below the surface mixed layer. Using near-surface values inflates the estimate because carbon in the mixed layer is not yet durably stored (Piñeiro-Juncal et al. 2023).

¶7 **Marker horizon method (feldspar plots) — operational alternative:** Feldspar clay spread across 50 x 50 cm plots captures recent accretion over months to years. Operationally simple but

systematically overestimates long-term burial rates. Use only to characterise recent accretion dynamics. Do not extrapolate to centennial burial rates without correction (Cahoon et al. 1995)[48].

¶8 Report the method used and time window. For 210Pb CRS, report as centennial mean and, where temporal variation is evident, as a 10- or 25-year recent average. For marker horizons, report as an explicit short-term estimate.

Human disturbance and the accounting treatment of emissions

¶1 When a blue carbon ecosystem is disturbed or converted, the account captures consequences through three mechanisms[49]:

1. ¶2 The **extent account** records area reduction (ha), disaggregated by conversion type (Section 3.1).
2. ¶3 The **condition account** records carbon stock decline across all pools.
3. ¶4 The **services flow account** records change in service supply: where NECB falls to zero or below following disturbance, the carbon sequestration service entry is set to zero (SEEA EA para. 6.114). Emission pulses are not recorded as negative service flows.

¶5 The physical measure for the carbon sequestration service is the Net Ecosystem Carbon Balance (NECB), preferred over Net Ecosystem Productivity because NECB additionally captures disturbance losses, harvest, and lateral fluxes.

¶6 Emission pulses from conversion are directed to the SEEA-CF Air Emission Accounts and to the SEEA-CF Thematic Carbon Stock Account (SEEA-CF 2028 Guidance Note D1, November 2025). Apply IPCC 2013 Wetlands Supplement Chapter 4 emission factors[50]:

Pool	Conversion driver	Default emission factor (IPCC 2013 WS)	Time profile
Above-ground biomass	Clear-cut (any driver)	(1 − harvested wood C retention fraction) x AGB stock	Year of conversion
Soil organic carbon (0–1 m)	Drainage for aquaculture, agriculture, settlements	**7.9 tC/ha/yr** (~29 tCO2/ha/yr) – tropical default for drained mangrove soils (Table 4.13, Section 4.2.2)	20 years post-drainage
Soil organic carbon (0–1 m)	Erosion exposing buried C	Site-specific (no Tier 1 default)	Year of exposure
Below-ground biomass	Conversion	Released with AGB unless retained as residue	Year of conversion

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¶7 The 7.9 tC/ha/yr factor is expressed in tonnes of carbon. Multiply by 44/12 for tCO2e. Cross-reference **TG-2.8 Climate Change Indicators** for NDC reporting.

Permanence and reversibility – accounting treatment

¶1 Physical carbon stocks are recorded at their measured face value. Risk adjustment belongs to the monetary valuation layer, not the physical account (SEEA EA para. 6.115)[51].

¶2 SEEA EA para. 6.114: "Where net carbon sequestration is zero or negative, the level of service supplied by an ecosystem is zero." A "permanence buffer" is a voluntary carbon market mechanism (e.g., Verra VM0033) and must not be applied to SEEA EA physical accounts.

¶3 Where blue carbon ecosystems are identified as "at risk": (a) prioritise high-quality measurement of the retention component (opening stock in tCO2e); and (b) update stock measurements more frequently, annually if feasible[52].

Non-CO2 greenhouse gases (CH4 and N2O)

¶1 CH4 (methane) contains one carbon atom per molecule and can be included in the carbon account expressed in tonnes of carbon. N2O contains no carbon and is out of scope for the

carbon account [53].

¶2 **Methane:** Include as an additional row in the carbon service account expressed in tC. A bridge table linking the carbon account (tC) to a GHG account (tCO2e) is recommended as a supplementary output. Where CH4 flux measurements are unavailable, apply IPCC Tier 1 defaults and document the omission.

¶3 Peer-reviewed evidence (Rosentreter et al. 2021, 2022) confirms CH4 emissions from tropical coastal wetlands can substantially offset CO2 sequestration benefits when expressed in CO2e.

¶4 **Supplementary GHG budget table:** Where a complete climate assessment is required, compile a supplementary table: CO2, CH4 (x GWP100 = 28), N2O (x GWP100 = 265), expressed as tCO2e/yr. This is supplementary and does not modify the core carbon account structure.

Tidal export and lateral carbon fluxes — scope note

¶1 Lateral carbon fluxes (DOC, POC, macroalgae from coastal ecosystems to the open ocean) are out of scope. No agreed accounting methodology exists, and attribution and permanence cannot be reliably established under any adopted framework [54]. Excluding lateral export introduces a conservative bias. Mangroves export an estimated 11–56 tC/ha/yr as POC and DOC (Bouillon et al. 2008). Future iterations will incorporate lateral export guidance as the evidence base matures.

Linking blue carbon accounts to national GHG inventories

¶1 Blue carbon ecosystem accounts are ecosystem accounts under the SEEA EA spatial perspective. National GHG inventories use the IPCC sector-based LULUCF framework. The two are complementary but not directly interchangeable [55].

¶2 The carbon sequestration service flow (NECB > 0, tCO2e/yr) corresponds directly to the sink function reported in LULUCF 4.C.1 (Coastal Wetlands). The extent account provides IPCC activity data. The retention service (opening stock, tCO2e) has no direct UNFCCC inventory equivalent.

¶3 **IPCC reporting category and unit conversion:** Blue carbon ecosystems are reported under LULUCF subcategory **4.C.1 — Coastal Wetlands**. Multiply NECB in tC/yr by **3.664** to obtain tCO2/yr, and multiply carbon stocks in tC by 3.664 for tCO2e comparison.

¶4 **Crosswalk — SEEA extent account to IPCC activity data:**

- ¶5 Managed reductions (aquaculture conversion) → IPCC “Land converted to Settlements” or “Land converted to Cropland”
- ¶6 Unmanaged reductions (erosion/SLR) → IPCC “Wetlands remaining Wetlands” with degradation flag
- ¶7 Managed expansions (restoration) → IPCC “Land converted to Wetlands (revegetation)”

¶8 **Large coastal wetland countries and peat-specific guidance:** For countries where coastal wetlands are a key category (Indonesia, Philippines, Malaysia, Madagascar, Australia, Brazil, Mexico), Tier 2 is the minimum for NDC and national communications. For countries with substantial coastal peatland (particularly Indonesia and Malaysia), apply IPCC Wetlands Supplement Chapter 4 Section 4.3 peat decomposition emission factors in addition to standard biomass and surface soil estimates.

¶9 **Recommended integration pathway:** Compile SEEA extent and condition accounts at the highest feasible tier; derive NECB via stock-difference method; classify data quality against IPCC tier framework; report to national GHG inventory compiler as Tier 2 or Tier 3 LULUCF input; document reconciliation between SEEA account boundaries and IPCC reporting categories. The SEEA-CF 2028 Guidance Note D1 (Carbon Stock Account, November 2025) describes the bridge table mechanism.

Carbon condition account (stock variables)

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Carbon Pool	Unit	Opening Stock (tC/ha)	Opening Total (tCO2e)	Closing Stock (tC/ha)	Closing Total (tCO2e)	Change (tCO2e)
Above-ground biomass	tC/ha					
Below-ground biomass	tC/ha					
Dead wood	tC/ha					
Litter	tC/ha					
Soil organic carbon (0-1m)	tC/ha					
Total carbon stock	tC/ha					

Carbon services flow account (flow variables)

Service Component	Physical Measure	Unit	Value
Carbon Retention			
Opening stock (reference for retention service)	tCO2e	tCO2e	
Carbon Sequestration (NECB)			
Net biomass carbon accumulation	tCO2e/yr	tCO2e/yr	
Net sediment carbon burial rate	tCO2e/yr	tCO2e/yr	
CH4 emissions (if measured)	tC/yr	tC/yr	
Total net sequestration (NECB)	tCO2e/yr	tCO2e/yr	

3.4 Coastal Protection Services

¶1 Coastal protection services are the ecosystem contributions of mangroves, saltmarshes, and other coastal wetlands in protecting shorelines from erosion, wave damage, and storm surge [56], [57]. The measurement approaches here are consistent with **TG-6.1 Coral Reef Accounting** Section 3.3, which supports cross-ecosystem aggregation. For general valuation methodology, see **TG-1.9 Valuation**.

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¶2 ⓘ **Recording rule — coastal protection service**

¶3 This Circular is the recording point for the coastal protection service supplied by mangroves, saltmarshes and other coastal wetlands. **TG-6.11 Coastal Infrastructure Accounting** Section 3.3.2 records the produced-asset side — the capital cost and depreciation of engineered and hybrid works — and cross-refers here for the service; it does not estimate a second protection value for the same area. **TG-6.15** Section 3.8 supplies the method for comparing the two.

Wave attenuation and storm surge reduction

¶1 Mangroves and saltmarshes reduce wave energy through friction with vegetation [58]. Wave height reductions of 13–66% per 100 metres of mangrove forest have been demonstrated, with higher attenuation in denser vegetation and lower water depths [59]. Saltmarshes attenuate approximately 78–95% over 100-metre widths [60].

¶2 Coastal wetlands also reduce storm surge heights by 4–50 cm per km of forest width depending on storm intensity and forest characteristics [61], [62]. Key factors determining supply:

- ¶3 Forest width and density
- ¶4 Species composition (different root structures provide varying resistance)
- ¶5 Bathymetry and coastal slope
- ¶6 Storm characteristics

¶7 **Reference values for benefit transfer and simplified spatial models:**

- ¶8 *Minimum mangrove width threshold:* 100 m for sheltered coastlines; 500 m for open-ocean exposed coasts (ABS 2022).
- ¶9 *Wave-height attenuation:* 30–70% per 100 m of vegetated width (McIvor et al. 2012); apply lower end to sparse/fragmented stands, upper end to dense mature stands.
- ¶10 *Global benefit transfer:* Menendez et al. (2020) report approximately USD 65 billion/yr avoided flood damages across 14 Mha globally; order-of-magnitude USD 4,600/ha/yr global average, adjusted by PPP and coastline exposure before local application.

¶11 Compilers with hydrodynamic modelling capacity should follow the World Bank expected damage function approach (World Bank 2016)[63]. Cross-reference **TG-2.8 Climate Change Indicators** for the linkage to climate-vulnerability indicators.

Physical measurement

¶1 Recommended metrics[64]:

- ¶2 **Wave attenuation rate** (% reduction per 100m width)
- ¶3 **Storm surge reduction** (cm reduction per km width)
- ¶4 **Shoreline erosion prevention** (m/yr erosion avoided)
- ¶5 **Protected coastline length** (km fronted by wetlands)

¶6 Beneficiary identification is essential: residential and commercial property owners; infrastructure; agricultural land; coastal communities.

Coastal protection service account

Metric	Unit	Value
Mangrove fringe width	m	
Wave attenuation rate	% per 100m	
Coastline protected	km	
Population protected	persons	
Property value protected	$	
Average annual protection service	$ avoided damages/yr	

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3.5 Nursery Habitat Services

¶1 Mangroves and coastal wetlands provide nursery habitat through structural complexity (roots and stems providing refuge), food resources (detritus and invertebrate prey), environmental moderation (reduced wave energy and thermal buffering), and connectivity to offshore adult habitats[65], [66]. The nursery function supports commercial and subsistence fisheries by providing juvenile habitat.

Ecological basis and intermediate service accounting

¶1 Nursery services are classified as intermediate ecosystem services in SEEA EA (para 6.15): they contribute to the final biomass provisioning services recorded in fisheries accounts[67]. To avoid double counting, nursery service values should not be added to the fisheries production they support. Record separately as an intermediate input using the supply-use framework in SEEA EA Chapter 7. If a fisheries accounting circular is compiled (e.g., TG-6.7), document the linkage explicitly[68].

Species-habitat relationships

¶1 Key evidence linking mangrove/wetland habitat to fisheries productivity[69], [70]:

- ¶2 Juvenile density surveys quantifying fish and invertebrate use of wetland habitats

- ¶3 Tagging and genetic studies tracing adult fish to nursery origins
- ¶4 Correlations between wetland extent and fisheries catch at regional scales

¶5 Published syntheses document positive relationships between mangrove area and catches of penaeid shrimp, mud crabs, barramundi, and snappers [71]. Anneboina & Kumar (2017) estimated the marginal effect at 1.86 t/ha fringe mangrove per year (~USD 1,900/ha/yr), derived from a stochastic production frontier model and not applicable as a universal transfer value without local calibration [72].

Fish recruitment metrics

Metric	Description
Juvenile fish density	Individuals per unit area or volume of habitat.
Species composition	Diversity and proportion of commercially important species.
Growth rates	Productivity of the nursery habitat.
Survival rates	Proportion of juveniles surviving to recruit to adult populations.
Recruitment contribution	Proportion of adult population derived from wetland nurseries.

¶1 Where field data are limited, wetland area with demonstrated fish use (based on published studies for the biogeographic region) provides a Tier 1 proxy.

¶2 **Allocation rule for intermediate vs final service value.** Record the intermediate nursery service at its marginal contribution to the final catch: production-function elasticity of catch with respect to nursery habitat multiplied by catch value. The final fisheries provisioning entry is reported net of this intermediate value. Published estimates indicate 30–50% of penaeid shrimp catch in tropical mangrove countries is traceable to mangrove nursery use (Hutchison et al. 2014). Cross-reference **TG-4.10 Fisheries Statistics and EBM** for the fisheries-account interface.

Nursery service account structure

Metric	Unit	Value
Wetland nursery habitat area	ha	
Juvenile fish density	individuals/ha	
Commercially important species	count	
Annual recruitment to fisheries	tonnes	
Proportion from wetland nurseries	%	
Contribution to fisheries production	tonnes/yr	

Provisioning services — partition with fisheries account

- ¶1 *Plant-derived NTFPs:* timber poles, fuelwood, honey, tannin, palm fronds, medicinal plants, dyes, and resins — recorded in this circular's provisioning section.
- ¶2 *Mangrove-substrate fauna harvest:* mud crab, cockle, wild shrimp post-larvae, mudskipper — route through the fisheries account (**TG-4.10**) where catch statistics exist. Where unavailable, record here as provisional pending fisheries account integration. The intermediate nursery allocation rule applies to wild post-larvae collection.

3.6 Valuation Methods

¶1 Monetary valuation applies the general framework from **TG-1.9 Valuation** to mangrove- and wetland-specific contexts [73].

Carbon pricing

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¶1 For blue carbon services [74]:

¶2 **Social cost of carbon (SCC):** Appropriate for the carbon retention component, applied as: (opening stock in tCO2e) x (SCC per tCO2e) x (rate of return). The SEEA Valuation gives a range of USD 14.9–80.5/t CO2 in 2020 [75], though subsequent analyses have revised that range substantially upward. Applying SCC to retention (standing stock) remains an area of active methodological debate, and the SEEA EA 2021 adopts the two-component model (Keith et al. 2019).

¶3 **Compliance market prices:** Appropriate for the carbon sequestration component [76]. Specify price source, date, and any adjustments applied. VCM prices are not recommended for SEEA-EA-aligned monetary accounts: VCM prices historically underestimate exchange values [77]. Obtain current prices from the World Bank State and Trends of Carbon Pricing report or national carbon pricing instruments.

Avoided damage valuation

¶1 Coastal protection services are valued using avoided damage cost methods [78]. The expected damage function (EDF) approach requires:

Element	Description
Hazard modelling	Probability distribution of storm events and surge heights/wave energy.
Exposure assessment	Identification and valuation of assets at risk.
Vulnerability functions	Relationship between hazard intensity and damage extent.
Counterfactual analysis	Comparison of damages with and without wetland protection.

¶2 Menendez et al. (2020) estimated global mangrove flood protection benefits exceed USD 65 billion annually [79], [80].

¶3 **Replacement cost methods** provide a Tier 2 alternative; for seawall unit cost benchmarks and annualisation procedure, see **TG-3.2 Flows from Environment to Economy** Section 3.5 [81].

¶4 **Benefit transfer:** Where primary EDF analysis is not feasible, draw on published global and regional valuations (Menendez et al. 2020; InVEST Coastal Vulnerability model), adjusting for coastline exposure, asset density, and PPP.

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Productivity change methods

¶1 Nursery habitat services are valued using productivity change methods [82]:

Step	Description
Production function estimation	Statistical relationship between wetland area/condition and fisheries catch.
Marginal productivity calculation	Additional catch attributable to marginal wetland area.
Market value application	Multiplication by appropriate fish prices.

¶2 Anneboina & Kumar (2017) estimated gross value at ~USD 1,900/ha/yr using a production frontier model for Indian mangroves [83], [84].

Aggregation and double counting

¶1 Carbon and coastal protection services are largely independent and additive. Nursery services are intermediate inputs and must not be summed with fisheries production values (see Section 3.5 allocation rule). The SEEA EA supply-use framework ensures each service flow is recorded once [85], [86].

Valuation summary table

Service	Valuation Method	Tier	Key Parameters
Carbon retention	Social cost of carbon	1-3	Carbon price, discount rate
Carbon sequestration	Compliance market price	2-3	Compliance market prices (VCM prices not SEEA-aligned)
Coastal protection	Avoided damage cost	2-3	Storm probabilities, asset values
Coastal protection	Replacement cost	2	Engineering cost estimates
Coastal protection	Benefit transfer	1	Published global estimates, PPP adjustment
Nursery habitat	Productivity change	2-3	Production function, fish prices
Nursery habitat	Habitat extent proxy	1	Area of suitable habitat, regional unit values

3.7 Compilation Procedure

¶1 **Step 1: Data Collection**

¶2 Compile: (1) spatial data (Landsat, Sentinel-2, SAR, national vegetation maps, protected area boundaries); (2) extent data (remote sensing, national wetland inventories, Global Mangrove Watch); (3) condition data (field surveys, remote sensing variables); (4) carbon data (biomass measurements, sediment cores, allometric equations, literature values); (5) service data (wave attenuation studies, storm assessments, fisheries statistics, juvenile fish surveys); (6) valuation data (carbon prices, coastal property values, fish prices, engineering cost estimates). Coordinate across environmental ministries, statistical offices, meteorological agencies, and fisheries authorities.

¶3 **Step 2: Classification and Mapping**

¶4 Map national classifications to IUCN GET functional groups (MFT1.1, MFT1.2, MFT1.3). Define EAA boundaries. Classify ecosystems by remote sensing. Validate using ground-truth surveys.

¶5 **Step 3: Extent Account Compilation**

¶6 Generate baseline extent map; detect changes using multi-date imagery; classify as managed/unmanaged expansions or reductions; populate extent account. Validate: Closing extent = Opening extent + Additions − Reductions.

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¶7 **Step 4: Condition Assessment**

¶8 Confirm minimum tier (IPCC Wetlands Supplement Tier Framework, Section 3.3) and record in account metadata. Select condition variables from all six ECT classes; measure using field surveys and remote sensing; establish reference conditions; normalise into indicators; compile condition account.

¶9 **Step 5: Ecosystem Service Quantification**

¶10 *Blue carbon:* Measure carbon stocks by pool; enter NECB into services flow account; document disturbance events and direct emission pulses to SEEA-CF accounts. Compile carbon condition account (stocks) and carbon services flow account (flows) as two separate tables.

¶11 *Coastal protection:* Map mangrove/wetland fringe and forest width; identify protected coastline and beneficiary populations; estimate wave attenuation; quantify storm surge reduction.

¶12 *Nursery habitat:* Delineate nursery habitat; measure juvenile fish density and species composition; estimate recruitment contribution; link extent/condition to fisheries production using production functions.

¶13 **Step 6: Monetary Valuation**

¶14 Apply carbon pricing (SCC for retention, compliance market price for sequestration; VCM prices are not SEEA-aligned). Calculate avoided damages or replacement costs for coastal protection. Estimate productivity contributions for nursery habitat. Document assumptions, price

sources, and uncertainty. For finance instrument applications, refer to **TG-1.8 OA and Project-Level Finance** [87] .

¶15 **Step 7: Account Integration and Balancing**

¶16 Reconcile accounts for mutual consistency. Check stock-flow balancing identities. Link to national ocean accounts, climate accounts, and fisheries accounts. Prepare metadata. Compile time series.

> *Note on additionality, leakage, and baseline analyses*
> *Where account outputs are intended to support carbon market instruments or results-based payments, additionality assessment, counterfactual baseline construction, and leakage analysis are applied on top of the account by the relevant market methodology (e.g., Verra VM0033). Document pre-intervention carbon stock values in the condition account to facilitate subsequent additionality assessment.*

3.8 Worked Example

¶1 This worked example demonstrates the full accounting sequence for a hypothetical coastal zone in a Southeast Asian setting. All data are synthetic and illustrative.

¶2 **Setting:** 8,000 ha of mangrove forest (MFT1.2) and 3,000 ha of salt marsh (MFT1.3), totalling 11,000 ha dominated by *Rhizophora* and *Avicennia* species.

¶3 **Step 1: Extent account (year t to t+1)**

Entry	Mangroves (MFT1.2)	Saltmarshes (MFT1.3)	Total
Opening extent (ha)	8,000	3,000	11,000
Additions to extent			
– Managed expansions (restoration planting)	120	25	145
– Unmanaged expansions (natural colonisation)	45	15	60
Total additions	165	40	205
Reductions in extent			
– Managed reductions (aquaculture conversion)	200	10	210
– Unmanaged reductions (erosion, storm damage)	65	30	95
Total reductions	265	40	305
Net change in extent	-100	0	-100
Closing extent (ha)	7,900	3,000	10,900

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¶4 **Interpretation:** Net loss of 100 ha of mangroves driven by aquaculture conversion exceeding restoration. Saltmarshes showed no net change.

¶5 **Step 2: Condition account**

¶6 Condition indicators derived from field survey and remote sensing, using minimally disturbed reference sites:

Condition variable	Observed value	VH (reference)	VL (degraded)	Indicator score
Canopy cover	72%	90%	20%	0.74
Seedling density	3,200 stems/ha	5,000	500	0.60
Sediment accretion rate	4.5 mm/yr	6.0	1.0	0.70
Water quality (dissolved oxygen)	5.8 mg/L	7.0	3.0	0.70

¶7 Composite condition index (equal weights): (0.74 + 0.60 + 0.70 + 0.70) / 4 = **0.69**

¶8 Indicator score calculated using the normalisation formula in **TG-2.1** Section 3.4.1. Example: canopy cover indicator = (72 - 20) / (90 - 20) = 52 / 70 = 0.74.

¶9 **Important:** The condition index of 0.69 is a tracker, not a carbon stock multiplier. Each pool is measured independently and entered at its measured value.

¶10 **Step 2b: Carbon condition account (mangroves, MFT1.2)**

Carbon pool	Method	Opening (tC/ha)	Closing (tC/ha)	Opening total (tC)	Closing total (tC)
Above-ground biomass	Komiyama et al. (2005) allometric	120	116	960,000	916,400
Below-ground biomass	Root:shoot ratio 0.70	84	81	672,000	640,000
Dead wood	Field inventory	5	5	40,000	39,500
Litter	Litterfall traps	2	2	16,000	15,800
SOC (0–1 m)	Sediment coring, bulk density	450	447	3,600,000	3,531,300
Total		**661**	**651**	**5,288,000**	**5,143,000**

¶11 Opening: 8,000 ha. Closing: 7,900 ha (net loss of 100 ha; 200 ha converted to aquaculture). Carbon fraction: a single illustrative 45% of dry biomass is applied to AGB and BGB; compilers apply the pool-specific fractions in footnote 34 (0.47 AGB, 0.39 BGB). SOC expressed directly in tC.

¶12 Net change: 5,143,000 − 5,288,000 = **−145,000 tC** (about 66,100 tC from the net loss of 100 ha at the opening density of 661 tC/ha, and about 79,000 tC from the decline of 10 tC/ha across the remaining 7,900 ha).

¶13 **Step 3a: Carbon services flow account (annual flows)**

Service flow component	Physical measure	Unit	Annual value
Change in biomass carbon pools (AGB, BGB, dead wood, litter)	Stock difference, Step 2b (−76,300 tC)	tCO2e/yr	−279,600
Change in soil organic carbon (0–1 m)	Stock difference, Step 2b (−68,700 tC)	tCO2e/yr	−251,700
Net ecosystem carbon balance (NECB)	Stock difference, −145,000 tC x 3.664	tCO2e/yr	−531,300
Net carbon sequestration service supply	NECB (floored at zero where negative)	**tCO2e/yr**	**0**

¶14 NECB is derived by the stock-difference method (Section 3.3): −145,000 tC x 3.664 = −531,300 tCO2e/yr. Because NECB is negative, the carbon sequestration service entry is set to zero (SEEA EA para. 6.114). A per-hectare burial or accumulation rate is not added on top of the measured stock change, which would double count. The loss is directed to SEEA-CF Air Emission Accounts (aquaculture sector) and the Thematic Carbon Stock Account. Carbon retention service (5,288,000 tC = 19,375,000 tCO2e opening stock) is recorded in the condition account above.

¶15 ⓘ **Corrected 24 September 2026**

¶16 This flow account previously showed net sequestration of +20,500 tCO2e/yr, built from per-hectare rates, while the measured stocks in Step 2b fell by 145,000 tC; on this circular's own stock-difference rule NECB is negative, so the sequestration service is now zero and the asset value falls from USD 201.3 million to USD 175.7 million.

¶17 **Step 3b: Ecosystem service monetary valuation summary**

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Service	Physical quantity	Monetary value (USD)
Carbon sequestration	0 tCO2e/yr (NECB negative)	0 (at USD 80/t CO2e)
Coastal protection	85 km coastline protected	6,400,000 (avoided damage)
Fisheries nursery habitat	2,100 tonnes recruitment	3,900,000 (productivity change)
Timber and NTFPs	1,500 m³ timber; assorted NTFPs	950,000 (market price)
Total valued services		**11,250,000**

¶18 *Carbon sequestration:* 0 x USD 80 = USD 0. The price applies in a period where NECB is positive.

¶19 *Coastal protection:* Expected damage function approach; avoided damages across storm probability distribution = USD 6.4 million/yr.

¶20 *Nursery habitat:* Marginal contribution: 0.25 t catch/ha/yr. Nursery area: 8,400 ha (8,000 ha mangrove fringe + 400 ha salt marsh adjacent to tidal creeks; 2,600 ha inland salt marsh excluded as lacking direct fish access). Contribution: 8,400 x 0.25 = 2,100 t/yr. At average fish price USD 1,857/t: USD 3,900,000. Note: If fisheries provisioning is separately valued in national accounts (TG-6.7), exclude the nursery value from the total to avoid double counting. Presented here for illustrative purposes.

¶21 **Step 4: Asset valuation**

> *Asset value = Annual service value x PV annuity factor (4%, 25 years) Asset value = 11,250,000 x 15.62 = **USD 175,700,000***

¶22 PV annuity factor: [1 - (1 + 0.04)^-25] / 0.04 = 15.62.

¶23 **Step 5: Upward connections to policy circulars**

¶24 **TG-2.8:** The net carbon stock change of –145,000 tC (–531,300 tCO2e, a net loss) and above-ground carbon stocks feed into NDC blue carbon reporting and SDG 13 monitoring.

¶25 **TG-2.9:** Coastal protection value of USD 6.4 million/yr and 85 km protected coastline feed into vulnerability assessments for disaster risk reduction.

¶26 **TG-1.8:** Asset value of USD 175.7 million and annual service flows provide the measurement foundation for blue bonds, debt-for-nature swaps, or payments for ecosystem services.

¶27 All values are illustrative. The carbon price of USD 80/t CO2e should be replaced with the prevailing compliance market price or social cost of carbon applicable in the compiler's jurisdiction.

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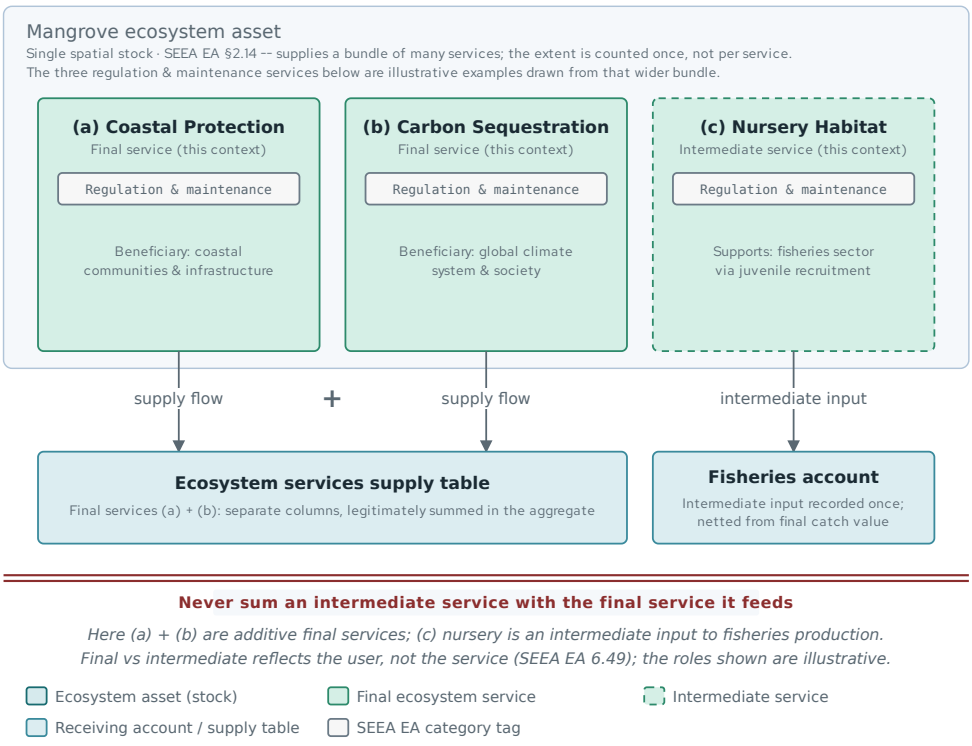


Figure 6.2.2 One mangrove ecosystem asset supplies a service bundle: two final services may be summed; nursery is intermediate; extent is counted once. Final/intermediate role is user-context dependent (SEEA EA para. 6.49).

Source: TG-6.2, Sections 3.3--3.6 (mangrove service bundle worked example); final/intermediate distinction per SEEA EA 2024, paras. 6.24 and 6.49; nursery treatment per para 6.15.

Adapted from: SEEA EA 2024 ecosystem service concepts (Chapter 6), with GOAP extensions (final/intermediate routing, single-extent caution, beneficiary sub-labels, illustrative-subset framing).

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4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

5. References and Further Reading

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FOOTNOTES

1. ¶1 IUCN GET describes the MFT1 Brackish Tidal Systems biome as "associated with prograding depositional shorelines at the interface of terrestrial, freshwater, and marine realms."
2. ¶2 IUCN GET, Biome MFT1 description; SEEA EA, Appendix A3.2 presents the IUCN GET reference classification.
3. ¶3 SEEA EA, para 4.11-4.12 on ecosystem type classification and the relationship between national classifications and the international reference classification.
4. ¶4 SEEA EA, para 1.1, noting that "ecosystem accounting provides a basis for compiling coherent and systematic data on the biophysical characteristics of ecosystems and their contribution to the economy and society"; see also World Bank (2016) on mangrove values.
5. ¶5 SEEA EA, para 4.1: "Ecosystem extent is the size of an ecosystem asset. It is usually measured in terms of spatial area."
6. ¶6 SEEA EA, para 4.11-4.12 on ecosystem type classification.
7. ¶7 National classification systems may distinguish mangrove types based on dominant species or structural classes; see FAO mangrove classification systems.
8. ¶8 SEEA EEA Technical Recommendations, Chapter 3 on spatial data organization.
9. ¶9 SEEA EEA Technical Recommendations, para 3.79.
0. ¶10 SAR applications for mangrove mapping are well-established; see references in Global Mangrove Watch methodology.
1. ¶11 Global Mangrove Watch provides globally consistent annual mangrove extent maps; available at www.globalmangrovewatch.org (http://www.globalmangrovewatch.org).
2. ¶12 Murray et al. (2019) on global tidal wetland change mapping.
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4. ¶14 IPCC (2006/2019 Refinement), Volume 4, Chapter 3 on consistent representation of lands. See also Bunting et al. (2018) on Global Mangrove Watch accuracy assessment procedures.
5. ¶15 SEEA EA, para 4.16.
6. ¶16 SEEA EA, para 4.8.
7. ¶17 SEEA EA, Table 4.1 provides the ecosystem extent account structure.
8. ¶18 SEEA EA, para 5.1: "Ecosystem condition accounts provide a structured approach to recording and aggregating data describing the characteristics of ecosystem assets and how they have changed."
9. ¶19 SEEA EA, para 5.2.
0. ¶20 SEEA EA, Section 5.2.4 on ecosystem condition variables and their selection.
1. ¶21 SEEA EA, Table 5.1 presents the SEEA Ecosystem Condition Typology with six classes.
2. ¶22 SEEA EA, para 5.36.
3. ¶23 SEEA EA, para 5.35.
4. ¶24 Hydrological connectivity is fundamental to tidal wetland function; disruption is a major driver of degradation globally.
5. ¶25 SEEA EA, para 5.11 notes ecosystem resilience considerations; sediment elevation monitoring is critical for sea-level rise adaptation.
6. ¶26 SEEA EA, Section 5.3 on reference conditions for ecosystem condition assessment.
7. ¶27 UNSD (2023), Method of the Ecosystem Condition Account; Howard et al. (2014) on minimum plot specifications for blue carbon surveys; GFOI (2025) on sampling requirements for national inventory submissions.
8. ¶28 SEEA EA, paras 6.110-6.115; UNSD (2023), Method of the Ecosystem Condition Account. SOC non-proportional degradation is well-established: deep sediment SOC may persist for centuries even after surface biomass removal because anaerobic conditions limit decomposition.
9. ¶29 SEEA EA, Table 5.2 provides the ecosystem condition variable account structure.
0. ¶30 United Nations (2022), Monetary Valuation Technical Report v1.5, Section 4.2.9; Keith et al. (2019), London Group paper on accounting for carbon stocks and flows.
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3. ¶33 SEEA EA, para 6.114; Lim et al. (2025) on macroalgal ecosystem inclusion in IPCC inventories.
4. ¶34 IPCC 2013 Wetlands Supplement provides methodology for blue carbon stock accounting across five standard pools.
5. ¶35 Above-ground biomass carbon fraction of 0.47 is sourced from IPCC 2006 Guidelines Volume 4 Chapter 4 Table 4.3 (forest biomass carbon fraction). Below-ground biomass carbon fraction of 0.39 is the mangrove-specific value derived from Kauffman et al. (2011) measurements and tabulated in Howard et al. (2014) Table 3.1; this should not be attributed solely to Kauffman & Donato (2012).
6. ¶36 Komiyama et al. (2008) on mangrove root:shoot ratios and allometry.
7. ¶37 IPCC 2013 Wetlands Supplement recommends 1-metre depth for sediment carbon reporting as the standard minimum. Howard et al. (2014) provide coring protocols for depths beyond 1 metre in high-carbon systems.
8. ¶38 IPCC (2013), Wetlands Supplement, Chapter 4; Murdiyarso et al. (2023) on national-scale Tier 2 methodology in Indonesia; Howard et al. (2014) on Tier 3 field protocols.
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0. ¶40 Berger et al. (2020) on allometric uncertainty quantification; SEEA EA conventions on uncertainty reporting in metadata rather than account tables.
1. ¶41 The distinction between carbon storage (stock) and sequestration (flow) is fundamental to carbon accounting; see SEEA Valuation Section 4.2.9.
2. ¶42 SEEA Valuation, Section 4.2.9 on carbon sequestration measurement.
3. ¶43 Duarte et al. (2005); Mcleod et al. (2011) on mangrove carbon sequestration rates.
4. ¶44 Chmura et al. (2003) on saltmarsh carbon sequestration.
5. ¶45 SEEA Valuation, Section 4.2.9 on carbon retention scope.
6. ¶46 SEEA EA and SEEA Valuation recommend distinguishing carbon retention and sequestration components; Keith et al. (2019).
7. ¶47 Arias-Ortiz et al. (2018) global synthesis of 210Pb-derived carbon accumulation rates.
8. ¶48 Cahoon et al. (1995) on the feldspar marker horizon technique; Piñeiro-Juncal et al. (2023) on mixed layer corrections and burial rate quantification.
9. ¶49 SEEA EA, paras 6.110-6.115 on disturbance treatment in ecosystem accounts; IPCC 2013 Wetlands Supplement, Chapter 4.
0. ¶50 UNSD/SEEA Technical Committee (2025), Draft Guidance Note D1 — Carbon Stock Account; UNSD/SEEA Technical Committee (2025), Draft Guidance Note B3; IPCC (2013), Wetlands Supplement, Chapter 4 emission factors for conversion events.
1. ¶51 SEEA EA, paras 6.110-6.115.
2. ¶52 SEEA EA, para 6.114; Verra (2018), VM0033; Bertram et al. (2021) on blue carbon wealth of nations and risk assessment.
3. ¶53 Rosentreter et al. (2021, 2022); UNSD/SEEA Technical Committee (2025), Draft Guidance Note D1.
4. ¶54 Bouillon et al. (2008) on mangrove carbon export; High Level Panel for a Sustainable Ocean Economy (2023), Blue Carbon Handbook; Howard et al. (2014).
5. ¶55 GFOI (2025), Blue Carbon Guidance for National GHG Inventories; UNSD/SEEA Technical Committee (2025), Draft Guidance Note D1; IPCC (2013), Wetlands Supplement, Chapter 4; Blue Carbon Partnership (2021).
6. ¶56 SEEA EA, Section 6.3 on ecosystem service reference list includes coastal protection.
7. ¶57 SEEA Valuation, Section 4.2.13 on coastal protection definition.
8. ¶58 Wave attenuation by mangroves has been extensively studied; see McIvor et al. (2012) review.
9. ¶59 Wave attenuation rates vary widely; ranges from synthesis studies.
0. ¶60 Saltmarsh wave attenuation from Moller et al. (2014) and related studies.
1. ¶61 Storm surge attenuation mechanisms differ from wave attenuation; both contribute to coastal protection.
2. ¶62 Storm surge reduction estimates from Krauss et al. (2009) and related studies.
3. ¶63 SEEA Valuation, Section 4.2.13 references World Bank (2016).
4. ¶64 World Bank (2016) provides detailed methodology for coastal protection measurement.
5. ¶65 Blue carbon terminology established by Nellemann et al. (2009); widely adopted in IPCC and UNFCCC contexts. For seagrass-specific guidance, see TG-6.3 Seagrass Ecosystem Accounting.
6. ¶66 Ecological mechanisms of mangrove nursery function; see Nagelkerken et al. (2008).
7. ¶67 SEEA EA reference list definition of nursery population and habitat maintenance services; SEEA Valuation, Section 4.2.14.
8. ¶68 SEEA EA, para 6.15.
9. ¶69 Quantifying nursery-fisheries linkages is essential but methodologically challenging.
0. ¶70 Nursery function metrics following Beck et al. (2001) framework.
1. ¶71 Multiple studies document mangrove-fisheries correlations; see Hutchison et al. (2014) meta-analysis.
2. ¶72 SEEA Valuation, Section 4.2.14 citing Anneboina and Kumar (2017).
3. ¶73 SEEA EA, Chapter 10 on ecosystem asset valuation; SEEA Valuation provides comprehensive guidance.

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4. ¶74 SEEA Valuation, Section 4.2.9 on carbon pricing approaches.
5. ¶75 SEEA Valuation, Section 4.2.9 on social cost of carbon estimates.
6. ¶76 SEEA Valuation, Section 4.2.9 on compliance market prices.
7. ¶77 United Nations (2022), Monetary Valuation Technical Report v1.5, Section 4.2.9; Edens et al. (2019); Keith et al. (2019).
8. ¶78 SEEA Valuation, Section 4.2.13 on coastal protection valuation methods.
9. ¶79 SEEA Valuation, Section 4.2.13.
0. ¶80 SEEA Valuation, Section 4.2.13 citing Menendez et al. (2020).
1. ¶81 SEEA Valuation, Section 4.2.13 notes replacement cost as Tier 2 method.
2. ¶82 SEEA Valuation, Section 4.2.14 on productivity change methods for nursery services.
3. ¶83 SEEA Valuation, Section 4.2.14.
4. ¶84 SEEA Valuation, Section 4.2.14 citing Anneboina and Kumar (2017).
5. ¶85 SEEA EA, Section 7.3 on avoiding double counting in ecosystem service accounting.
6. ¶86 SEEA EA supply-use framework ensures consistent recording of service flows.
7. ¶87 Verra (2018), VM0033 Methodology for Tidal Wetland and Seagrass Restoration.

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Seagrass Ecosystem Accounting

Provides seagrass-specific guidance for ecosystem accounts, covering subtidal mapping, species-dependent service parameters and the blue carbon storage–sequestration distinction.

Version 0.9.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This circular provides seagrass-specific guidance for ecosystem accounts. It addresses the distinct challenges of subtidal mapping, species-dependent service parameters, and the blue carbon storage—sequestration distinction.
Upon implementation, countries will be able to: (a) compile seagrass extent accounts; (b) develop condition accounts using seagrass-specific indicators; (c) quantify ecosystem service flows, with emphasis on carbon sequestration, nursery habitat, and coastal protection; and (d) apply monetary valuation and integrate seagrass accounts within national ocean accounting frameworks.
Carbon stock and sequestration methods align with the parallel blue carbon guidance for mangroves and coastal wetlands in TG-6.2 Mangrove and Coastal Wetland Accounting.

Framework Position

This Circular owns the extent, condition, service and asset accounts for IUCN GET M1.1 seagrass meadows, and the seagrass-specific measurement problems: subtidal optical limits and deep-meadow undercoverage, species-dependent service parameters, and the carbon storage-versus-sequestration distinction.
It cross-refers for the account structure and the NPV and condition-adjustment rules (TG-3.1), extent and condition measurement (TG-4.1, TG-4.8, TG-4.9) and indicator derivation (TG-2.1, TG-2.4).
The carbon pricing rule is not this Circular's: it is owned by TG-6.2 Section 3.6 and applies unchanged to seagrass. This matters because seagrass credits trade almost entirely on the voluntary market, which that rule excludes.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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1. Outcome

¶1 This circular provides seagrass-specific guidance for ecosystem accounts. It addresses the distinct challenges of subtidal mapping, species-dependent service parameters, and the blue carbon storage–sequestration distinction.[1]

¶2 Upon implementation, countries will be able to: (a) compile seagrass extent accounts; (b) develop condition accounts using seagrass-specific indicators; (c) quantify ecosystem service flows, with emphasis on carbon sequestration, nursery habitat, and coastal protection; and (d) apply monetary valuation and integrate seagrass accounts within national ocean accounting frameworks.[2]

¶3 Carbon stock and sequestration methods align with the parallel blue carbon guidance for mangroves and coastal wetlands in **TG-6.2 Mangrove and Coastal Wetland Accounting**.

¶4 ⓘ **Framework Position**

¶5 This Circular owns the extent, condition, service and asset accounts for **IUCN GET M1.1 seagrass meadows**, and the seagrass-specific measurement problems: subtidal optical limits and deep-meadow undercoverage, species-dependent service parameters, and the carbon storage-versus-sequestration distinction.

¶6 It cross-refers for the account structure and the NPV and condition-adjustment rules (**TG-3.1**), extent and condition measurement (**TG-4.1**, **TG-4.8**, **TG-4.9**) and indicator derivation (**TG-2.1**, **TG-2.4**).

¶7 The **carbon pricing rule is not this Circular's**: it is owned by **TG-6.2** Section 3.6 and applies unchanged to seagrass. This matters because seagrass credits trade almost entirely on the voluntary market, which that rule excludes.

2. Requirements

2.1 Prerequisite Knowledge

¶1 This Circular requires familiarity with:

- ¶2 **TG-0.1 General Introduction** – ocean accounts framework and terminology.
- ¶3 **TG-0.7 Quality Assurance** – applied to deep-meadow undercoverage (Section 3.1.2) and the compilation procedure (Step 8).
- ¶4 **TG-2.1 Biophysical Indicators** – indicator-selection framework and the normalisation formula applied in Section 3.2.
- ¶5 **TG-2.4 Ecosystem Goods and Services** – service identification methodology applied in Section 3.3.
- ¶6 **TG-2.8 Climate Change Indicators** – climate-account linkages for carbon services (Sections 3.3.2, 3.4.1).
- ¶7 **TG-3.1 Asset Accounts** – extent and condition account templates applied throughout Section 3.
- ¶8 **TG-4.1 Remote Sensing and Geospatial Data** – satellite platforms, water-column correction, and mapping QA, supplemented by acoustic methods in Section 3.1.3 below.

¶9 **TG-1.9 Valuation** is not a direct prerequisite (physical accounts may be compiled without monetary valuation), but is required where Section 3.4 is applied.[3]

2.2 Institutional and Technical Requirements

¶1 Coordination across NSO, marine environment agency, and fisheries authority follows **TG-0.1**. Technical capacity is required for: (a) optical satellite classification and acoustic survey for extent mapping (Section 3.1); (b) field measurement of shoot density, canopy height, percent cover, and epiphyte load; (c) carbon stock estimation following Fourqurean et al. (2012) and Howard et al. (2014); and (d) biophysical modelling per the SEEA EA guidelines.[4]

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¶2 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

3.1 Extent Accounting

¶1 The extent account structure (opening stock, additions, reductions, closing stock) follows **TG-3.1** Section 3.4. This section addresses seagrass-specific issues: subtidal detection limits, species-level stratification, and the acoustic methods required for deep meadows.[5]

3.1.1 Classification Framework

¶1 Seagrass meadows correspond to IUCN GET functional group **M1.1 Seagrass meadows** (Marine Shelf biome M1). The GET hierarchy and national crosswalk requirement are in **TG-4.1** Section 3.2.4.[6] National classifications should disaggregate by:

- ¶2 **Dominant species** (e.g., *Posidonia*, *Zostera*, *Thalassia*, *Halophila*): a required stratification, since carbon, productivity, and service parameters differ by up to an order of magnitude across genera (Section 3.2)
- ¶3 **Depth zone** (intertidal versus subtidal)
- ¶4 **Density class** (sparse, moderate, dense)

3.1.2 Mapping Challenges

¶1 Optical remote sensing is limited to approximately 10–15 m depth in clear waters and less in turbid coastal environments.[7] Meadows below that limit are undetectable by standard optical methods and require the acoustic methods in Section 3.1.3. In exceptionally clear waters they reach 40–60 m. Additional constraints include spectral confusion with macroalgae and bare sediment,[8] seasonal biomass variation (30–50% in temperate regions, so imagery acquisition should be timed consistently across years), and fragmented patch distributions that demand higher-resolution imagery.

¶2 As TG-4.1 focuses on optical and bathymetric platforms, this circular serves as the interim GOAP reference for acoustic survey methods pending a dedicated acoustic circular.

3.1.3 Mapping Methods

¶1 Tiered approach following GOAP convention:[9]

¶2 **Tier 1 — Global data products.** UNEP-WCMC Global Distribution of Seagrasses, Allen Coral Atlas benthic classes (see **TG-4.1** Section 3.2.2), and regional initiatives. Indicative only, with insufficient temporal consistency for formal accounts.[10]

¶3 **Tier 2 — Satellite classification.** Sentinel-2 (10 m visible bands, 5-day revisit) and Landsat with supervised classification, object-based analysis, water-column correction, and multi-temporal compositing. Platform specifications in **TG-4.1** Section 3.1.1. Field ground-truthing is required.

¶4 **Tier 3 — Integrated multi-source mapping.** Optical satellite combined with aerial/UAV imagery, **acoustic surveys** (sidescan sonar or multibeam echosounder at 100–500 kHz, detecting seagrass-sediment contrast beyond 30 m depth[11]), underwater video transects, and diver surveys. Acoustic protocols and calibration must be documented to enable reproducibility across accounting periods.

3.1.4 Recording Extent Changes

¶1 Extent change categories follow SEEA EA Table 4.2:

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Change category	Description
Managed expansion	Restoration, transplanting, or facilitated recovery through pressure reduction.
Managed reduction	Dredging, coastal development, infrastructure.
Natural expansion	Colonisation of suitable substrates, recovery from disturbance.
Natural reduction	Storm damage, disease, grazing.
Catastrophic losses	Marine heatwaves, sediment burial, toxic algal blooms, oil spills.

¶2 Anthropogenic pressure-driven loss is recorded under "Other reductions — degradation" (SEEA EA Table 4.2), with optional memorandum sub-rows attributing the pressure category. The principal pressure categories from the seagrass-loss literature (Waycott et al. 2009; Dunic et al. 2021) are eutrophication, sediment loading from coastal development, physical disturbance (anchoring, propeller scarring, dredging), destructive fishing gear, coastal engineering, marine heatwaves, and wasting disease.[12] The memorandum-row convention is demonstrated in Section 3.6 Step 1.

3.2 Condition Assessment

¶1 The SEEA EA three-stage approach (variables → indicators → optional composite) and the normalisation formula are defined in **TG-3.1** Section 3.5.2 and **TG-2.1** Section 3.4.1. The measurement protocols for the variables themselves — how each is observed, at what frequency and to what tolerance — are owned by **TG-4.8 Physical Condition Measurement** and **TG-4.9 Biological Condition Measurement**; this Section selects and interprets them for seagrass meadows.

¶2 **Species identity is a stratification variable, not a condition indicator.** *Posidonia oceanica*, *Thalassia testudinum*, *Zostera marina*, *Halophila* spp., and *Enhalus acoroides* differ in morphology, longevity, and carbon density by up to an order of magnitude, so reference values and service coefficients must be selected per genus.

¶3 **Sediment organic carbon stock is an asset attribute, not a condition variable**, and is treated in Section 3.3.2 to avoid double counting. Where a sediment-carbon condition signal is desired, use a process metric (observed sediment accumulation rate against a reference rate) rather than the stock.

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3.2.1 Condition Variables

¶1 Candidate variables fall into four groups: structural (shoot density, canopy height, percent cover, above- and below-ground biomass), sediment process (grain size, accumulation rate, sulphide concentrations), water quality (Kd, Secchi depth, nutrient and chlorophyll-a concentrations), and associated biota (epiphyte load, mesograzer abundance, fish community).[13] The recommended minimum set for international comparability is in Table 3.2.1.

¶2 *Table 3.2.1: Recommended minimum condition variables for seagrass ecosystem accounts*

Condition Variable	Measurement	Indicator Direction	Reference Condition	Data Source
Percent cover	% bottom covered	Positive (higher = better)	Site-specific historical	Remote sensing, transects
Shoot density	Shoots/m²	Positive (higher = better)	Species-specific	Quadrat sampling
Canopy height	cm	Positive (higher = better)	Species-specific	Field measurement
Epiphyte load	% coverage	Inverse (lower = better)	Low (indicative default: < 10%)	Visual assessment
Species diversity	Species count	Positive (higher = better)	Site-specific	Surveys

¶3 **QA check:** indicators should fall within [0, 1]. Values outside this range indicate a direction or reference-level error.

3.2.2 Reference Conditions

¶1 Few pristine seagrass meadows remain and historical baselines are typically unavailable. Compilers should apply the SEEA EA reference-condition hierarchy on a document-and-justify basis: natural reference preferred, historical baseline where natural is undeterminable, best observed as fallback, and policy target where mandated for regulatory reporting.[14] Sources include protected marine areas, historical photographs and traditional knowledge, palaeoecological sediment cores, and scientific literature on relatively pristine systems.

3.2.3 Condition Indicators

¶1 The illustrative table below uses the Table 3.2.1 minimum set. The simplified ratio shown is for introductory purposes only.

Variable	Reference Value	Current Value	Indicator
Percent cover	60%	45%	0.75
Shoot density	800 shoots/m²	560 shoots/m²	0.70
Canopy height	40 cm	28 cm	0.70
Epiphyte load (inverse)	< 10% (VH); 50% (VL)	18%	0.80
Species diversity	7 species	5 species	0.71

¶2 Note: The percent cover, shoot density, canopy height, and species diversity rows use the simplified ratio of current value to reference value, equivalent to the full normalisation formula (defined in **TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.1) only when VL = 0. The epiphyte load row is an inverse indicator. Compilers should apply the full formula with site-specific VL values, as demonstrated in the worked example (Section 3.6) and the compilation procedure (Step 4). Where additional indicators are illustrated outside the minimum set (e.g., light at depth, sediment process metrics), they should be flagged as supplementary.

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3.2.4 Composite Condition Indices

¶1 Where condition indicators are aggregated into a single composite index, compilers may apply one of four documented approaches:

Approach	Strength	Limitation
Equal-weight (documented default)	Transparent, no training data required, easily replicated	Treats unequal-signal metrics as equivalent; can dilute the dominant structural indicator
Local-expert weighting	Captures site-specific ecological knowledge; prioritises relevant structural indicator	Subjective; reduced inter-jurisdiction comparability
Data-driven (PCA / factor analysis)	Empirically derived from pressure-response data; objective	Requires large multi-site training dataset; weights not easily transferable
Regulatory-endorsed multimetric	Comparable across reporting unit; pre-validated thresholds	Fixed metric set restricts updating; jurisdiction-bounded

¶2 GOAP does not endorse a single index. Worked examples in the published literature include SEQI (Indonesia), POMI and BiPo (W Mediterranean), PREI (France WFD), SQI (UK WFD), GBR MMP Seagrass Condition Index, and Chesapeake Bay SAV scorecard.[15] Compilers selecting an equal-weight default should specify which structural indicator (shoot density or canopy cover) anchors the composite, document any metric excluded or down-weighted, and defer to regulatory indices

where the accounting unit overlaps a regulatory reporting unit. The worked example in Section 3.6 uses the equal-weight default for illustrative purposes.

3.3 Ecosystem Services

¶1 Services are organised per SEEA EA classification. The general identification and measurement framework is in **TG-2.4**.

¶2 ⓘ **Recording rule — coastal protection service**

¶3 This Circular is the recording point for the coastal protection service supplied by seagrass meadows. **TG-6.11 Coastal Infrastructure Accounting** Section 3.3.2 records the produced-asset side — the capital cost and depreciation of engineered and hybrid works — and cross-refers here for the service; it does not estimate a second protection value for the same area. **TG-6.15** Section 3.8 supplies the method for comparing the two.

3.3.1 Provisioning Services

¶1 **Biomass provisioning.** Seagrass-attributable fish catch is estimated through catch data from associated fishing grounds, bio-economic models linking extent to productivity, meta-analysis of seagrass-fishery relationships,[16] or trophic-based seagrass dependency (TB-SGd), a food-web network analysis tracing the proportion of each trophic level's biomass originating from seagrass as a primary producer (Addamo et al. 2024).[17] TB-SGd is more rigorous than habitat-area ratios where trophic data are available.

¶2 Only the ecosystem contribution should be attributed (excluding labour, capital, technology). Residual value and simulation methods are in SEEA EA and **TG-2.4 Environmental (including Ecosystem) Goods and Services** Section 3.10.[18] The seagrass-attributable share may appear small (Addamo et al. estimate ~1% for a Mediterranean model), yet the entire dependent catch is at risk if seagrass disappears. Compilers may record this broader 'flow at risk' as a supplementary memorandum entry distinct from the directly attributed flow.[19]

¶3 **Raw biomass provision (prospective service).** Stranded seagrass leaves (banquettes) have potential uses as biofuel feedstock, soil amendments, and composite materials.[20] Conservative valuation uses the avoided cost of removal and disposal (approx. EUR 30–155 per tonne; Di Gennaro 2018; Balata and Tola 2016). Record as prospective, and flag species-specific leaf-turnover and local waste-management costs.

¶4 **Other provisioning.** Traditional uses (thatching, fertiliser, crafts) are typically minor in economic terms.

3.3.2 Regulating and Maintenance Services

¶1 **Global climate regulation — carbon sequestration and storage.** Two distinct services:

- ¶2 **Carbon sequestration** (Cseq) — annual flux into long-term storage, recorded as service flow (tonnes CO2e/ha/yr). Mean long-term burial rates 48–138 g C/m²/yr (1.8–5.1 t CO2e/ha/yr), distinct from total NPP (>400 g C/m²/yr but not equivalent to sequestration).[21]
- ¶3 **Carbon storage** (Cstor) — long-term sediment stock (up to 140 Mg C/ha in top 1 m, with ~90% of total seagrass carbon held in soils), recorded as asset stock attribute. Cstor accumulates over centuries to millennia and can be permanently released if meadows are destroyed.[22]

¶4 The three-pool measurement framework (above-ground biomass, below-ground biomass, sediment organic carbon) and IPCC Wetlands Supplement Tier framework are in **TG-6.2 §3.3**. Species-appropriate values must be used: *Posidonia* stocks and rates exceed *Halophila* by up to an order of magnitude.

¶5 Where meadows are being lost, the climate regulation entry records both annual sequestration flow and the emissions associated with degradation. Condition–service linkage may be quantified

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through regression of shoot density or percent cover against carbon accumulation rates per the SEEA EA biophysical-modelling guidelines.[23]

¶6 **Coastal and sediment stabilisation.** Seagrass canopies attenuate wave energy at 20–40% per 100 m of meadow width (Ondiviela et al. 2014[24]). Measured through wave-attenuation rates, sediment trapping, and erosion comparisons between protected and unprotected coastlines. Valuation by replacement cost / avoided damage per Section 3.4.2 and **TG-1.9**.

¶7 **Water purification and nutrient cycling.** Denitrification in seagrass sediments can exceed unvegetated rates by 2–4x.[25] Nutrient-removal capacity exhibits non-linear threshold and hysteresis behaviour: where epiphyte cover exceeds the Table 3.2.1 threshold (indicative default: 10%), apply a condition-adjusted service flow scaling capacity by canopy health. Where eutrophication has caused meadow collapse, record as zero. Compilers with local evidence for a different threshold should document and cite it.

¶8 **Nursery population and habitat maintenance.** Seagrass meadows are nursery habitat for snapper, sea bream, mullet, prawns, blue swimmer crabs, scallops, queen conch, and megafauna (dugongs, green turtles).[26] The nursery-as-intermediate-service double-counting method follows **TG-6.2 §3.5**. **GOAP default for seagrass:** where stage-structured production-function data are unavailable, assign the full seagrass-attributable fisheries contribution to biomass provisioning (Section 3.3.1). Where such data exist, the contribution may be apportioned between nursery habitat and biomass provisioning, with the partitioning method documented and verified to sum without overlap.

3.3.3 Cultural Services

¶1 **Recreation and tourism.** Snorkelling, diving, recreational fishing, and megafauna viewing (dugongs, manatees, turtles). Measured via visitor numbers, expenditure, or travel cost / revealed preference studies. **Seagrass-density and megafauna-density proxies:** where direct visitor data are unavailable, shoot density (proxy for dive-site attractiveness) and dependent-megafauna density rank recreation opportunity into high/medium/low classes with per-visit net benefit values. Addamo et al. (2024) demonstrate this for the Mediterranean using logit (visit probability) and Poisson (visit frequency) models with landscape and demographic covariates.[27] The full nature-based recreation value associated with seagrass-dependent megafauna may be at risk if seagrass disappears, even where direct attribution is small (flow-at-risk concept, see Section 3.3.1).

¶2 **Education and research.** Sites for marine education and scientific research. Such sites are difficult to quantify but support knowledge generation.

3.4 Valuation Methods

¶1 The exchange-value preference hierarchy is in **TG-2.4 Environmental (including Ecosystem) Goods and Services** Section 3.10 and **TG-3.2 Flows from Environment to Economy**. The seagrass-specific application follows below.

3.4.1 Valuing Carbon Sequestration

¶1 The carbon pricing rule is common to all blue carbon ecosystems and is owned by **TG-6.2 Mangrove and Coastal Wetland Accounting** Section 3.6, which applies the SEEA EA two-component model: the **social cost of carbon** for the retention (stock) component, and **compliance market prices** for the sequestration (flow) component.[28] It is not restated here.

¶2 Two points bear on seagrass specifically. Voluntary carbon market prices are **not** used for SEEA-EA-aligned monetary accounts, which matters more for seagrass than for mangroves because seagrass credits are traded almost entirely on the voluntary market and seagrass-specific methodologies remain under development.[29] And the price must be the same one applied to mangroves, saltmarsh and terrestrial sinks in the same account: a national account that prices mangrove carbon at

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the social cost of carbon and seagrass carbon at a voluntary credit price is internally inconsistent (**TG-2.8**).

3.4.2 Replacement Cost Approaches

¶1 **Coastal protection.** Replacement-cost / avoided-damage method including seawall unit costs and annualisation is in **TG-3.2 Flows from Environment to Economy** Section 3.5. The seagrass-specific parameter is wave-attenuation capacity (20–40% per 100 m of meadow width; Ondiviela et al. 2014 [24]). Document protected-coastline length and attenuation rate in the service flow record.

¶2 **Water purification.** Tertiary-treatment unit costs vary by orders of magnitude across jurisdictions. Derive them from national wastewater cost data and document the source.

¶3 Replacement-cost approaches assume the engineered alternative would actually be built and provides equivalent benefits. [30]

3.4.3 Fisheries Contribution

¶1 Per the GOAP default (Section 3.3.2), the full seagrass-attributable contribution is recorded under biomass provisioning, valued as the seagrass-attributable share of landed catch (ex-vessel price × physical share). Where stage-structured production-function data exist, apportion between nursery and biomass provisioning, documenting the partitioning and verifying no overlap. Methods: **production function** (econometric models of extent–catch relationship), [31] **resource rent** apportioned between stocks and habitat (see **TG-3.1** Section 3.3), and **benefit transfer** with context adjustment. [32]

3.4.4 Asset Valuation

¶1 The NPV method, the perpetuity-or-finite-horizon choice, and the rule that the condition index is applied **once** – at the physical service flow stage, not again at discounting – are set out in **TG-3.1 Asset Accounts** Section 3.5.3 and are not restated here. [33] In this Circular the single application is at Step 3 of the compilation procedure, where the literature-derived service rate is treated as a reference-condition value and scaled by the composite condition index; Step 4 then discounts that condition-adjusted flow directly.

¶2 A perpetuity is defensible for seagrass assets under effective protection and management. It is not defensible for a meadow on a documented declining trajectory, which is the more common case: project the service flow forward on the trend instead, and state the assumption. Discount-rate choice matters more for seagrass than for most marine assets because carbon storage dominates the service mix and has the longest horizon; the rate must be the one used for other natural assets in the same national accounts. [34]

3.5 Compilation Procedure

Step 1: Delineate EAA and stratify by species

¶1 Delineate the EAA per **TG-4.1** Section 3.4, Step 1. Classify to GET M1.1 and **stratify by dominant species** (*Posidonia*, *Thalassia*, *Zostera*, *Halophila*) as a default, not "where data permit", since species drives carbon, productivity, and service parameters. Disaggregate further by depth zone (Section 3.1.1) and document the national-to-GET crosswalk.

Step 2: Map extent using tiered approach

¶1 Select Tier 1, 2, or 3 (Section 3.1.3). Where acoustic or diver data are unavailable for deep meadows (beyond ~10–15 m), record mapped extent as a lower bound with a quality-statement note documenting the estimated deep-meadow proportion from bathymetric and habitat suitability data. Where feasible, apply a regional-study-based coverage correction. Validate against ground-truth with confusion matrices (**TG-4.1** Section 3.5.1) and the **TG-0.7** quality framework.

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Step 3: Populate extent account

¶1 Compare opening and closing maps, then classify changes per Section 3.1.4. Anthropogenic pressure-driven loss is recorded under "Other reductions — degradation" (SEEA EA Table 4.2) with memorandum sub-rows attributing the pressure.

Step 4: Measure condition variables and derive indicators

¶1 Sample sites stratified by species, depth, and pressure exposure. Measure the Table 3.2.1 minimum set. Normalise using the **TG-2.1** Section 3.4.1 formula. Tag each variable as **standard** or **inverse** in a direction column before applying. Optionally aggregate using one of the Section 3.2.4 approaches. Equal weighting is the documented default, with the dominant structural indicator (shoot density or cover) anchoring the composite.

Step 5: Quantify service flows in physical units

¶1 For carbon sequestration: measure sediment accumulation rates from dated cores (Pb-210 or Cs-137), then multiply extent × species-appropriate rate × composite condition index to obtain observed-condition flow (tonnes CO2e/yr). Condition adjustment is applied once, here, so Step 7 uses the condition-adjusted total without a further multiplier (Section 3.4.4).

¶2 For coastal protection: model wave attenuation per Ondiviela et al. (2014)[24], then document protected coastline length and implied attenuation rate.

¶3 For fisheries: apply the GOAP default (full seagrass-attributable contribution to biomass provisioning) unless stage-structured production-function data permit partitioning (Section 3.3.2).

¶4 For water purification: where epiphyte load exceeds the Table 3.2.1 threshold, apply a condition-adjusted nutrient-removal service flow. Where eutrophication has caused meadow collapse, record as zero.

¶5 Record physical quantity and natural spatial unit (hectares, kilometres, tonnes) per SEEA EA Table 7.1.

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Step 6: Apply monetary valuation (optional)

¶1 Apply Section 3.4 methods. Ensure carbon-price and discount-rate consistency with other blue carbon and natural-asset accounts. Record in SEEA EA Table 9.3.

Step 7: Compile asset valuation and degradation accounts

¶1 Apply the NPV formula from Section 3.4.4. For first-time compilations, the opening NPV uses current observed-condition flows (no degradation charge unless condition or extent changes within the period).

¶2 Degradation = Opening asset value - Closing asset value (at opening-period prices and discount rate). Record separately: (a) revaluations from price or discount-rate changes, and (b) within-period condition and extent decline. Where significant losses occurred, disaggregate by driver (eutrophication, storm damage, dredging). Standard structure: SEEA EA Chapter 10 / Table 10.5.

Step 8: Document methods and quality assurance

¶1 ISO 19115 metadata + **TG-0.7** framework. Include coherence checks across extent, condition, and services accounts.

Annex: SEEA EA table cross-reference for compilation steps

Step	SEEA EA Table	Purpose
Step 3	Table 4.2	Standard ecosystem extent account format
Step 4	Table 5.2	Condition indicator standardisation

Step	SEEA EA Table	Purpose
Step 5	Table 7.1	Ecosystem services flow account
Step 6	Table 9.3	Monetary ecosystem services supply table
Step 7	Chapter 10 / Table 10.5	Monetary ecosystem asset account

3.6 Worked Example

¶1 This worked example demonstrates the compilation of seagrass ecosystem accounts for a hypothetical 12,000-hectare seagrass meadow system spanning temperate and tropical waters. The example follows the extent-condition-services-valuation sequence presented in Section 3 and illustrates the key accounting entries and calculations. All monetary values are illustrative composites and should not be used as benchmarks for specific national contexts.

¶2 **Setting:** The ecosystem accounting area (EAA) is a two-embayment coastal zone of approximately 450 km². Within this geographic frame, seagrass (M1.1 Seagrass meadows) occupies 12,000 hectares as the opening-year asset stock. The EAA is larger than the seagrass extent, with the remaining EAA area comprising unvegetated soft sediment and mixed benthic habitat. The seagrass stock comprises temperate *Posidonia* beds (7,500 ha, to 15 m depth) and tropical *Thalassia-Halophila* meadows (4,500 ha, to 12 m depth), distributed across the two embayments.

¶3 **Step 1: Extent account (year t to t+1)**

Accounting entry	Seagrass extent (hectares)
Opening extent (year t)	12,000
Additions to extent	
– Managed expansion (restoration transplanting)	50
– Natural expansion (colonisation of adjacent substrate)	80
Total additions	130
Reductions in extent	
– Managed reduction (dredging for port expansion)	60
– Natural reduction (storm scour, wasting disease)	120
– Other reductions – degradation	150
of which: eutrophication-related light limitation (memorandum)	*150*
Total reductions	330
Closing extent (year t+1)	11,800

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¶4 **Step 2: Condition account**

¶5 Condition indicators are derived from field survey data using species-specific reference levels from protected reference sites. The variable set matches the Table 3.2.1 minimum set:

Condition variable	Observed value	VH (reference)	VL (degraded)	Indicator score
Percent cover	45%	60%	5%	0.73
Shoot density	520 shoots/m²	800	100	0.60
Canopy height	30 cm	45 cm	10 cm	0.57
Epiphyte load (inverse)	18%	5% (VH)	50% (VL)	0.71
Species diversity	5 species	7	1	0.67

¶6 Note: For epiphyte load, a lower value indicates better condition. VH = 5% is the load observed at the protected reference sites, within the Table 3.2.1 indicative default (< 10%). Using the inverse normalisation formula (see **TG-2.1** Section 3.4.1): (50 - 18) / (50 - 5) = 0.71.

¶7 Composite condition index (equal-weight default per Section 3.2.4): (0.73 + 0.60 + 0.57 + 0.71 + 0.67) / 5 = **0.66**

¶8 **Step 3: Ecosystem services (annual flows)**

Service	Physical quantity	Monetary value (USD, illustrative)
Carbon sequestration	27,720 t CO2e/yr (42,000 t CO2e/yr reference-condition flow x condition index 0.66)	2,218,000 (at USD 80/t CO2)
Biomass provisioning (fisheries; default per Section 3.3.2)	1,800 t seagrass-attributable landed catch	3,200,000 (ex-vessel composite at ~USD 1,780/t; illustrative)
Sediment stabilisation	65 km coastline stabilised	4,100,000 (avoided damage/replacement cost; illustrative)
Water filtration (nutrient removal)	480 t N removed/yr	1,900,000 (replacement cost; illustrative)
Total valued services		**11,418,000 (illustrative)**

¶9 Notes:

- ¶10 The carbon sequestration rate of 3.5 t CO2e/ha/yr is a mid-range reference-condition value within the 1.8-5.1 t CO2e/ha/yr range given in Section 3.3.2 (Fourqurean et al. 2012 synthesis). Compilers should select species- and site-specific values with citation. Within the cited range, 1.8 represents a conservative lower bound and 5.1 an upper bound.
- ¶11 The reference-condition flow (12,000 ha x 3.5 = 42,000 t CO2e/yr) is adjusted by the composite condition index at Step 3: 42,000 x 0.66 = 27,720 t CO2e/yr. This convention treats the literature rate as a reference-condition value and applies the condition adjustment once, at the physical flow stage. The Step 4 asset valuation uses the condition-adjusted annual service total (USD 11,418,000) without a further condition multiplier, avoiding double-counting. See Section 3.4.4. For periods with significant extent change, compilers may use the mean of opening and closing extent.
- ¶12 The fisheries entry applies the GOAP default rule (Section 3.3.2): the full seagrass-attributable fisheries contribution is assigned to biomass provisioning, not split between nursery habitat and biomass provisioning. Compilers with stage-structured production-function data may apportion per Section 3.4.3, documenting the partitioning method.
- ¶13 Monetary values for sediment stabilisation and water filtration are illustrative composites. Published seawall replacement costs (USD 1,000-10,000 per linear metre) and tertiary nutrient-removal unit costs vary by orders of magnitude across jurisdictions. Compilers must derive their own unit prices from national engineering or wastewater cost data and document the calculation.

¶14 **Step 4: Asset valuation**

¶15 Apply the NPV formula from Section 3.4.4 using the condition-adjusted annual service total from Step 3 (USD 11,418,000). Because the condition index has already been applied at the physical flow stage (Step 3), no further condition multiplier is applied here, since doing so would double-count the condition adjustment:

> *Annual service value (condition-adjusted at Step 3):* ***USD 11,418,000***
> *Perpetuity (indefinite horizon, r = 4%): Asset value = 11,418,000 / 0.04 =* ***USD 285,450,000 (illustrative)***
> *25-year finite horizon: Asset value = 11,418,000 x AF, where AF = [1 - (1 + r)^-T] / r = [1 - (1.04)^-25] / 0.04 = 15.62*

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> *Asset value (25-year) = 11,418,000 x 15.62 = **approximately USD 178,349,000 (illustrative)***

¶16 Compilers should recalculate the annuity factor (AF) using their national discount rate. Where condition is declining, compilers should project forward service flows using trend data rather than applying the perpetuity formula directly.

¶17 This worked example illustrates the full accounting sequence for seagrass ecosystems. Actual compilations will require country-specific data, species-appropriate reference levels, and primary valuation studies for each service type. The carbon price of USD 80/t CO2 is illustrative and should be replaced with the prevailing compliance market price or social cost of carbon applicable in the compiler's jurisdiction. The eutrophication-related decline is classified under "Other reductions – degradation" per SEEA EA Table 4.2, with a memorandum sub-row attributing the pressure, consistent with the guidance in Sections 3.1.4 and 3.5 Step 3.

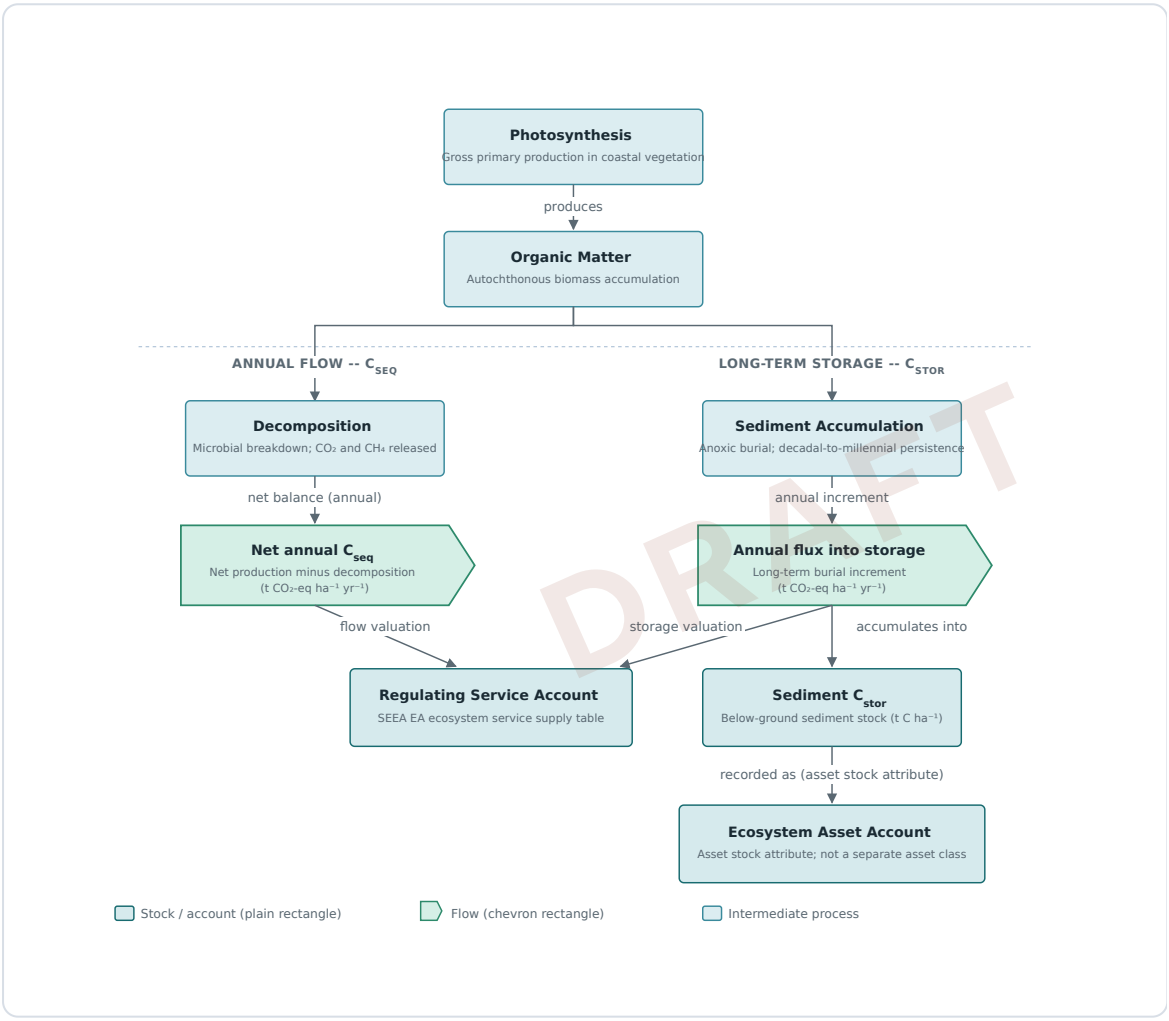


Figure 6.3.1 In a vegetated coastal habitat, Cseq is an annual regulating-service flow while Cstor is the accumulated sediment stock attribute. Flow and permanence valuations are alternatives -- not summed. Rectangles: chevron-tail = flows; plain = stocks.

Source: TG-6.3, Section 3.3.2 (carbon sequestration and storage); SEEA EA 2024, paras. 10.20-10.40 (ecosystem carbon pools and asset accounting).

4. Acknowledgements

¶1 This guidance draws on the conceptual framework and methodological recommendations of the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) and its sup-

porting technical materials. The IUCN Global Ecosystem Typology provides the ecosystem classification framework. Scientific understanding of seagrass ecosystem services draws on extensive research literature, including foundational works by Costanza et al., Duarte et al., Fourqurean et al., and the global seagrass research community.

¶2 **Authors:** [To be confirmed]

¶3 **Reviewers:** [To be confirmed]

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FOOTNOTES

1. ¶1 Keith et al. (2020), M1.1 Seagrass meadows: "Seagrasses are the only subtidal marine flowering plants and underpin the high productivity of these systems."
2. ¶2 United Nations (2021), SEEA EA Chapters 4-11.
3. ¶3 Countries may compile physical seagrass accounts without monetary valuation as a first step. See TG-1.9.
4. ¶4 United Nations (2022), *Guidelines on Biophysical Modelling for Ecosystem Accounting*.
5. ¶5 Keith et al. (2020), M1.1 Key Ecological Drivers — maximum depth limited by light attenuation; minimum depth by wave orbital velocity, tidal exposure, and wave energy.
6. ¶6 Keith et al. (2020), Section M1.1.
7. ¶7 Beer-Lambert; coastal Kd typically 0.1–0.5 m^-1.
8. ¶8 Water-column correction (e.g., Lyzenga 1981; Maritorena 1996) requires accurate optical-property data.
9. ¶9 GOAP tiered approach; see TG-4.1 for the general framework.
0. ¶10 Global seagrass datasets underestimate extent in data-poor regions and have significant temporal lags.
1. ¶11 Kenny et al. (2003), *ICES J. Mar. Sci.* 60(2): 411-418.
2. ¶12 Waycott et al. (2009) and Dunic et al. (2021) provide the canonical global loss synthesis.
3. ¶13 Van der Heide et al. (2012) describe the three-stage seagrass-lucinid-bacteria symbiosis underpinning mesograzer and microbial controls.
4. ¶14 SEEA EA para 5.30-5.35.
5. ¶15 Worked examples of seagrass composite condition indices: SEQI (Wahyudin et al. 2021, *Sci. Total Environ.*); POMI (Romero et al. 2007, *Mar. Pollut. Bull.*); BiPo (Lopez y Royo et al. 2010, *Ecol. Indic.*); PREI (Gobert et al. 2009); SQI (Foden & Brazier 2007; Neto et al. 2013, *Ecol. Indic.*); GBR MMP Seagrass Condition Index (GBRMPA Marine Monitoring Program annual reports); Chesapeake Bay SAV scorecard (Chesapeake Bay Program SAV technical synthesis); Tampa Bay Seagrass Assessment (TBEP / SIMM reports).
6. ¶16 Heck et al. (2003), *Mar. Ecol. Prog. Ser.* 253: 123-136 — fish densities in seagrass are typically 2–5x higher than in adjacent unvegetated areas.
7. ¶17 Addamo et al. (2024) define trophic-based seagrass dependency (TB-SGd) as the product of diet-contribution proportions ($DCF_{Gx \to Fy}$) for all prey–predator pairs across trophic levels linking seagrass to the target species, multiplied by prey biomass. Applied to seven Mediterranean fish species, the estimated seagrass contribution averaged approximately 1% of total landed biomass, though the entire trophic chain was considered at risk in the absence of seagrass. Species-specific trophic parameters for the Mediterranean are provided in Piroddi et al. (2017, 2022).
8. ¶18 SEEA EA Chapter 7 and NCAVES/MAIA (2022) describe residual-value and simulation approaches.
9. ¶19 The "flow at risk" concept distinguishes (a) the direct seagrass-attributable share of a service (e.g. 1% of fish biomass directly traceable through the trophic web) from (b) the total service value that would be lost if seagrass disappeared (e.g. the entire trophic chain collapses). Compilers recording only the attributable share may significantly understate the economic dependency on seagrass. A memorandum row in the supply table labelled "flow at risk — seagrass dependency" can record this broader exposure without double-counting the attributable flow.
0. ¶20 Mediterranean seagrass species (primarily *Posidonia oceanica*) shed leaves seasonally; annual leaf-turnover rates provide the biophysical basis for raw biomass estimates. Cebrian et al. (1997) provide above-ground biomass estimation methods applicable to multiple Mediterranean species. Alternative uses for stranded seagrass biomass (banquettes) include biofuel feedstock (Masri et al. 2017), composite materials (Scaffaro et al. 2018), and animal fodder; current regulatory status varies by Mediterranean jurisdiction.
1. ¶21 Fourqurean et al. (2012), *Nature Geoscience* 5: 505-509 — synthesis of 946 meadows; sediment stocks up to 140 Mg C/ha (top 1 m), ~90% of total carbon in soils, global stock to 19.9 Pg C. Burial rates 48-138 g C/m²/yr (1.8-5.1 t CO2e/ha/yr) reflect long-term sequestration, distinct from NPP >400 g C/m²/yr.
2. ¶22 Addamo et al. (2024) operationalise this distinction in their Mediterranean supply table, recording carbon sequestration and carbon storage as separate line items. Carbon storage (Cstor) from *Posidonia oceanica* sediment stocks may represent centuries of accumulation and is not recoverable on human timescales once a meadow is destroyed; this asymmetry between sequestration flow and storage stock has implications for degradation accounting (see Step 7 of the compilation procedure).
3. ¶23 United Nations (2022), Section 4.3.
4. ¶24 Ondiviela et al. (2014), *Coastal Engineering* 87: 158-168 — 20–40% wave attenuation per 100 m of meadow width.
5. ¶25 Reynolds et al. (2016), *Restoration Ecology* 24(5): 583-588.
6. ¶26 Keith et al. (2020), M1.1 Ecological Traits.
7. ¶27 Addamo et al. (2024) apply a logit model for visit probability and a weighted Poisson regression for visit frequency across 137 Mediterranean NUTS3 coastal regions, using landscape composition, marine protected area presence, and GDP as covariates. The per-visit net benefit value of EUR 15.02 (lower bound) to EUR 37.28 (upper bound) is drawn from Stebbings et al. (2021). This approach is transferable to other regions with appropriate recalibration of the visit-prediction models using local survey data.
8. ¶28 US EPA Interagency Working Group (2023) — central SCC ~USD 190/t CO2 at 2.0% near-term discount rate; values exceed USD 300 under some specifications.

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9. ¶29 Verra VCS methodologies exist for mangrove and salt marsh; seagrass-specific methodologies remain under development.
0. ¶30 SEEA EA para 9.49-9.52.
1. ¶31 Production-function approaches require detailed habitat-recruitment-yield ecological data.
2. ¶32 Benefit transfer requires adjustments for ecological, social, and economic context.
3. ¶33 SEEA EA Chapter 10.
4. ¶34 SEEA EA Annex A10.1.

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Kelp Forest and Temperate Reef Accounting

Provides guidance on compiling ecosystem accounts for kelp forests and temperate rocky reef ecosystems.

Version 0.8.2 **Status** Draft **Stability** Emerging

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on compiling ecosystem accounts for kelp forests and temperate rocky reef ecosystems. These systems are classified as Emerging because methodological development remains less advanced than for tropical marine ecosystems, so guidance should be treated as indicative rather than prescriptive. The extent and condition methods build on TG-3.1 Asset Accounts, and ecosystem services follow TG-2.4 Ecosystem Goods and Services and TG-1.9 Valuation. For the foundational accounting framework, see TG-0.1 General Introduction to Ocean Accounts. For comparison with other biogenic marine ecosystems, see TG-6.1 Coral Reef Accounts and TG-6.3 Seagrass Accounts.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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1. Outcome

¶1 This Circular provides guidance on compiling ecosystem accounts for kelp forests and temperate rocky reef ecosystems. These systems are classified as Emerging because methodological development remains less advanced than for tropical marine ecosystems, so guidance should be treated as indicative rather than prescriptive. The extent and condition methods build on **TG-3.1 Asset Accounts**, and ecosystem services follow **TG-2.4 Ecosystem Goods and Services** and **TG-1.9 Valuation**. For the foundational accounting framework, see **TG-0.1 General Introduction to Ocean Accounts**. For comparison with other biogenic marine ecosystems, see **TG-6.1 Coral Reef Accounts** and **TG-6.3 Seagrass Accounts**.

Decision use cases

¶1 **Kelp restoration prioritisation:** Extent and condition accounts identify degraded areas suitable for restoration. Condition indicators tracking canopy density, urchin barrens extent, and species richness provide baseline data for restoration site selection and success monitoring. The kelp-to-barren transition dynamics documented in Section 3.1 inform restoration feasibility assessment.

¶2 **Urchin barren remediation:** Condition accounts tracking urchin density and predator abundance support culling and reintroduction decisions. Phase shift dynamics and hysteresis effects are described in Section 3.1.

¶3 **Temperate reef fisheries support:** Extent accounts quantifying reef area and connectivity inform fisheries management plans for reef-associated species (rock lobster, abalone, temperate reef fish). Condition indicators for herbivore biomass and rugosity provide early warning of trophic cascade effects. Integration with **TG-6.7 Fisheries Accounting** enables assessment of habitat-fisheries linkages.

¶4 **Marine protected area effectiveness:** Condition accounts compiled inside and outside MPAs support quantitative evaluation of protection effectiveness, analogous to the approach described in **TG-6.1 Coral Reef Accounts** Section 3.2.

¶5 **Climate change vulnerability assessment:** Temperature anomaly indicators (Section 3.2) and extent change attributable to marine heatwaves (Section 3.1) provide spatially explicit climate impact metrics. For linking biophysical indicators to climate policy frameworks, see **TG-2.1 Biophysical Indicators** Section 3.4.

¶6 ⓘ **Framework Position**

¶7 This Circular owns the extent, condition, service and asset accounts for **IUCN GET M1.2 kelp forests and M1.6 subtidal rocky reefs**, and the temperate-reef judgements the generic method does not reach: the canopy-density classification threshold that separates the two types, and the kelp-to-urchin-barren phase shift, which is a reclassification rather than a reduction and exhibits hysteresis across accounting periods.

¶8 It cross-refers for the account structure and the reclassification block (**TG-3.1** Section 3.5.1), extent and condition measurement (**TG-4.1**, **TG-4.8**, **TG-4.9**) and indicator derivation (**TG-2.1**).

¶9 Cultural services recorded for Indigenous communities carry the consent and data-governance requirements in **TG-3.6**.

2. Requirements

¶1 This Circular requires familiarity with **TG-0.1 General Introduction to Ocean Accounts** and **TG-3.1 Asset Accounts**. Compilers will also benefit from **TG-4.1 Remote Sensing Data** for subtidal mapping approaches, **TG-2.1 Biophysical Indicators** for condition indicator derivation, and **TG-0.7 Quality Assurance** for uncertainty documentation.

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¶2 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 Kelp forests and temperate rocky reefs are classified as GET **M1.2** and **M1.6** within the Marine Shelf biome (M1). For the GET realm/biome/EFG hierarchy and the national crosswalk obligation, see **TG-4.1 Remote Sensing and Geospatial Data** Section 3.2.4.[1]

3.1 Extent Accounting

¶1 Ecosystem extent accounts record the area of kelp forests and temperate reef ecosystems and changes over accounting periods, following **TG-3.1 Asset Accounts**[2].

Ecosystem type definitions

¶1 **Kelp forests** (IUCN GET M1.2) are characterised by dense canopies of large brown macroalgae (Order Laminariales)[3]. Key genera include *Macrocystis* (giant kelp), *Laminaria*, *Ecklonia*, *Lessonia*, and *Eisenia*. Some kelps (notably *Macrocystis*) can grow to over 30 metres in length with growth rates up to 0.5 metres per day[4]. Kelp forests occur on hard rocky substrates in the photic zone, typically to depths of 30 metres[5], and are limited to temperate and polar waters, absent from warm tropical waters except in upwelling zones off Peru, the Galapagos, Namibia, Oman, and Cape Verde[6].

¶2 **Subtidal rocky reefs** (IUCN GET M1.6) are characterised by hard minerogenic substrates supporting communities of macroalgae, sessile invertebrates, and associated mobile fauna[7]. Unlike kelp forests, rocky reefs lack dense macroalgal canopies, with algal growth kept in check by herbivory, storm disturbance, and depth-related light limitation[8].

¶3 For accounting purposes, the boundary between kelp forests and rocky reefs may be dynamic as kelp canopies expand or contract in response to environmental conditions and herbivore populations[9]. Compilers should establish clear canopy density thresholds or classification rules, document them, and record the rationale for any reclassification decisions.

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Mapping challenges

¶1 **Subtidal location.** Subtidal kelp and rocky reef habitats cannot be directly observed from above the water surface in most conditions, limiting the applicability of conventional aerial and satellite remote sensing[10].

¶2 **Water column effects.** Remote sensing of benthic habitats requires correction for water column effects, which adds uncertainty to extent estimates[11]. The SEEA EA notes that marine ecosystems extend "throughout the water column and include the underlying sediment and seabed"[12]. The resulting three-dimensional complexity may not be fully captured by area-based extent measures.

¶3 **Canopy structure variability.** Some kelps form floating surface canopies (e.g., *Macrocystis*), whilst others have subsurface canopies (e.g., *Laminaria*, *Ecklonia*), requiring different detection approaches[13].

¶4 **Seasonal dynamics.** Kelp biomass can vary substantially across seasons. To address this in annual accounting, compilers should standardise the observation period (for example, recording extent at the late summer maximum) or apply multi-temporal averaging. The chosen approach must be documented and held constant across accounting periods (see Step 2.4)[14].

Recommended approaches

¶1 **Tier 1 (basic)**: Use existing global or regional habitat maps (e.g., UNEP-WCMC Ocean Data Viewer or national marine habitat mapping programmes)[15].

¶2 **Tier 2 (intermediate)**: Combine satellite remote sensing of surface-canopy kelp with acoustic surveys or diver transects for subsurface habitats. For remote sensing data acquisition and processing, see **TG-4.1 Remote Sensing Data**[16].

¶3 **Tier 3 (advanced)**: Develop high-resolution benthic habitat maps using multibeam sonar, underwater video transects, and species distribution modelling, integrated with satellite time series[17].

Extent account structure

¶1 The extent account structure, including the reclassification row block, is set out in **TG-3.1 Asset Accounts** Section 3.5.1 (Tables 2a and 2b) and is not restated here[18]. Compile one column per ecosystem type present — typically kelp forests (M1.2) and subtidal rocky reefs (M1.6), and a third for urchin barrens where the national classification recognises them as a distinct type.

¶2 The reclassification block matters more for kelp than for most ecosystems, because the kelp-to-urchin-barren transition is the dominant form of loss and it is a change of **type**, not a reduction: the area stays in the accounting area. Kelp lost to storm damage where the substrate is exposed but not yet colonised is the opposite case and is an unmanaged reduction. A worked illustration of the three available classification approaches is at Box 1 in Section 3.6.

¶3 **Transitions between ecosystem types.** Kelp forests can transition to "urchin barrens" (rocky substrates dominated by sea urchins with minimal macroalgal cover) when herbivore populations increase following predator loss[19]. These trophic cascades are ecosystem conversions and should be recorded in extent accounts. Three classification approaches are available (see Box 1 in Section 3.6 for a worked illustration). Compilers should document their chosen approach and its rationale.

Phase shift dynamics

¶1 The kelp-to-urchin-barren transition is characterised by nonlinear dynamics and hysteresis: conditions required to trigger degradation differ from those required for recovery.

State	Dominant Species	Ecosystem Services	Transition Triggers
Kelp-dominated	Kelp canopy	High (habitat, carbon, fisheries)	Urchin increase + warming
Transition	Mixed	Declining	Intermediate grazing pressure
Urchin barren	Urchins on bare rock	Low	Sustained overgrazing

¶2 *Table 2: Kelp-urchin phase shift characteristics*

¶3 Recovery from urchin barrens requires temperature decrease OR urchin removal AND kelp reseeding. The recovery threshold is higher than the degradation threshold (hysteresis), so reversing the conditions that caused degradation is often insufficient. Phase shifts may result in persistent ecosystem state changes that affect both extent and condition accounts over multiple accounting periods.

3.2 Condition Assessment

¶1 Ecosystem condition accounts record the quality of kelp forest and temperate reef assets using indicators of biotic and abiotic characteristics[20]. For the general condition accounting methodology, see **TG-3.1 Asset Accounts** Section 3.5.2. For deriving biophysical indicators and connecting them to policy frameworks, see **TG-2.1 Biophysical Indicators**. The measurement protocols for the variables themselves — how each is observed, at what frequency and to what tolerance — are owned

by **TG-4.8 Physical Condition Measurement** and **TG-4.9 Biological Condition Measurement**; this Section selects and interprets them for kelp forests and temperate reefs.

Condition variables

¶1 The SEEA EA identifies six classes of condition characteristics applicable to marine ecosystems [21]. Recommended condition variables for kelp forests and temperate reefs include:

¶2 **Physical and chemical state (A1, A2)**:

- ¶3 Sea surface temperature and subsurface temperature profiles
- ¶4 Nutrient concentrations (nitrate, phosphate)
- ¶5 Dissolved oxygen levels
- ¶6 Sedimentation rates

¶7 **Compositional state (B1)**:

- ¶8 Kelp species diversity and relative abundance
- ¶9 Abundance of herbivores (particularly sea urchins)
- ¶10 Abundance of apex predators (e.g., sea otters, large fish)
- ¶11 Invasive species presence

¶12 **Structural state (B2)**:

- ¶13 Canopy extent and density (for kelp forests)
- ¶14 Urchin barrens extent
- ¶15 Sessile invertebrate cover
- ¶16 Reef structural complexity (rugosity)

¶17 **Functional state (B3)**:

- ¶18 Primary productivity
- ¶19 Recruitment of key species
- ¶20 Kelp detritus export

¶21 **Landscape context (C1)**:

- ¶22 Connectivity to adjacent ecosystem types
- ¶23 Level of protection (MPA status)

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Tiered framework for condition assessment

¶1 **Tier 1 (remote sensing and existing data only)**:

- ¶2 Sea surface temperature anomaly (satellite SST)
- ¶3 Surface-canopy kelp extent as a proxy for density (for *Macrocystis* and other surface-canopy species)
- ¶4 Marine protected area coverage (existing GIS layers)

¶5 **Tier 2 (periodic diver and acoustic surveys)**:

- ¶6 Kelp canopy density (plants/m² or % cover, diver transects)
- ¶7 Urchin barrens extent (acoustic survey, video)
- ¶8 Species richness (fish and invertebrate counts)
- ¶9 Herbivore abundance

¶10 **Tier 3 (full monitoring programme)**:

- ¶11 Reef rugosity index (structure-from-motion photogrammetry, fine-scale bathymetry)
- ¶12 Connectivity metrics from telemetry or genetic data
- ¶13 Functional rates (primary productivity, herbivory rates, recruitment)

¶14 The chosen tier should be documented. For data quality and tiered reporting frameworks, see **TG-0.7 Quality Assurance**.

Climate stressors

¶1 **Ocean warming.** Kelp forests have truncated thermal niches and are sensitive to elevated temperatures [22]. Marine heatwaves have caused widespread kelp losses, including documented decline of *Ecklonia radiata* forests in Western Australia following the 2011 marine heatwave [23]. For the relationship between ecosystem condition and climate-related pressures, see **TG-2.1 Biophysical Indicators**.

¶2 **Ocean acidification.** Reduced pH can affect calcifying organisms such as coralline algae, sea urchins, and shellfish that are integral components of reef communities [24].

¶3 **Storm regime changes.** Increased storm intensity can dislodge kelp and create gaps in canopy cover [25]. Recovery depends on recruitment success and may be impaired if environmental conditions have shifted.

Reference conditions

¶1 Condition indicators should be expressed relative to a reference level representing ecosystem integrity [26]. Establishing appropriate reference conditions for kelp forests is challenging for three reasons: long-term baselines are often lacking, many systems have been affected by fishing pressure, pollution, and climate change for decades, and natural variability is high. Compilers should document the reference conditions applied and their rationale. Historical reconstructions, minimally impacted reference sites, or modelled baselines may each be appropriate depending on context [27].

¶2 Condition accounts should track the area of kelp forests in degraded (barren) versus healthy states, as this provides baseline data for restoration targeting and MPA effectiveness assessment.

3.3 Ecosystem Services

¶1 For the general methodology of ecosystem service measurement and valuation, see **TG-2.4 Ecosystem Goods and Services** and **TG-1.9 Valuation** [28].

Provisioning services

¶1 **Wild-harvested products.** Kelp is harvested in some regions for food, fertiliser, animal feed, and industrial products. Sea urchins harvested from rocky reefs are a valuable food product [29]. These should be recorded as provisioning services with physical flows measured in tonnes and valued at market prices where available.

Regulating services

¶1 **Fisheries habitat.** Kelp forests and rocky reefs provide habitat for commercially important fish and invertebrate species, including rockfish, sea bass, abalone, lobster, and bivalves [30]. For accounting purposes, this is treated as a habitat or nursery maintenance service (an intermediate service) following the SEEA EA classification [31]. Habitat and nursery services are intermediate services. Their monetary value cannot equal the full resource rent of an associated fishery without an attribution model, and only the share attributable to the habitat (via a habitat dependency coefficient, dose-response function, or similar) should be recorded as the service value [32]. For the intermediate-versus-final service distinction, see **TG-2.4 Ecosystem Goods and Services**.

¶2 **Carbon sequestration** (emerging). Kelp forests are productive systems with rapid photosynthetic carbon uptake, but long-term carbon sequestration remains uncertain [33]. Unlike seagrasses and mangroves, kelps do not accumulate carbon in sediments at the site of growth. Kelp-derived carbon may be consumed by herbivores, exported as drift material to deep sea sediments, or remineralised in the water column. Recent research suggests a substantial proportion may reach the deep ocean where it can be sequestered on long timescales [34]. However, quantification methods

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are not yet standardised, and the SEEA EA requires that only carbon stored long-term (at least several decades) be counted [35]. IPCC does not currently include kelp in the wetlands supplement for national greenhouse gas inventories. Compilers who include kelp carbon should flag the provisional nature of current methods.

¶3 **Coastal protection.** Kelp canopies can dampen wave energy, but the magnitude of this service is less well documented than for coral reefs or mangroves [36]. Empirical studies report wave-height reductions of approximately 7–60% depending on species, canopy density, bathymetry, and wave period, but kelp-specific attenuation coefficients are not yet validated for accounting use. Any estimate should be reported at low confidence with an explicit uncertainty range. See Step 6.4 for the methodological approach and **TG-6.1 Coral Reef Accounts** for the analogous coral reef method.

¶4 **Water quality regulation.** Kelp forests take up nutrients from surrounding waters and can help mitigate eutrophication effects in nutrient-enriched coastal areas [37].

Cultural services

¶1 **Recreation and tourism.** Kelp forests and temperate reefs are popular destinations for recreational diving and snorkelling [38].

¶2 **Scientific and educational value.** Long-term monitoring sites such as those established by the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) provide valuable scientific data [39].

¶3 **Cultural and spiritual significance.** Where these services are recorded, the consent, attribution and data-governance requirements in **TG-3.6 Traditional Knowledge** apply and are not restated here. Kelp forests and rocky reefs may have cultural significance for coastal Indigenous communities, supporting traditional fishing practices, food security, and cultural identity [40].

Service quantification challenges

¶1 For Emerging-status ecosystems, quantification faces particular challenges: limited spatial extent data, less-developed ecological production functions, poorly documented beneficiary populations, and fewer monetary valuation studies to support benefit transfer. Compilers should document methods and assumptions, and communicate uncertainty to users. See **TG-0.7 Quality Assurance**.

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3.4 Compilation Procedure

¶1 The procedure follows the asset accounting framework from **TG-3.1 Asset Accounts** and data quality protocols from **TG-0.7 Quality Assurance**.

Step 1: Define ecosystem accounting area (EAA)

¶1 Define the spatial boundary of the accounting area, typically aligned with national marine waters or a regional marine planning area. Document the coordinate system, vertical datum for depth measurements, and seaward boundary (territorial sea, EEZ, or other jurisdictional limit).

¶2 **1.1 Spatial disaggregation within the EAA.** Decision use cases in Section 1 (MPA effectiveness, restoration targeting) require accounts at the management unit level (individual MPAs, bioregions, depth bands) as well as the EAA-wide aggregate. Sub-unit accounts must be additive to the national total. Compilers should adopt the MPA comparison approach described in **TG-6.1 Coral Reef Accounts** Section 3.2, noting that kelp distribution is typically patchier than coral reef distribution and sub-unit boundaries should reflect ecological structure where possible.

Step 2: Delineate ecosystem assets

¶1 **2.1 Assemble spatial data layers:**

- ¶2 Bathymetric data (depth)

- ¶3 Substrate classification (rocky vs. soft sediment)
- ¶4 Water quality data (turbidity, nutrient levels)
- ¶5 Existing habitat maps (national, regional, or global datasets)

¶6 **2.2 Apply ecosystem type criteria:**

- ¶7 M1.2 Kelp forests: Rocky substrate + depth 3-30m + kelp canopy present
- ¶8 M1.6 Temperate reefs: Rocky substrate + depth <50m + no kelp canopy or sparse kelp

¶9 **2.3 Map ecosystem extent** using the Tier approach described in Section 3.1.

¶10 **2.4 Address seasonal variation:**

- ¶11 Option A: Standardise observation to late summer (maximum canopy extent)
- ¶12 Option B: Multi-temporal averaging across seasons
- ¶13 Document chosen approach and rationale
- ¶14 **Consistency principle**: The seasonal standardisation method must be held constant across consecutive accounting periods. Switching methods introduces spurious extent changes. If a method change is unavoidable, back-calculate prior period estimates using the new method and document the revision as a methodological break in the time series, following **TG-0.7 Quality Assurance**.

¶15 **2.5 Generate extent account:**

- ¶16 Calculate opening extent (t0) for each ecosystem type
- ¶17 Identify additions, reclassifications, and reductions during accounting period
- ¶18 Calculate closing extent (t1)

Step 3: Select condition variables

¶1 **3.1 Apply SEEA ECT framework:**

- ¶2 Select 1-2 variables per ECT class (A1 physical, A2 chemical, B1 compositional, B2 structural, B3 functional, C1 landscape)
- ¶3 Aim for 6-10 variables total
- ¶4 Prioritise variables with available data and policy relevance
- ¶5 ECT class coding affects how accounts are aggregated and compared internationally. Brief justifications for each class assignment should be documented.

¶6 **3.2 Recommended minimum set (with ECT class justifications):**

- ¶7 **B2: Kelp canopy density (plants/m² or % cover)** — B2 (structural state). Canopy density characterises the physical structure and architectural organisation of the ecosystem (SEEA EA Table 5.1).
- ¶8 **B2: Urchin barrens extent (% of reef area)** — B2 (structural state). Habitat-state coverage metrics measure structural arrangement, not species composition.
- ¶9 **B1: Species richness (fish + invertebrate count)** — B1 (compositional state). Directly measures which species are present.
- ¶10 **A1: Water temperature anomaly (°C above baseline)** — A1 (physical state). Standard abiotic descriptor.
- ¶11 **A2: Dissolved oxygen concentration (ml/L at depth) or nutrient anomaly (% deviation from baseline nitrate)** — A2 (chemical state). Where both are available, dissolved oxygen is preferred as a primary stress indicator because sub-threshold values can trigger rapid kelp degradation independent of temperature.
- ¶12 **B2: Reef rugosity index (structural complexity)** — B2 (structural state). Rugosity quantifies the three-dimensional physical structure of the reef.

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- ¶13 **B3: Kelp net primary productivity (t C/ha/yr) or recruitment rate (juvenile sporophytes/m²)** – B3 (functional state). Measures the rate of ecological processes. Recruitment rate is preferred where annual survey data are available, whilst net primary productivity is appropriate for data-rich compilations.
- ¶14 **C1: Connectivity to adjacent kelp patches (habitat fragmentation metric)** – C1 (landscape/seascape context). Characterises the spatial configuration of the ecosystem relative to its surroundings.

¶15 **3.3 Data collection methods:**

- ¶16 Diver transect surveys for canopy density, species richness, rugosity
- ¶17 Satellite SST data for temperature anomaly
- ¶18 Acoustic surveys and video for urchin barren extent
- ¶19 GIS analysis for connectivity

Step 4: Establish reference conditions

¶1 **4.1 Select reference condition approach:**

- ¶2 Historical baselines: Pre-1950 or earliest available monitoring data
- ¶3 Contemporary reference sites: Minimally impacted reefs within biogeographic region
- ¶4 Modelled baselines: Species distribution models for pristine conditions
- ¶5 Policy targets: National marine park standards or regional management targets
- ¶6 **Biogeographic calibration is required.** Reference levels (V_good, V_bad) vary substantially across kelp species and regions and must be calibrated to the biogeographic context of the EAA before use.

¶7 **4.2 Assign reference levels:**

- ¶8 V_good: Value at reference condition (high integrity)
- ¶9 V_bad: Value at degraded/collapsed state
- ¶10 For "normal" (direct-direction) variables (higher values = better condition), V_good > V_bad numerically.
- ¶11 For "inverse" variables (lower values = better condition, e.g., urchin barrens extent, temperature anomaly), V_good < V_bad numerically.

¶12 **4.3 Example for kelp canopy density (*Ecklonia radiata*, temperate Australia):**

- ¶13 V_good = 14 plants/m² (upper reference for dense canopy)
- ¶14 V_bad = 1 plant/m² (functional threshold below which recruitment fails)

¶15 These values are specific to *Ecklonia radiata* in temperate Australia and should not be applied without recalibration to other species or regions. Indicative reference ranges for other major kelp genera are in Table 3.

Genus / region	Typical reference range	Notes
Ecklonia radiata (temperate Australia)	V_good ~4–14 plants/m²; V_bad <1 plant/m²	Adult density categorised in WA studies as low (<2), medium (2–4), high (>4) thalli/m²; values at the upper end (14) represent dense canopy under optimal conditions.
Macrocystis pyrifera (California, Southern Ocean)	V_good ~10–18 stipes/m²; commonly reported as stipes/m² rather than plants/m²	Each plant produces multiple stipes; frond/stipe density is a better proxy for standing crop than plant counts. Reference condition often operationalised at the surface-canopy biomass level.
Laminaria hyperborea (NE Atlantic / Norway)	V_good ~5–15 plants/m² at exposed shallow sites	Standing stock in 3–5 m exposed sites approximately 6–16 kg fresh weight/m²; values vary with wave exposure, depth, and latitude.

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¶16 *Table 3: Indicative reference ranges for kelp canopy density by genus and region. All ranges must be verified against primary literature for the specific biogeographic context before use in accounts.*

¶17 **4.4 Document rationale:**

- ¶18 Cite data sources for reference levels
- ¶19 Explain biogeographic context
- ¶20 Note limitations and uncertainties

Step 5: Derive condition indicators

¶1 **5.1 Apply normalisation formula:**

¶2 Condition variables are normalised using the standard formula defined in **TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.1. For kelp forest and temperate reef ecosystems, the formula uses V_good (reference, good condition) and V_bad (degraded) as parameter names.

¶3 **Worked calculations (kelp-specific examples):**

¶4 *Normal variable — kelp canopy density (V_good = 14, V_bad = 1, V = 8.5):* Indicator = (8.5 − 1) / (14 − 1) = 7.5 / 13 = 0.58

¶5 *Inverse variable — urchin barrens extent (V_good = 2%, V_bad = 60%, V = 22%):* Indicator = (22 − 60) / (2 − 60) = (−38) / (−58) = 0.66

¶6 Both cases yield values in [0, 1] without sign reversal.

¶7 **5.2 Calculate indicators for each variable:**

- ¶8 Opening indicators (t0)
- ¶9 Closing indicators (t1)
- ¶10 Change in indicators

¶11 **5.3 Aggregate to composite index (optional):**

- ¶12 Equal-weighted arithmetic mean across indicators
- ¶13 Or apply ECT-weighted approach if ecological rationale supports differential weighting

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Step 6: Quantify ecosystem services

¶1 **6.1 Prioritise measurable services:**

- ¶2 Fisheries habitat (regulating and maintenance; an intermediate service — see Section 3.3)
- ¶3 Recreation and tourism (cultural)
- ¶4 Coastal protection (regulating)
- ¶5 Carbon sequestration (regulating, provisional)

¶6 **6.2 Fisheries habitat:**

- ¶7 Estimate proportion of commercial catch attributable to kelp/reef habitat
- ¶8 Habitat and nursery services are intermediate services. Their monetary value cannot equal the full resource rent of an associated fishery without an explicit attribution model. Apply a habitat dependency coefficient (e.g., 0.4–0.6 for obligate reef species) or dose-response function to isolate the ecosystem contribution from the total resource rent.
- ¶9 Where attribution coefficients are unavailable, report "total resource rent from reef-associated fisheries" with an explicit note that full attribution to the habitat service requires additional modelling. See **TG-2.4 Ecosystem Goods and Services** for the intermediate-versus-final service distinction.
- ¶10 Physical units: tonnes of fish
- ¶11 Monetary units: ecosystem-attributable share of resource rent (catch value minus costs, multiplied by habitat dependency coefficient)

¶12 **6.3 Recreation and tourism:**

- ¶13 Estimate person-visits to kelp/reef diving sites
- ¶14 Apply simulated exchange value or travel cost method
- ¶15 Physical units: person-visits
- ¶16 Monetary units: consumer surplus or expenditure-based value

¶17 **6.4 Coastal protection:**

- ¶18 Identify length of coastline protected by kelp/reef
- ¶19 Estimate wave attenuation capacity (% reduction in wave height)
- ¶20 Apply avoided damage cost method
- ¶21 **Methodological note**: Kelp-specific wave attenuation coefficients are not yet validated for accounting use. Empirical studies report reductions ranging from approximately 7–60% depending on species, canopy density, bathymetry, and wave period. Adopt the analogous method from **TG-6.1 Coral Reef Accounts**, parameterised with the most defensible kelp-specific values available for the biogeographic context. Report any coastal protection estimate at low confidence with an explicit uncertainty range. Where a defensible parameterisation cannot be constructed, flag the service as unquantified.
- ¶22 Physical units: km coastline protected
- ¶23 Monetary units: expected annual damages avoided (low confidence)

¶24 **6.5 Carbon sequestration (provisional):**

- ¶25 Estimate kelp biomass production (t dry weight/ha/year)
- ¶26 Apply export coefficient representing the proportion of kelp-derived carbon reaching depths >200 m, where long-term sequestration is assumed
- ¶27 Convert to CO2 equivalents
- ¶28 Flag as provisional with high uncertainty, not suitable for national GHG inventory use

Step 7: Value ecosystem assets

¶1 **7.1 Project future service flows:**

- ¶2 Assume stable condition: Use current service values for projection
- ¶3 Assume degradation trend: Adjust service values based on condition change rate
- ¶4 Scenario analysis: Model alternative management/climate scenarios

¶5 **7.2 Select discount rate:**

- ¶6 Social discount rate typically 3-5% for ecosystem assets
- ¶7 Document rate selection and sensitivity (see Step 7.4)

¶8 **7.3 Calculate net present value:**

> *Asset value = Σ (Service value year t × Discount factor)*

¶9 The annuity formulation below applies only under the "stable flows" assumption from Step 7.1. Where service flows are projected to change over the horizon, the year-by-year discounted sum must be used.

¶10 For stable flows over the projection horizon:

> *Asset value = Annual service value × Present value annuity factor*

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¶11 **Treatment of the provisional carbon sequestration component.** Because kelp carbon sequestration is an emerging-confidence service (Section 3.3), it should not be capitalised into a single baseline asset value. Compilers should either (a) quarantine the carbon sequestration row from the baseline asset valuation, or (b) report two asset value estimates (one including and one excluding the provisional carbon component) and quantify the difference.

¶12 **Biomass stocks within ecosystem versus natural resource asset accounts.** Standing kelp biomass forms part of the ecosystem asset. Harvestable seaweed biomass extracted from the ecosystem falls under natural resource assets within the SEEA Central Framework rather than the SEEA EA ecosystem asset. Compilers should keep these stock dimensions distinct to avoid double-counting. See **TG-3.1 Asset Accounts** for the conceptual boundary.

¶13 **7.4 Present value annuity factor (PVAF) and discount-rate sensitivity:**

¶14 For 25 years at 4%: PVAF = [1 – (1.04)^–25] / 0.04 = 15.62.

Discount rate	25-year horizon	50-year horizon
1%	22.02	39.20
2%	19.52	31.42
3%	17.41	25.73
4%	15.62	21.48
5%	14.09	18.26

¶15 *Table 4: Present value annuity factors for selected discount rates and projection horizons.*

¶16 Compilers must select a discount rate consistent with national Treasury guidance or SEEA EA recommendations, document the chosen rate, and report at least one sensitivity case (e.g., +/-1% around the central rate).

Step 8: Compile integrated accounts

¶1 **8.1 Extent-condition-services linkage:**

- ¶2 Document how condition affects service capacity
- ¶3 Link condition indicators to service quantification assumptions

¶4 **8.2 Populate account tables:**

- ¶5 Extent account (Table 1 structure)
- ¶6 Condition variable account
- ¶7 Condition indicator account
- ¶8 Ecosystem services flow account
- ¶9 Monetary asset account

¶10 **8.3 Quality assurance:**

- ¶11 Apply quality dimensions: accuracy, completeness, timeliness, coherence
- ¶12 Document data sources, methods, and limitations for each account component
- ¶13 Assign quality ratings per **TG-0.7 Quality Assurance**.

Step 9: Connect to policy indicators

¶1 **9.1 Derive policy-relevant indicators:**

- ¶2 Kelp extent change (% per annum) → MPA effectiveness indicator
- ¶3 Urchin barren extent (%) → Restoration targeting indicator
- ¶4 Composite condition index → Ocean health dashboard
- ¶5 Temperature anomaly trend → Climate vulnerability indicator

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¶6 **9.2 Link to decision contexts:**

- ¶7 Reference decision use cases from Section 1
- ¶8 Provide indicator time series and spatial maps

¶9 For detailed guidance on connecting accounts to policy indicators, see **TG-2.1 Biophysical Indicators** Section 3.3.

3.5 Data and Methods Gaps

¶1 The Emerging status of this Circular reflects gaps in data availability and methodological development.

Extent mapping

¶1 **Priority gaps:**

- ¶2 Globally consistent mapping of kelp forest extent remains incomplete
- ¶3 Subsurface kelp species are poorly captured by current satellite-based approaches
- ¶4 Temporal coverage is insufficient to distinguish long-term trends from natural variability
- ¶5 Standardised protocols for classifying transitions between kelp forests, rocky reefs, and urchin barrens are lacking

¶6 **Development priorities:**

- ¶7 Investment in satellite-based monitoring capable of detecting subsurface macroalgae
- ¶8 Integration of acoustic survey methods with remote sensing
- ¶9 Development of change detection algorithms suited to dynamic kelp systems [41]
- ¶10 Engagement with international research networks such as the Kelp Ecosystem Ecology Network (KEEN). The Emerging badge may be revisited if major mapping advances emerge from these initiatives.

Condition assessment

¶1 **Priority gaps:**

- ¶2 Reference conditions for many kelp and reef systems are poorly established
- ¶3 Monitoring of herbivore (urchin) populations is inconsistent across regions
- ¶4 Climate change impact attribution methods need development

¶5 **Development priorities:**

- ¶6 Establishment of long-term monitoring programmes in under-represented regions
- ¶7 Development of composite condition indices suited to kelp and reef systems
- ¶8 Improved understanding of phase shift dynamics and early warning indicators [42]

Carbon accounting

¶1 **Priority gaps:**

- ¶2 Fate of kelp-derived carbon remains uncertain
- ¶3 Methods for quantifying carbon export to deep ocean are not standardised
- ¶4 IPCC does not currently include kelp in the wetlands supplement for national greenhouse gas inventories

¶5 **Development priorities:**

- ¶6 Research to quantify carbon sequestration pathways
- ¶7 Development of accounting protocols that reflect current scientific understanding
- ¶8 Coordination with IPCC and blue carbon initiatives [43]

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Valuation

¶1 **Priority gaps:**

- ¶2 Economic valuation studies for kelp and temperate reef services are limited compared to tropical systems
- ¶3 Resource rent estimates for kelp-associated fisheries are rarely compiled
- ¶4 Benefit transfer approaches lack locally calibrated studies

¶5 **Development priorities:**

- ¶6 Primary valuation studies in the North Pacific, Southern Ocean, and North Atlantic
- ¶7 Integration of kelp forest values into broader natural capital assessments [44]

3.6 Worked Example

¶1 This worked example demonstrates the compilation of kelp forest and temperate reef ecosystem accounts for a hypothetical coastal system in a southern Australian setting. Given the Emerging status of this Circular, methods and values below should be treated as indicative rather than prescriptive.

¶2 **Setting:** A national ecosystem accounting area (EAA) containing 6,500 hectares of kelp forest (M1.2, dominated by *Ecklonia radiata*) and 2,500 hectares of subtidal temperate rocky reef (M1.6), totalling 9,000 hectares.

¶3 **Step 1: Extent account (year t to t+1)**

Accounting entry	Kelp forests (M1.2)	Subtidal rocky reefs (M1.6)	Total
Opening extent (ha)	6,500	2,500	9,000
Additions to extent			
– Managed expansion (kelp restoration trials)	10	0	10
– Natural expansion (recolonisation)	40	15	55
Total additions	50	15	65
Reclassifications			
– Kelp to urchin barren (M1.2 to M1.6)	-250	+250	0
Net reclassification	-250	+250	0
Reductions in extent			
– Managed reduction (infrastructure, pipelines)	5	5	10
– Natural reduction (marine heatwave, non-reclassified losses)	100	0	100
Total reductions	105	5	110
Net change in extent	-305	+260	-45
Closing extent (ha)	6,195	2,760	8,955

¶4 Note: Net change = Total additions + Net reclassification - Total reductions. For kelp: 50 + (-250) - 105 = -305. For rocky reefs: 15 + 250 - 5 = +260. The 250 hectares of kelp that transitioned to urchin barrens are recorded as a reclassification from M1.2 to M1.6, consistent with the phase shift dynamics in Section 3.1. An additional 100 hectares were lost to marine heatwave damage without transitioning to urchin barrens (recorded as natural reduction).

> *Box 1: Consequences of the urchin-barren classification choice*

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Section 3.1 identifies three possible treatments for the 250 ha of kelp that transitioned to urchin barrens. The table below illustrates how each option changes the headline extent figures and kelp extent change rate for the same ecological event.

Option	*Treatment of 250 ha*	*Closing kelp extent (M1.2)*	*Kelp extent change rate*
(a) Reclassify to M1.6 (option used here)	*250 ha moves to M1.6 (degraded rocky reef)*	*6,195 ha*	*–4.7%*
(b) New sub-category M1.6b "Urchin barrens"	*250 ha moves to new M1.6b class; baseline M1.6 unchanged*	*6,195 ha*	*–4.7% (but barren-specific area visible separately)*
(c) Track as condition variable, not extent change	*250 ha remains in M1.2 with degraded condition score*	*6,445 ha*	*–0.8%*

Under options (a) and (b) the headline kelp extent change rate is –4.7%. Under option (c) the same ecological event produces –0.8%, with the 250 ha instead appearing as a decline in the composite condition index. The choice materially changes the headline trend signal and policy interpretation (permanent ecosystem-type loss versus reversible condition degradation). Compilers must document which option they adopt and justify it consistently across accounting periods.
Note on option (b): The 250 ha is allocated to a new sub-category M1.6b ("Urchin barrens"), whilst baseline M1.6 remains at 2,500 ha. The M1.2 closing extent (6,195 ha) and kelp extent-change rate (–4.7%) are identical to option (a). The difference is that option (b) makes the barren-specific area visible as a distinct entry rather than merged into the undifferentiated M1.6 total.

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¶5 **Step 2: Condition account**

¶6 Condition indicators are derived from diver transect surveys and satellite monitoring, using pre-2010 baselines as reference conditions and the normalisation formula from **TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.1 (see also Step 5.1):

Condition variable	Observed value (V)	V_good (reference)	V_bad (degraded)	Indicator score
Kelp canopy density	8.5 plants/m²	14	1	0.58
Urchin barrens extent (% of reef, inverse)	22%	2%	60%	0.66
Species richness (fish + invertebrate)	48 species	70	15	0.60
Water temperature anomaly (inverse)	+1.2°C above baseline	0°C	+3.0°C	0.60

¶7 Note: For inverse variables (urchin barrens extent, temperature anomaly), V_good < V_bad numerically. The unified formula handles both cases without sign reversal. For urchin barrens: (22 – 60) / (2 – 60) = –38 / –58 = 0.66.

¶8 Composite condition index (equal weights): (0.58 + 0.66 + 0.60 + 0.60) / 4 = **0.61**

¶9 This worked example uses four of the six minimum-set variables recommended in Step 3.2. Rugosity (B2) and connectivity (C1) are excluded for illustrative simplicity. Operational composite indices must cover the full minimum set, and omissions should be justified and documented.

¶10 Interpretation: A composite condition index of 0.61 indicates the ecosystem is at 61% of reference condition, reflecting canopy density reduction, expanding urchin barrens, and elevated

water temperatures.

¶11 **Step 3: Ecosystem services (annual flows)**

Service	Physical quantity	Monetary value (USD)
Fisheries (rock lobster) — total resource rent from reef-associated fishery	180 tonnes	5,400,000 (total resource rent; full habitat-service attribution requires a habitat dependency coefficient — see Step 6.2)
Fisheries (abalone) — total resource rent from reef-associated fishery	95 tonnes	4,750,000 (total resource rent; full habitat-service attribution requires a habitat dependency coefficient — see Step 6.2)
Carbon sequestration (kelp export to depths >200 m)	9,750 t CO2/yr (estimated as 6,195 ha x 0.43 t C/ha/yr export to >200 m x 44/12 CO2/C; provisional, uncertainty range 0.1–0.9 t C/ha/yr; see [34])	780,000 (at USD 80/t CO2; provisional, not suitable for national GHG inventory use)
Coastal protection (wave attenuation)	40 km coastline (low confidence; wave-attenuation parameterisation per Step 6.4)	2,800,000 (avoided damage, low confidence)
Recreation (diving and snorkelling)	85,000 person-visits	3,400,000 (simulated exchange)
Total valued services (gross)		**17,130,000**
Total excluding provisional carbon sequestration		**16,350,000**

¶12 Note: The fisheries values shown are total resource rents of reef-associated fisheries, not the share attributable to the kelp/reef habitat as an intermediate service. The carbon sequestration estimate is provisional and presented with explicit uncertainty so its effect on downstream valuation can be quarantined. The coastal protection figure is reported at low confidence given the wide range of empirical wave-attenuation values for kelp (Step 6.4 and Section 3.3).

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¶13 **Step 4: Asset valuation**

¶14 Applying a 4% social discount rate over a 25-year projection horizon under the stable-flows assumption (Step 7.3) and using PVAF = 15.62 (Step 7.4):

> *Asset value (including provisional carbon) = 17,130,000 x 15.62 = **approximately USD 267,500,000** Asset value (excluding provisional carbon) = 16,350,000 x 15.62 = **approximately USD 255,400,000***

¶15 The two estimates bracket the influence of the provisional carbon service. The difference (approximately USD 12,200,000, or about 4.6% of gross asset value) is the value the carbon row contributes when capitalised over 25 years at 4%. Compilers should report both figures and avoid embedding the provisional carbon component in a single headline number.

¶16 Sensitivity: PVAF = 15.62 at 4%, 19.52 at 2%, and 22.02 at 1% (Table 4). Applied to the asset value excluding provisional carbon, the sensitivity range spans approximately USD 230 million (at 5%) to USD 360 million (at 1%).

¶17 **Policy indicator derivation:**

- ¶18 **Kelp extent change rate (combined):** −4.7% for the accounting period (−305 ha / 6,500 ha opening extent: the two components below, offset by +0.8% from 50 ha of additions). This figure must not be used as a trend metric without disaggregation.

- ¶19 *Permanent-loss component:* approximately –1.6% (–105 ha total permanent reduction divided by opening extent). Losses not expected to recover without active management.
- ¶20 *Phase-shift component:* approximately –3.8% (–250 ha kelp-to-barren reclassification divided by opening extent). Phase-shift area is a candidate for urchin removal and kelp restoration, and should not be interpreted as permanent loss.

- ¶21 **Urchin barren extent:** 22% of reef area (early warning threshold typically 15–20%).
- ¶22 **Composite condition index:** 0.61 (moderate condition requiring intervention).
- ¶23 **Climate stress indicator:** Temperature anomaly +1.2°C (approaching stress threshold).

¶24 The disaggregation of the kelp extent change rate is particularly relevant for restoration targeting: the –3.8% phase-shift area is the practical management opportunity, distinct from the –1.6% of permanently lost kelp habitat.

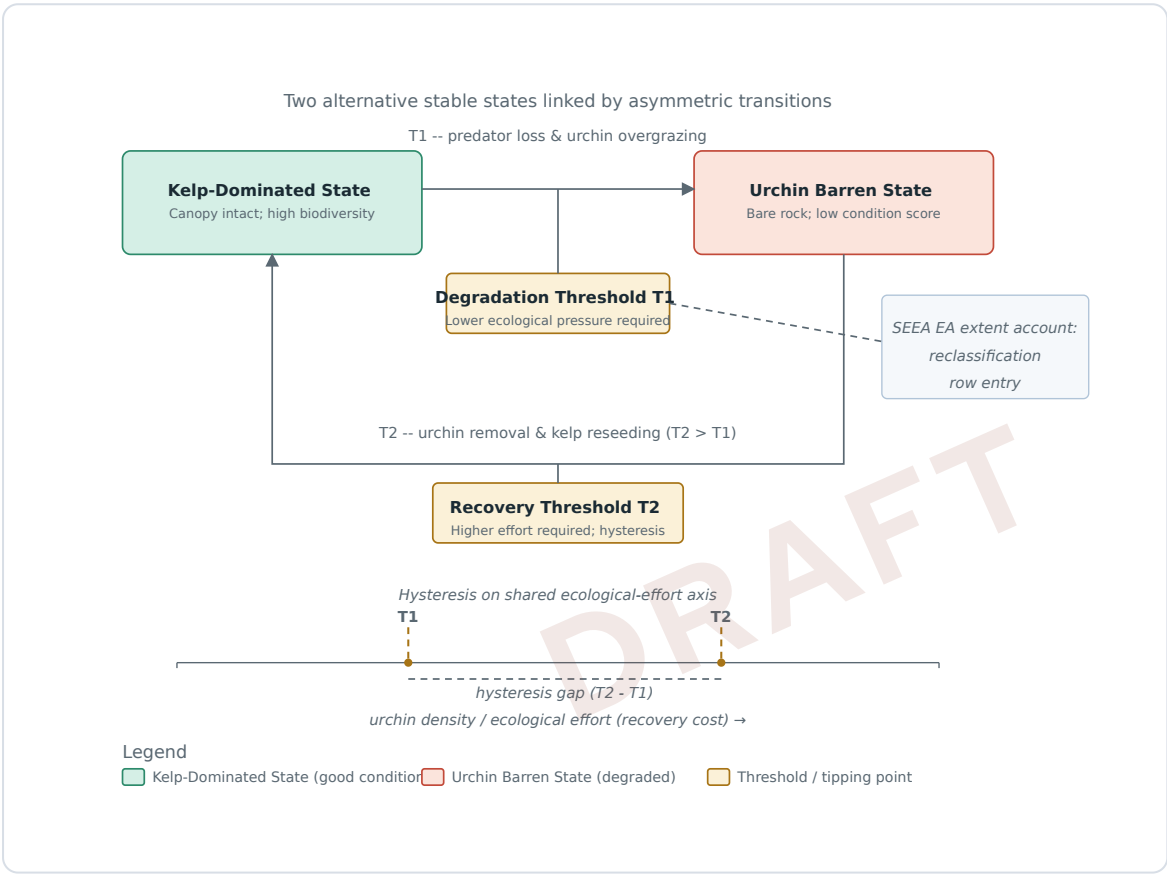


Figure 6.4.1 Kelp-to-urchin-barren phase shift with asymmetric thresholds: recovery (T2) is harder than the forward transition (T1) -- hysteresis. Both transitions write extent-account reclassification and condition-score change rows.

Source: TG-6.4 draft-v7, Section 3.1 (phase-shift dynamics & hysteresis, Table 2) and Box 1 (Section 3.6, classification options for the urchin-barren transition); SEEA EA Table 4.1 (extent account reclassification row); IUCN GET M1.2 (trophic-cascade mechanism).

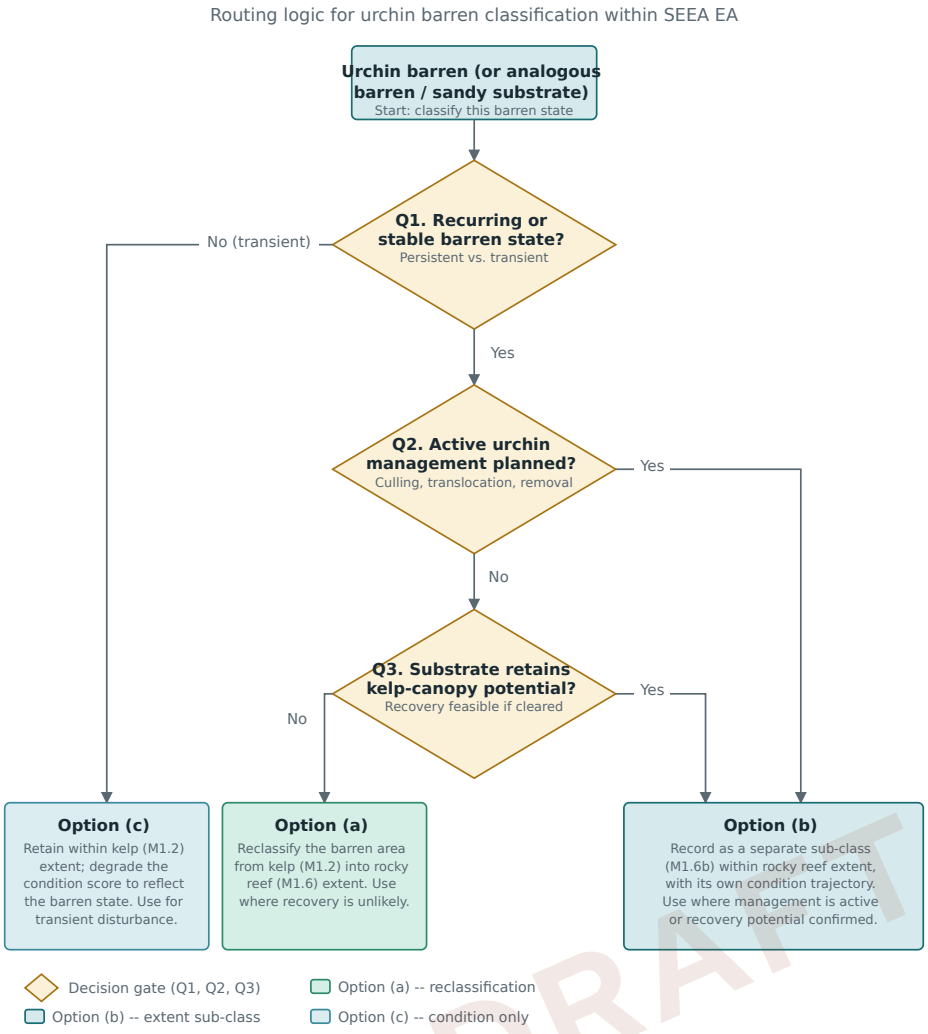


Figure 6.4.2 Three sequential criteria route a kelp area to one of three SEEA EA treatments for urchin barrens (reclassify, sub-class, or condition-only). Option letters match Box 1 (Section 3.6); tree also covers analogous sandy barrens.

Source: TG-6.4 draft-v7, Box 1 (Section 3.6, three options for classifying urchin barrens within national ocean accounts) and Section 3.1 (classification criteria for recurring vs. transient barren states).

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

5. References

1. ¶1 IUCN Global Ecosystem Typology (GET), M1 Marine Shelf biome, Functional Groups M1.2 and M1.6.
2. ¶2 SEEA EA para 4.1. “Ecosystem extent is the size of an ecosystem asset.”
3. ¶3 IUCN GET M1.2 Ecological Traits description.
4. ¶4 IUCN GET M1.2. Kelps can reach “up to 30 m in length” and grow “up to 0.5 m/day.”
5. ¶5 IUCN GET M1.2 Distribution. “Nearshore rocky reefs to depths of 30 m in temperate and polar waters.”
6. ¶6 IUCN GET M1.2 Distribution. “Absent from warm tropical waters but present in upwelling zones off Oman, Namibia, Cape Verde, Peru and the Galapagos.”

7. ¶7 IUCN GET M1.6 Ecological Traits. "Submerged rocky reefs host trophically complex communities lacking a dense macroalgal canopy."
8. ¶8 IUCN GET M1.6. "Algal productivity and abundance decline with depth due to diminution of light and are also kept in check by periodic storms and a diversity of herbivorous fish, molluscs and echinoderms."
9. ¶9 IUCN GET M1.2. "Herbivores keep epiphytes in check, but kelp sensitivity to herbivores makes the forests prone to complex trophic cascades."
0. ¶10 Remote sensing of subtidal habitats is addressed generally in TG-4.1 Remote Sensing Data.
1. ¶11 Water column correction methods are an active area of research in marine remote sensing.
2. ¶12 SEEA EA para 3.11. "Marine ecosystems are not concentrated near one surface (i.e. the air-land/water interface) but extend throughout the water column and include the underlying sediment and seabed."
3. ¶13 Giant kelp (*Macrocystis pyrifera*) forms floating surface canopies visible from satellites; other genera form subsurface canopies.
4. ¶14 Bennett, S., Wernberg, T., De Bettignies, T., Kendrick, G.A., Anderson, R.J., Bolton, J.J., Rodgers, K.L., Shears, N.T., Leclerc, J.C., Leveque, L., Davoult, D. (2015). 'Canopy interactions and physical stress gradients in subtidal communities'. Ecology Letters 18(7): 677-686.
5. ¶15 UN Environment World Conservation Monitoring Centre Ocean Data Viewer provides global habitat data at moderate resolution.
6. ¶16 Multi-sensor approaches combining optical and acoustic data improve benthic habitat mapping coverage.
7. ¶17 Species distribution modelling can extend point-based survey data to estimate ecosystem extent across larger areas.
8. ¶18 SEEA EA para 4.10 and Table 4.1. The standard ecosystem extent account distinguishes additions, reductions, and conversions/reclassifications from other ecosystem types; reclassifications sum to zero at the total level across the accounting area.
9. ¶19 IUCN GET M1.2. "Trophic cascades when declines in top predators release herbivore populations from top-down regulation… may drastically reduce the abundance of kelps and dependent biota, and lead to replacement of the forests by urchin barrens, which persist as an alternative stable state."
0. ¶20 SEEA EA para 5.1. "Ecosystem condition accounts record information on the quality of ecosystem assets."
1. ¶21 SEEA EA para 5.32 and Table 5.1. Condition characteristics are grouped into six classes: physical state (A1), chemical state (A2), compositional state (B1), structural state (B2), functional state (B3), and landscape/seascape characteristics (C1).
2. ¶22 IUCN GET M1.2. "Truncated thermal niches limit the occurrence of kelps in warm waters."
3. ¶23 Marine heatwave impacts on kelp documented in Western Australia, eastern Tasmania, and other temperate regions. See Wernberg, T., Bennett, S., Babcock, R.C. et al. (2016). 'Climate-driven regime shift of a temperate marine ecosystem'. Science 353(6295): 169-172.
4. ¶24 Ocean acidification effects on calcifying organisms may have indirect effects on kelp community structure.
5. ¶25 IUCN GET M1.2. "Storms may dislodge kelps, creating gaps that may be maintained by herbivores or rapidly recolonized."
6. ¶26 SEEA EA para 5.35-5.48 on reference conditions.
7. ¶27 Documentation of reference condition selection is essential for transparent condition accounting.
8. ¶28 SEEA EA Chapter 6 on ecosystem services.
9. ¶29 CPC Version 2.1 includes wild sea urchins (04521) and farmed sea urchins (04522) as classified products.
0. ¶30 IUCN GET M1.2. "The structure and diversity of life in kelp canopies provide forage for seabirds and mammals, such as gulls and sea otters, while small fish find refuge from predators among the kelp fronds."
1. ¶31 SEEA EA para 6.42-6.43 on nursery population and habitat maintenance services as intermediate services.
2. ¶32 SEEA EA describes nursery and habitat services as intermediate services that support the supply of other ecosystem services (notably provisioning biomass via associated fisheries); their monetary value must be derived by attribution to the habitat, not equated with the full resource rent of the associated fishery.
3. ¶33 Carbon sequestration by kelp forests is an emerging research area with considerable uncertainty regarding magnitude and pathways.
4. ¶34 Krause-Jensen, D. and Duarte, C.M. (2016). 'Substantial role of macroalgae in marine carbon sequestration'. *Nature Geoscience* 9: 737-742. DOI: 10.1038/ngeo2790. This paper establishes the conceptual framework for macroalgal export to the deep sea (>200 m) as a long-term carbon sequestration pathway. The 0.43 t C/ha/yr export coefficient used in the worked example represents kelp-derived carbon estimated to reach depths greater than 200 m, where long-term sequestration is assumed. Plausible uncertainty range: approximately 0.1–0.9 t C/ha/yr, reflecting variation across species, biogeographic settings, and methodological choices in the macroalgal carbon export literature (Krause-Jensen & Duarte 2016 and subsequent syntheses). This coefficient is not suitable for national GHG inventory use and is provided here for illustrative accounting purposes only.
5. ¶35 SEEA EA Technical Recommendations on climate regulation - carbon sequestration. "Assessments of this service should only consider carbon stored long-term (i.e. at least several decades) in the ecosystem."
6. ¶36 Empirical wave-attenuation studies for kelp canopies include work on *Macrocystis pyrifera* in southern California (seafloor interaction reduces wave energy flux by approximately 12% with a further approximately 7% reduction over established canopies), *Laminaria hyperborea* in Norway (reductions reported up to approximately 60% through dense canopy), and *Ecklonia radiata* in shallow Australian coastal bays. Reported reductions range across approximately 7–60% depending on species, canopy density, bathymetry, and wave period.

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7. ¶37 Nutrient uptake by kelp can reduce eutrophication impacts in coastal waters.
8. ¶38 Recreational diving and snorkelling in kelp forests contributes to coastal tourism economies.
9. ¶39 Long-term monitoring programmes such as PISCO provide valuable baseline data for condition assessment.
0. ¶40 Cultural services provided by kelp forests to Indigenous communities documented in multiple regions.
1. ¶41 Development of kelp-specific remote sensing algorithms is an active research area.
2. ¶42 Early warning indicators of kelp forest decline could support adaptive management.
3. ¶43 Coordination with IPCC and blue carbon initiatives needed to establish appropriate accounting treatment for kelp carbon.
4. ¶44 Primary valuation studies needed to support benefit transfer approaches for kelp forest ecosystem services.

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Pelagic and Open Ocean Accounting

Provides guidance on compiling accounts for pelagic and open ocean ecosystems.

Version 0.8.1 **Status** Draft **Stability** Emerging

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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ABOUT THIS CIRCULAR

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This Circular provides guidance on compiling accounts for pelagic and open ocean ecosystems, the water column environments that extend seaward to the high seas and downward to the abyssal depths. As an Emerging circular, it acknowledges that methodologies for pelagic ocean accounting remain less developed than for coastal and benthic ecosystems, with substantial uncertainties in spatial delineation, stock measurement, and the attribution of assets and services across jurisdictional boundaries. Pelagic ecosystems present distinctive accounting challenges. They are defined by water masses rather than fixed substrates, primary production occurs diffusely throughout enormous volumes, and key species are highly migratory across multiple jurisdictions. Much of the domain also lies beyond national jurisdiction, in high seas areas governed by the freedom of the seas principle, whilst the seabed beneath is subject to the common heritage of mankind regime.

Key decision use cases include quota allocation for tuna and billfish managed through Regional Fisheries Management Organisations (RFMOs), ocean carbon sink quantification to measure the biological carbon pump for nationally determined contributions (NDCs) under the Paris Agreement, and BBNJ Agreement implementation, where area-based management tools, environmental impact assessments, and benefit-sharing arrangements for marine genetic resources require accounts extending beyond national jurisdiction.

Pelagic primary productivity measurements feed into TG-2.1 Biophysical Indicators and biological carbon pump quantification connects to TG-2.8 Climate Change Indicators. The foundational concepts for Ocean Accounts are established in TG-0.1 General Introduction to Ocean Accounts. Physical and monetary asset accounting methodology is in TG-3.1 Asset Accounts. As an Emerging circular, this document should be reviewed in two to three years as methodologies mature.

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Framework Position

This Circular owns the delineation and accounting of the open-ocean water column, IUCN GET biome M2 (M2.1 epipelagic through M2.4 abyssopelagic, and M2.5 sea ice), where the SEEA EA's seabed-based delineation does not apply. It also owns the treatment of migratory and straddling stocks: the recordable national asset is the agreed access right, not the biomass in the water.

It cross-refers for the account structure (TG-3.1) and for the UNCLOS zones, ABNJ asset boundary and BBNJ provisions, which are owned by TG-6.6 Section 3.1 and apply to the water column as they do to the seabed. Stock assessment inputs come from TG-6.7.

M1.9 upwelling zones sit in the Marine Shelf biome and are outside this Circular. No circular in this edition covers them; Section 3.1 states the interim treatment.

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2. Requirements

¶1 This Circular requires familiarity with:

- ¶2
  TG-0.1 General Introduction to Ocean Accounts – conceptual framework, key components, and spatial scope definitions for pelagic ecosystems within and beyond national jurisdiction.
- ¶3
  TG-3.1 Asset Accounts – methodology for physical and monetary asset accounts, including aquatic resources, ecosystem assets, and the treatment of assets not clearly associated with specific seabed areas.
- ¶4
  TG-6.7 Fisheries Stock Assessment – stock assessment concepts (biomass, natural mortality M, fishing mortality F, recruitment, VPA, close-kin mark-recapture) required before attempting Steps 4 and 5 of the compilation procedure.

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¶5 Readers may also benefit from:

- ¶6 **TG-6.6 Deep Sea and Seabed Accounting** — complementary guidance on benthic ecosystems underlying pelagic waters.
- ¶7 **TG-2.8 Climate Change Indicators** — carbon sequestration and climate regulation services from pelagic ecosystems.

¶8 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 The pelagic ocean is the largest biome on Earth, comprising the open-ocean water column across all latitudes and spanning depths from the surface to nearly 11 kilometres in the deepest trenches[5]. Unlike coastal and benthic ecosystems where spatial units can be delineated by substrate or shoreline, pelagic ecosystems are structured by the physical and chemical properties of water masses: temperature, salinity, light penetration, oxygen concentration, and nutrient availability.

3.1 Spatial Delineation

> *Scope boundary: TG-6.5 covers only open-ocean M2 biome units (M2.1 Epipelagic, M2.2 Mesopelagic, M2.3 Bathypelagic, M2.4 Abyssopelagic, M2.5 Sea ice). M1.9 upwelling zones fall under the Marine Shelf biome (M1) and are outside TG-6.5. No circular in this edition covers the M1 shelf ecosystems other than M1.1 (TG-6.3), M1.2 and M1.6 (TG-6.4) and M1.3 (TG-6.1); until one is issued, compile M1.9 using the generic ecosystem asset method in TG-3.1 Asset Accounts with condition variables selected under TG-4.8 and TG-4.9, and document the departure. Open-ocean upwelling features (e.g., intertropical convergence) are included within M2.1. See TG-6.6 Deep Sea and Seabed Accounting for the shelf/benthic boundary treatment.*

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¶1 Spatial delineation must address three considerations: vertical zonation of the water column, horizontal biogeographic regions, and jurisdictional boundaries under international law.

Vertical zonation

¶1 Pelagic ocean waters are classified within the IUCN Global Ecosystem Typology as biome **M2**. For the GET realm/biome/EFG hierarchy and the national crosswalk obligation, see **TG-4.1 Remote Sensing and Geospatial Data** Section 3.2.4.[6] Table 3.1.1 summarises the M2 functional groups relevant to this Circular.

Functional group	Description
M2.1 Epipelagic ocean waters (0-200m)	The sunlit surface layer where photosynthesis occurs, supporting primary production by phytoplankton and the highest biodiversity and biomass of pelagic organisms[7], [8].
M2.2 Mesopelagic ocean waters (200-1,000m)	The "twilight zone" receiving insufficient light for photosynthesis, dominated by detritivores and predators, and characterised by high biomass of small fishes and extensive diel vertical migration[9], [10].
M2.3 Bathypelagic ocean waters (1,000-3,000m)	Dark waters dependent on organic fallout from above, with low biomass, long-lived organisms, and truncated food webs[11].

Functional group	Description
M2.4 Abyssopelagic ocean waters (3,000-6,000m)	Extreme depths with low biomass and specialised fauna adapted to high pressure and nutrient scarcity[12] .
M2.5 Sea ice	The seasonally frozen surface of polar oceans supporting specialised ice-associated communities[13] .

¶2 For practical accounting purposes, the epipelagic zone is of primary importance as it contains most commercially exploited fish stocks, supports virtually all primary production, and generates the ecosystem services of greatest current economic relevance[14] . The mesopelagic zone is now recognised as a large carbon reservoir and a potential future fishery resource. The SEEA EA notes that "marine ecosystems are not concentrated near one surface (i.e. the air-land/water interface) but extend throughout the water column and include the underlying sediment and seabed"[15] . For the open ocean, where the seabed-based delineation approach recommended by SEEA EA is less suitable, alternative approaches are summarised in Table 3.1.2.

Approach	Description
Water-mass-based delineation	Defining ecosystem units by oceanographic characteristics such as temperature, salinity, and circulation patterns.
Biogeographic provinces	Using established marine biogeographic classifications such as Longhurst provinces[16] .
Depth-zone layers	Treating vertical zones as separate accounting units overlaying the horizontal extent.

¶3 Countries operationalising pelagic ecosystem delineation within their EEZs may find it practical to begin with Longhurst biogeographic provinces (for horizontal delineation) combined with GET M2 depth-zone layers (for vertical stratification), and to focus on the epipelagic zone alone for initial implementation.

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Biogeographic regions

¶1 Productive pelagic regions include eastern boundary upwelling systems (Canary, Benguela, California, and Humboldt currents), tropical and subtropical gyres, polar and subpolar regions, and frontal zones and convergences. The GET recognises coastal upwelling zones as functional group M1.9 within the Marine Shelf biome[17] , whilst weaker open-ocean upwelling (e.g., intertropical convergence zone) falls within M2.1.

Jurisdictional boundaries

¶1 The UNCLOS maritime zones, the SEEA CF asset-boundary treatment of areas beyond national jurisdiction, the extended continental shelf claim states, and the BBNJ Agreement provisions are set out once in **TG-6.6 Deep Sea and ABNJ Accounting** Section 3.1, which owns them for the publication[18] , [19] , [20] , [21] , [22] . That treatment applies to the pelagic water column exactly as it does to the seabed.

¶2 One rule is pelagic-specific and is stated here because it has no seabed equivalent. Stocks that migrate across zones, straddle a boundary, or complete their life cycle on the high seas are not excluded from the national asset boundary merely because the fish are outside the EEZ for part of the year. The SEEA CF provides that "when exploitation control over migrating and straddling fish stocks, and fish stocks that complete their life cycle in international waters (high seas), has been established and the access rights of a country to them are defined in international agreements, that portion of agreed access rights to those aquatic resources can be considered to belong to the country"[23] . The recordable asset is therefore the **agreed access right**, sized by the allocation instrument — an RFMO quota share, a bilateral access agreement — and not the biomass in the water.

Section 3.3 below applies this to migratory species, and **TG-6.7 Fisheries Accounting** gives the stock-assessment inputs the allocation is derived from.

¶3 For how jurisdictional boundaries interact with extent and condition accounts, see **TG-0.1 General Introduction to Ocean Accounts**.

3.2 Extent and Condition

Extent measurement

¶1 Unlike terrestrial or benthic ecosystems measured in hectares, pelagic ecosystem extent may be expressed in multiple dimensions:

- ¶2 **Surface area** – the horizontal extent of water masses or biogeographic provinces (km²)
- ¶3 **Volume** – the three-dimensional extent of depth zones (km3)
- ¶4 **Mixed metrics** – surface area combined with characteristic depth range

¶5 For national accounts within the EEZ, extent may be calculated as the area of the EEZ multiplied by relevant depth zones. For initial implementation, the epipelagic zone is the most tractable focus, as extent changes there are detectable through satellite-observable indicators such as sea surface temperature and chlorophyll-a fronts. Changes in pelagic extent reflect continuous oceanographic variation (water mass boundary shifts, thermocline movement, photic zone depth changes) rather than the discrete conversions characteristic of benthic ecosystems.

¶6 Table 1 presents an illustrative structure for a pelagic ecosystem extent account (Pacific SIDS, 500,000 km² EEZ, two depth zones). Derivation: epipelagic 500,000 km² x 0.2 km = 100,000 km3, and mesopelagic 500,000 km² x 0.8 km = 400,000 km3.

Accounting entry	M2.1 Epipelagic	M2.2 Mesopelagic	Total
Opening extent (km3)	100,000	400,000	500,000
Changes			
– Water mass shifts	-500	+500	0
– Depth zone changes	+200	-200	0
Net change	-300	+300	0
Closing extent (km3)	99,700	400,300	500,000

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¶7 *Table 1: Illustrative structure for pelagic ecosystem extent account within EEZ (Pacific SIDS, 500,000 km² EEZ)*

¶8 **Crosswalk to SEEA EA standard extent change categories.** The change categories used here reflect the continuous rather than discrete nature of pelagic extent changes.

Pelagic-specific category	SEEA EA standard category	Notes
Water mass shift (climate-driven warm pool expansion/contraction)	Natural reduction / natural expansion	Where a net volume change of a water mass type occurs
Depth zone reclassification (thermocline movement with no net volume change)	Reclassification (not an extent change)	Per SEEA EA para 6.14, statistical re-classifications are recorded separately from extent losses and gains
Sea ice seasonal/multi-year change (M2.5)	Natural reduction / natural expansion	Where multi-year ice extent shifts

¶9 Thermocline-driven movements that shift volume between depth zones without changing total water column volume should be recorded as reclassifications, not as paired losses and gains, to preserve consistency with SEEA EA para 6.12-6.15.

¶10 **Working from a regional habitat map.** Compilers whose extent data come from a regional seas habitat product rather than from oceanographic fields should check whether that product carries pelagic classes at all. The first ecosystem accounts compiled for a regional sea — the preliminary OSPAR accounts for the North-East Atlantic — recorded extent for six seabed classes and no pelagic class, because the seabed map available (EUSeaMap, on the EUNIS classification then published) resolved substrate rather than water column, and its authors noted the resulting two-dimensional treatment as a principal limitation to be addressed by extending accounts into the water column [24]. The 2022 revision of EUNIS disaggregated marine habitats into benthic and pelagic components, so a regional map may now support a pelagic extent account where an earlier vintage of the same map could not. Two consequences for compilation:

- ¶11 A regional habitat map that predates the benthic/pelagic split supports the seabed account of **TG-6.6 Deep Sea and Seabed Accounting** but not the pelagic extent account of this Section. Compile pelagic extent from oceanographic fields and biogeographic provinces per Section 3.1 instead of forcing a benthic classification into the water column.
- ¶12 Where both a benthic and a pelagic classification are available from the same regional product, they remain separate extent accounts over the same footprint, per the double-counting rule in Section 3.4. Record the vintage of the classification used in account metadata, as the class definitions have changed.

Condition variables

¶1 The SEEA EA condition framework applies to pelagic ecosystems with appropriate variable selection. Key condition characteristics include [25]:

¶2 **Abiotic characteristics:**

- ¶3 Sea surface temperature and thermal stratification
- ¶4 Ocean acidification (pH, aragonite saturation)
- ¶5 Dissolved oxygen concentration (with attention to oxygen minimum zones)
- ¶6 Nutrient concentrations (nitrate, phosphate, silicate, iron)
- ¶7 Salinity and density structure

¶8 **Biotic characteristics:**

- ¶9 Chlorophyll-a concentration as a proxy for phytoplankton biomass [26]
- ¶10 Primary productivity rates (net primary production, NPP)
- ¶11 Zooplankton biomass and community composition
- ¶12 Fish biomass and species composition
- ¶13 Marine mammal and seabird abundance

¶14 **Functional characteristics:**

- ¶15 Primary productivity (carbon fixation rates)
- ¶16 Export production (flux of organic matter to depth)
- ¶17 Community structure and trophic organisation

¶18 The epipelagic zone's primary production "largely by diatoms, accounts for around half of all global carbon fixation" [27]. Productivity metrics are therefore of particular importance in pelagic condition accounts. The mesopelagic zone contains fish biomass estimated at possibly "two orders of magnitude larger than global fisheries landings" [28], though precise quantification remains uncertain.

¶19 For how condition variables translate into indicators, see **TG-2.1 Biophysical Indicators**.

Reference conditions

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¶1 Establishing reference conditions for pelagic ecosystems is complicated by high natural variability from climate oscillations (El Nino-Southern Oscillation, Pacific Decadal Oscillation) and the lack of historical baseline data. Possible approaches include pre-industrial baselines (for temperature, acidification), model-based reference states from ecosystem models, and policy-based targets established under regional fisheries agreements. Given these challenges, condition accounts may need to focus on tracking trends and rates of change rather than departures from fixed reference conditions.

3.3 Migratory Species

¶1 Highly migratory species present particular challenges for asset accounting, as their distribution spans multiple EEZs and the high seas. The treatment of aquatic resources in asset accounts is addressed in **TG-3.1 Asset Accounts** Section 3.4.1. This section provides supplementary guidance specific to highly migratory pelagic species.

UNCLOS provisions

¶1 Article 64 of UNCLOS requires coastal States and other fishing States to cooperate through appropriate international organisations to ensure conservation and optimal utilisation of highly migratory species throughout the region, both within and beyond the EEZ [29]. UNCLOS Annex I lists highly migratory species. Table 3.3.1 summarises the principal groups [30].

Group	Species included
Tunas	Albacore, bluefin (Atlantic, Pacific, southern), bigeye, skipjack, yellowfin, blackfin, little tuna, frigate mackerel.
Billfish	Marlins, sailfishes, swordfish.
Other pelagic fish	Sauries, pomfrets, dolphinfish (mahi-mahi).
Oceanic sharks	Various families including Carcharhinidae, Alopiidae, Isurida (now Lamnidae).
Cetaceans	All whale and dolphin families.

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¶2 The 1995 UN Fish Stocks Agreement further elaborates obligations for straddling and highly migratory stocks, requiring cooperation through RFMOs [31].

Accounting approaches

¶1 The SEEA CF provides that "migrating and straddling fish stocks are considered to belong to a country during the period when those stocks inhabit its EEZ" [32]. Alternative attribution approaches are summarised in Table 3.3.2.

Approach	Description
Proportional allocation	Attributing stock shares based on time spent in each EEZ or catch proportions.
RFMO-based allocation	Using catch quotas allocated by regional management bodies as the basis for national asset shares.
Flag State attribution	Attributing catches to the flag State of the harvesting vessel (as done for production in the SNA).
Ecosystem-based accounts	Maintaining accounts at the scale of the stock's range rather than national boundaries.

¶2 For highly migratory species managed under RFMOs, quota allocations provide a practical basis for attributing asset shares, since "that portion of agreed access rights to those aquatic resources can be considered to belong to the country" [33]. RFMO quotas are expressed as catch limits (flows) rather than stock shares (assets). Converting to asset shares requires (1) total stock biomass from the RFMO stock assessment, (2) each country's proportional quota share, and (3) the application of that share to the total stock estimate to derive attributed asset value. This conversion intro-

duces uncertainties from stock assessment precision, the catch-share-as-asset-share assumption, and temporal mismatch.

Handling temporal mismatch between stock assessments and accounting periods

¶1 RFMO stock assessments are conducted every 3 to 5 years. In years without a new assessment, compilers should:

1. ¶2 Use the most recent assessment as the opening stock for the accounting period.
2. ¶3 Update to a closing stock using the stock account flow identity: closing stock = opening stock + natural growth − catch − natural mortality, with growth, M, and F parameters carried forward from the last assessment.
3. ¶4 Flag the resulting entry as "model-projected" rather than "assessment-based" in account metadata.
4. ¶5 When a new stock assessment becomes available, retrospectively revise the affected accounting periods and record the change as a statistical revision (reappraisal) consistent with SEEA CF para 5.393.

¶6 For revision protocols, see **TG-0.7 Quality Assurance**.

¶7 Table 2 presents an approach to structuring highly migratory species asset accounts using RFMO-based allocation.

Accounting entry	National EEZ stock	High seas allocation (quota-based)	Total attributed
Opening stock (tonnes)	8,200	4,100	12,300
Additions			
– Natural growth	1,200	600	1,800
– Immigration/movement in	500	0	500
– Reappraisals	0	0	0
Reductions			
– Catch – landings (by residents)	850	520	1,370
– Catch – discards (by residents)	50	30	80
– Catch (by non-residents, licensed)	200	0	200
– Emigration/movement out	400	0	400
– Natural mortality	800	400	1,200
– Reappraisals	0	0	0
Closing stock (tonnes)	7,600	3,750	11,350

¶8 *Table 2: Illustrative structure for highly migratory species asset account with synthetic values*

¶9 **Methodological note.** The "Total attributed" column sums the National EEZ stock (physical biomass) and the High seas allocation (quota-based financial asset share). These two quantities are not dimensionally homogeneous: the EEZ column records physical fish location, whilst the high seas column records a treaty-defined access right. Compilers should treat the "Total attributed" column as a memo aggregate only. Immigration and emigration entries appear only in the National EEZ stock column: movement out of the EEZ does not transfer biomass into the quota-based high seas allocation, as that allocation is defined by treaty share rather than physical residence. Changes to the quota share (renegotiated allocations) are recorded as reappraisals, not as flows. The approach chosen should be documented in metadata.

Cetaceans and marine mammals

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¶1 UNCLOS Article 65 addresses marine mammals separately, requiring States to cooperate for conservation through appropriate international organisations [34]. Unlike fish stocks, cetaceans are not typically harvested commercially, so their treatment in accounts focuses on ecosystem condition, ecosystem services (tourism, existence value), and biodiversity indicators. For whale watching and marine mammal tourism, see **TG-2.4 Ecosystem Goods and Services**.

3.4 Accounting Boundaries for Pelagic Activities

¶1 Table 3 summarises the principal boundary challenges and their treatment, drawing on UNCLOS jurisdictional provisions, SEEA CF asset boundary rules, and SNA residence principles.

Accounting Challenge	Treatment Approach	Data Implications
Migratory species crossing EEZ	Allocate by RFMO quota share (recommended); or by residence time / catch location where quotas unavailable (see Section 3.3)	VMS data, tagging studies, RFMO quota records
Stocks shared with neighbours	Joint stock assessment	Regional cooperation
High seas activity by residents	Include in national accounts	Flag state reporting
High seas activity by non-residents	Exclude from national production	Distinguish by flag
Water column vs seabed ecosystems	Separate extent accounts	3D spatial data

¶2 *Table 3: Pelagic accounting boundary treatments*

¶3 **Migratory species crossing EEZ boundaries** are allocated to the EEZ in which they reside at the accounting date or, where continuous tracking is unavailable, in proportion to catch location data from vessel monitoring systems (VMS) and scientific tagging programmes.

¶4 **Stocks shared with neighbouring countries** require joint stock assessments through bilateral or multilateral arrangements. Each country's asset share reflects its agreed access rights.

¶5 **High seas activity by resident economic units** is included in national production accounts per the SNA residence principle: output of fishing vessels on the high seas is attributed to the flag State's economy.

¶6 **High seas activity by non-resident units** (foreign-flagged vessels) is excluded from national production but may appear where foreign vessels operate under access agreements within the EEZ. AIS data supports flag state identification.

¶7 **Water column versus seabed ecosystems** are treated as separate extent accounts to avoid double-counting. The relationship between these overlapping accounts is addressed in **TG-6.6 Deep Sea and Seabed Accounting**.

3.5 Ecosystem Services

¶1 Pelagic ecosystems generate a range of ecosystem services, though many are difficult to measure and value. This section should be read in conjunction with **TG-2.4 Ecosystem Goods and Services** for the general framework. For valuation approaches, see **TG-1.9 Valuation**.

Provisioning services

¶1 **Fisheries production** is the dominant provisioning service. The SEEA AFF distinguishes "Pelagic fish, including Tunas, bonitos, billfishes" and "Other pelagic fish" [35]. For pelagic fisheries accounting, see **TG-3.2 Flows from the Environment to the Economy** and **TG-6.7 Fisheries Stock Assessment**.

¶2 **Landings data will not attribute the service to an ecosystem type.** Reported landings — whether national, FAO or RFMO — carry a fleet, a species and a management area, not the ecosys-

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tem that supplied the catch. In the preliminary OSPAR regional-sea accounts, fish provisioning was compiled from FAO landings and could not be assigned to any individual ecosystem type; the flow was recorded against the full set of ecosystem classes as a group, and the compilers identified the absence of spatially explicit links between landings and ecosystems as one of the two gaps blocking further extension of the accounts [24]. For pelagic accounts this constraint is structural rather than incidental: catch is taken from a moving stock over a wide area, and no realistic reporting improvement will locate a landing in a single water mass. Recommended treatment:

- ¶3 Record the service against the set of pelagic ecosystem types plausibly supplying the stock, labelled as a group, rather than apportioning it to one type on an unstated assumption.
- ¶4 Where an apportionment is required, derive it from VMS or observer effort distribution rather than from landings, and disclose the effort series and the period used.
- ¶5 Do not read a service flow recorded against a group of ecosystem types as evidence of the condition of any one of them.

¶6 **Access licence fees vs ecosystem service supply.** A common compilation issue for SIDS whose primary ocean revenue is access fee income is the distinction between the ecosystem service flow value and the economic transaction value represented by licence fees.

Item	Conceptual nature	Recording location
Ecosystem service supply (sustainable yield x resource rent per tonne)	The value of the provisioning service generated by the stock	SEEA EA ecosystem service supply table; physical and monetary ecosystem service accounts
Access licence fee receipts from foreign fleets	A payment for the right to exploit the provisioning service; an economic transaction	SNA current account (current transfers / service exports under the balance of payments); recording basis described in **TG-3.2 Flows from the Environment to the Economy**

¶7 Licence fees should not be added to the ecosystem service supply value, as that addition would double-count the underlying provisioning service. The resource rent component embedded in the licence fee is conceptually part of the ecosystem service value, but the fee itself is recorded as a current transaction (see SEEA EA para 8.40-8.42 and SEEA CF para 5.395).

¶8 **Resource rent does not track the stock.** Compilers should expect the monetary series for fish provisioning to move independently of, and sometimes opposite to, the physical series. The OSPAR accounts recorded 8.33 Mt landed valued at EUR 2,846 million in one year against 9.15 Mt landed valued at EUR 1,728 million in another, because resource rent per tonne is a residual sensitive to fuel and input prices rather than to the state of the stock [24]. The consequence is that the monetary account should be read for relative change over a run of years and not as a level, and that a fall in the monetary value of the provisioning service is not evidence of stock decline. Where the physical and monetary series diverge in direction, state the input-price movement responsible in account metadata.

¶9 **Genetic resources** from pelagic organisms represent an emerging provisioning service category. The BBNJ Agreement establishes a benefit-sharing framework for marine genetic resources in areas beyond national jurisdiction [36].

¶10 **Mesopelagic resources as a prospective asset.** Mesopelagic fish biomass may be two orders of magnitude larger than global fisheries landings (estimate carries high uncertainty from acoustic backscatter conversion). As commercial exploitation has not yet emerged at scale, the recommended treatment is:

- ¶11 Where no commercial exploitation control has been established, the monetary value within the SEEA CF asset boundary is zero (per SEEA CF para 5.6 asset recognition criterion requiring exploitation control).

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- ¶12 Countries may include mesopelagic stock in a physical-only experimental account recording biomass estimates with explicit uncertainty ranges, clearly distinguished from core SEEA EA/CF tables.
- ¶13 When commercial exploitation begins and exploitation control is established, the resource moves into the core asset account.

¶14 See **TG-3.1 Asset Accounts** on the asset boundary criterion and contingent resources.

Regulating services

¶1 **Climate regulation through carbon sequestration.** Primary production in the epipelagic zone fixes atmospheric CO2 into organic matter. A portion is exported to depth through sinking particles, vertical migration, and physical mixing. These processes, collectively the "biological pump"[37], sequester carbon from the atmosphere for centuries to millennia. Diel vertical migration in the mesopelagic zone enhances this transport[38].

¶2 Quantifying carbon sequestration services requires estimates of net primary production rates, export production (fraction of NPP exported below the mixed layer), and sequestration efficiency (fraction reaching long-term storage depths)[39]. Attribution to national accounts raises challenges, as the service is generated by global ocean circulation that is not confined to any single EEZ, whilst the benefits are global rather than national. For initial compilations, recording carbon sequestration within the EEZ as a nationally generated service is the recommended default, with metadata noting that benefits are global and the recording does not imply exclusive national claim. For guidance on integrating carbon sequestration into accounts, see **TG-2.8 Climate Change Indicators**.

¶3 **Nutrient cycling** through upwelling and vertical mixing redistributes nutrients that support productivity throughout the ocean and in coastal zones.

Cultural services

¶1 Pelagic cultural services include marine scientific research and oceanographic monitoring, whale watching and recreational fishing, and ocean cruising. Existence and bequest values attach to healthy ocean ecosystems and charismatic marine megafauna (whales, sharks, sea turtles). For measuring cultural ecosystem services, see **TG-2.4 Ecosystem Goods and Services**.

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3.6 Data and Methods

¶1 Pelagic ecosystems present data challenges due to their remoteness, vast scale, and dynamic nature.

Satellite oceanography

¶1 Remote sensing provides essential data for pelagic ecosystem monitoring at scales not achievable by in situ methods. Principal satellite data streams include[40] (1) ocean colour (MODIS, VIIRS, Sentinel-3 OLCI) for chlorophyll-a and primary productivity, (2) sea surface temperature from thermal infrared and microwave sensors, (3) sea surface height from altimetry for circulation, eddies, and fronts, and (4) sea ice extent from passive microwave sensors. Limitations include penetration limited to the near-surface, cloud cover affecting visible-band sensors, and the need for atmospheric correction. For detailed guidance on remote sensing in ocean accounts, see **TG-4.1 Remote Sensing Data**.

In situ oceanography

¶1 Principal in situ platforms are (1) research vessels (CTD profiles, water sampling, net sampling), (2) Argo floats (global array of >4,000 profiling floats to 2,000m), (3) Biogeochemical Argo (oxygen, nitrate, pH, chlorophyll, particle sensors), and (4) moorings and buoys for time-series observations. The Global Ocean Observing System (GOOS) coordinates international observation with Essential Ocean Variables (EOVs) relevant to ecosystem accounting.

Fish stock assessment

¶1 Pelagic fish stock assessment employs methods distinct from demersal fisheries due to species mobility and aggregating behaviour: acoustic surveys (echosounders estimating biomass of schooling fish), electronic tagging and tracking (archival, satellite tags for migration patterns), virtual population analysis (age-structured models from catch-at-age data), and close-kin mark-recapture (genetic methods for absolute abundance). For detailed guidance on stock assessment methods, see **TG-6.7 Fisheries Stock Assessment**. For survey methodologies, see **TG-4.2 Survey Methods**.

Model-based approaches

¶1 Pelagic ecosystem accounting may rely substantially on models: biogeochemical models (primary production, carbon cycling, nutrient dynamics), ecosystem models such as Ecopath with Ecosim and Atlantis (trophic interactions and biomass flows), species distribution models (habitat suitability and distribution shifts), and stock assessment models. Best practice involves ensemble approaches, uncertainty quantification, and validation against available observations.

Uncertainty characterisation

¶1 Key sources of uncertainty include structural uncertainty in model formulations, parametric uncertainty in model calibration, observational uncertainty in sparse in situ validation data, and spatial extrapolation from point observations to large pelagic domains. Compilers should report confidence intervals or uncertainty ranges where feasible, use ensemble modelling to capture structural uncertainty, and clearly distinguish between observation-based and model-derived entries in published accounts. See **TG-0.7 Quality Assurance** for systematic guidance on uncertainty communication.

3.7 Compilation Procedure and Worked Example

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Step 1: Define spatial accounting units

¶1 **Action:** Delineate the pelagic accounting area within the EEZ, distinguishing depth zones and, where relevant, biogeographic provinces.

¶2 **Data requirements:**

- ¶3 Bathymetric data to determine water column depth
- ¶4 Oceanographic data (temperature, salinity) to identify water mass boundaries
- ¶5 EEZ boundary data from national maritime authorities

¶6 **Output:** A spatial framework defining accounting units (e.g., “Epipelagic zone within EEZ”, “Mesopelagic zone within EEZ”).

Step 2: Compile extent accounts

¶1 **Action:** Measure the opening and closing extent of each pelagic ecosystem type, recording changes during the accounting period.

¶2 **Data requirements:**

- ¶3 Volume calculations from bathymetry and depth zone definitions
- ¶4 Time-series satellite data for sea surface temperature and chlorophyll-a to detect water mass shifts
- ¶5 Oceanographic model outputs for thermocline depth changes

¶6 **Calculation:**

- ¶7 Epipelagic extent (km3) = EEZ surface area (km²) x mean depth of photic zone (km)
- ¶8 Record changes as water mass boundary shifts or depth zone reclassifications

¶9 **Output:** Physical extent account showing opening extent, changes (water mass shifts, depth zone changes), and closing extent by ecosystem type.

Step 3: Compile condition accounts

¶1 **Action:** Measure condition variables for each ecosystem type at representative monitoring stations.

¶2 **Data requirements:**

- ¶3 Satellite-derived chlorophyll-a and SST (for epipelagic zone)
- ¶4 Argo float profiles for subsurface temperature, salinity, dissolved oxygen
- ¶5 Research vessel surveys for nutrient concentrations and plankton biomass
- ¶6 Stock assessment outputs for fish biomass

¶7 **Calculation:**

- ¶8 Condition variables are normalised using the standard formula defined in **TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.1. For pelagic negative indicators (e.g., SST anomaly, acidification stress), transform the variable to its negative form (e.g., use -1 x SST anomaly) so that the standard formula applies directly. See the SST worked cell in the worked example below.
- ¶9 Document reference condition selections and the treatment of any negative indicators.

¶10 **Output:** Condition variable account with raw measurements and normalised indicators for each ecosystem type. Composite indices are optional. Where compiled, the weighting scheme must be documented (see Step 2 of the worked example).

Step 4: Compile fish stock asset accounts

¶1 **Action:** Record opening stock, natural growth, catch, mortality, and closing stock for commercially important pelagic species.

¶2 **Data requirements:**

- ¶3 RFMO stock assessment reports providing biomass estimates, recruitment, natural mortality, fishing mortality
- ¶4 National catch statistics by species, distinguishing **landings** and **discards**
- ¶5 VMS data for catch location (to attribute shared stocks)

¶6 **Data note on discards.** Discard estimates for highly migratory pelagic species should be drawn from RFMO observer programme data where available. For the Western and Central Pacific, the WCPFC Regional Observer Programme is the recommended primary source: it places trained independent observers on fishing vessels with mandated coverage of 100% for purse-seine vessels (since 2010) and 5% for longline vessels (since 2012). Actual coverage rates vary by fleet and year and must be documented in account metadata. Where RFMO observer data are unavailable or coverage is insufficient, compilers may use FAO global discard estimates as a fallback. [41]

¶7 **Calculation:**

- ¶8 Opening stock from most recent stock assessment (flag "model-projected" if the assessment predates the accounting year, and see Section 3.3 for the temporal-mismatch protocol)
- ¶9 Natural growth = recruitment + somatic growth (from stock assessment model)
- ¶10 Extraction = gross catch (landings + discards) attributed to national fleet
- ¶11 Natural mortality from stock assessment parameter M applied to population size
- ¶12 Closing stock = opening stock + growth − extraction − natural mortality

¶13 **Output:** Physical fish stock asset account with entries in tonnes, distinguishing EEZ and high seas components for migratory species, and reporting landings and discards on separate rows.

Step 5: Estimate ecosystem service flows

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¶1 **Action:** Quantify the annual supply of ecosystem services from pelagic ecosystems.

¶2 **Data requirements:**

- ¶3 Primary productivity estimates from satellite ocean colour and biogeochemical models
- ¶4 Export production rates from sediment trap data or models
- ¶5 Fish catch data and resource rent estimates for fisheries provisioning services

¶6 **Calculation:**

- ¶7 Carbon sequestration (t CO2/yr) = NPP (t C/yr) x export ratio x sequestration efficiency x 44/12
- ¶8 Fisheries provisioning service (physical) = sustainable yield (from stock assessment)
- ¶9 Fisheries provisioning service (monetary) = sustainable yield x resource rent per tonne

¶10 **Output:** Ecosystem service supply table (physical and monetary) by service type and ecosystem type.

Step 6: Value ecosystem assets (optional)

¶1 **Action:** Estimate the monetary value of pelagic ecosystem assets as the NPV of expected future service flows.

¶2 **Data requirements:**

- ¶3 Annual ecosystem service values from Step 5
- ¶4 Discount rate (4% real is commonly applied)
- ¶5 Assumptions about service flow duration and projection horizon

¶6 **Calculation:**

- ¶7 Asset value = Annual service value x PV annuity factor (r, n), where n is the projection horizon and r is the real discount rate
- ¶8 A finite 25-year horizon is recommended as the default, as RFMO stock assessment projections and SEEA EA practice for ecosystem services with substantial methodological uncertainty typically use a horizon comparable to the stock assessment projection period rather than perpetuity. Compilers adopting a perpetual annuity (Asset value = Annual service value / r) should document the assumption explicitly and apply it consistently
- ¶9 Apply to carbon sequestration and fisheries services separately
- ¶10 Document uncertainties and sensitivity to discount rate and horizon

¶11 **Output:** Monetary ecosystem asset account showing opening value, changes (enhancement, degradation), and closing value.

Worked Example

¶1 This worked example demonstrates the compilation of pelagic and open ocean ecosystem accounts for a hypothetical Pacific small island developing state (SIDS), following the extent-condition-services-valuation sequence in Sections 3.1-3.5. Given the Emerging status of this Circular, compilers should treat the methods and values below as indicative rather than prescriptive.

¶2 **Setting:** A Pacific SIDS with an EEZ of 500,000 km², predominantly comprising epipelagic waters (M2.1) over a deep ocean basin. The nation's economy depends heavily on tuna fisheries managed through the Western and Central Pacific Fisheries Commission (WCPFC). The EEZ intersects the warm pool region of the western Pacific, with seasonal upwelling along its southern boundary.

¶3 **Step 1: Extent account (year t to t+1)**

Accounting entry	M2.1 Epipelagic (km3)	M2.2 Mesopelagic (km3)	Total (km3)
Opening extent	100,000	400,000	500,000

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Accounting entry	M2.1 Epipelagic (km3)	M2.2 Mesopelagic (km3)	Total (km3)
— Water mass boundary shifts (warming-driven)	-500	+500	0
— Thermocline depth change (reclassification)	+200	-200	0
Net change	-300	+300	0
Closing extent	99,700	400,300	500,000

¶4 The thermocline depth change is a reclassification (no net volume change, per SEEA EA para 6.14). The water mass shift is a natural reduction in epipelagic with a corresponding natural expansion in mesopelagic.

¶5 **Step 2: Condition account**

¶6 Condition indicators are derived from satellite oceanography, Argo float data, and RFMO stock assessments. Reference levels are based on 1990-2010 climatological means. The four indicators are presented separately rather than aggregated, consistent with **TG-2.1 Biophysical Indicators** on indicator selection and weighting.

Condition variable	Observed value	VH (reference good)	VL (degraded)	Indicator score
Primary productivity (mg C/m²/day)	280	350	150	0.65
Dissolved oxygen at 200m (ml/L)	3.8	4.5	2.0	0.72
Tuna stock biomass (% of unfished)	42%	60%	20%	0.55
SST anomaly, transformed (-1 x C above 1990-2010 mean)	-0.8	0.0	-2.0	0.60

¶7 Worked cell — SST anomaly normalisation:

> *Raw SST anomaly = +0.8 C above the 1990-2010 mean. As lower SST anomalies indicate better condition, the variable is transformed to V = -0.8. With VH = 0.0 (reference good, no anomaly) and VL = -2.0 (degraded, +2 C anomaly transformed), applying the standard normalisation formula (see TG-2.1 §3.4.1):*
> *Indicator = (V - VL) / (VH - VL) = (-0.8 - (-2.0)) / (0.0 - (-2.0)) = 1.2 / 2.0 = **0.60***

¶8 Composite index (optional): An equal-weighted arithmetic mean of the four indicators yields (0.65 + 0.72 + 0.55 + 0.60) / 4 = 0.63. Compilers should consider alternative weightings (e.g., management-relevance weights placing greater weight on the tuna stock variable for a fisheries-dependent SIDS) and report sensitivity to weighting choices. See SEEA EA para 5.72-5.76 and **TG-2.1 Biophysical Indicators**.

¶9 **Step 3: Ecosystem services (annual flows)**

¶10 The carbon sequestration physical rate of 4.5 t CO2/km²/yr applied below is derived from biological-pump parameters as follows:

Parameter	Value	Source
Net primary production (NPP)	280 mg C/m²/day x 365 days = 102.2 g C/m²/yr = 102.2 t C/km²/yr	Satellite ocean colour mean for the EEZ (matches Step 2 observed productivity)
Export ratio (e-ratio, fraction of NPP exported below mixed layer)	0.12	Henson et al. (2011), open-ocean global mean for the biological carbon pump

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Parameter	Value	Source
Sequestration efficiency (fraction of exported flux reaching long-term storage depths > 1,000 m)	0.10	Siegel et al. (2014), *Global Biogeochemical Cycles*, on mesopelagic transfer efficiency in the open ocean
Derived rate	**4.5 t CO2/km²/yr**	102.2 x 0.12 x 0.10 x 3.667 = 4.50 t CO2/km²/yr (×44/12 to convert C to CO2-equivalent)

¶11 Total carbon sequestration over the EEZ: 500,000 km² x 4.5 t CO2/km²/yr = 2,250,000 t CO2/yr.

Service	Physical quantity	Monetary value (USD)
Fisheries (tuna — national quota allocation)	45,000 tonnes	54,000,000 (resource rent)
Carbon sequestration (biological pump within EEZ)	2,250,000 t CO2/yr (at 4.5 t CO2/km²/yr)	Range: 45,000,000 (low) – 114,750,000 (central) – 303,750,000 (high)
Climate regulation (ocean heat uptake)	(not separately valued)	–
Genetic resources	(qualitative — emerging)	–
Total valued services (central)		**168,750,000**

¶12 Carbon price range applied: (1) USD 20/t CO2 (low, marginal abatement cost reference), (2) USD 51/t CO2 (central, US IWG 2021 Social Cost of Carbon, 3% discount rate, 2020 USD), and (3) USD 135/t CO2 (high, IPCC AR6 WG3 lower bound of the 1.5 C-compatible carbon price range for 2030). Compilers should present sensitivity analysis across the full range and check for updates to the US IWG SCC at the time of compilation. See **TG-1.9 Valuation** for carbon price selection.

¶13 Note: The tuna fisheries value reflects only the national quota allocation managed through WCPFC. Licence fees paid by distant-water fishing nations (approximately USD 30,000,000/yr for this hypothetical SIDS) are recorded as economic flows in the national accounts (SNA current account) and are not added to the ecosystem service supply value — the conceptual basis is described in the Section 3.5 mapping table.

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¶14 **Step 4: Asset valuation**

¶15 Applying a 4% real social discount rate over a 25-year projection horizon (basis: a horizon broadly comparable to the RFMO stock assessment projection period, and compilers electing a perpetual annuity should substitute 1/r = 25.0 and document the change):

> *Asset value (central carbon price) = 168,750,000 x PV annuity factor(4%, 25) = 168,750,000 x 15.62 = approximately **USD 2,635,875,000***

¶16 Sensitivity to carbon price (annual service value x 15.62 PV annuity factor):

- ¶17 Low (USD 20/t CO2): annual services 99,000,000 -> asset value approximately USD 1,546,380,000
- ¶18 Central (USD 51/t CO2): annual services 168,750,000 -> asset value approximately USD 2,635,875,000
- ¶19 High (USD 135/t CO2): annual services 357,750,000 -> asset value approximately USD 5,588,055,000
- ¶20 Fisheries only (excluding carbon): annual services 54,000,000 -> asset value approximately USD 843,480,000

¶21 The wide range illustrates the dominant role of the carbon price in pelagic ecosystem asset valuation. Compilers adopting a perpetual annuity at 4% would multiply annual service values by 25.0 instead of 15.62. The choice should be documented and applied consistently.

¶22 This worked example illustrates the full accounting sequence for pelagic ecosystems. Actual compilations will require nationally specific oceanographic data, RFMO stock assessments, and careful consideration of how transboundary services are attributed. The treatment of carbon sequestration in pelagic accounts remains an active area of methodological development.

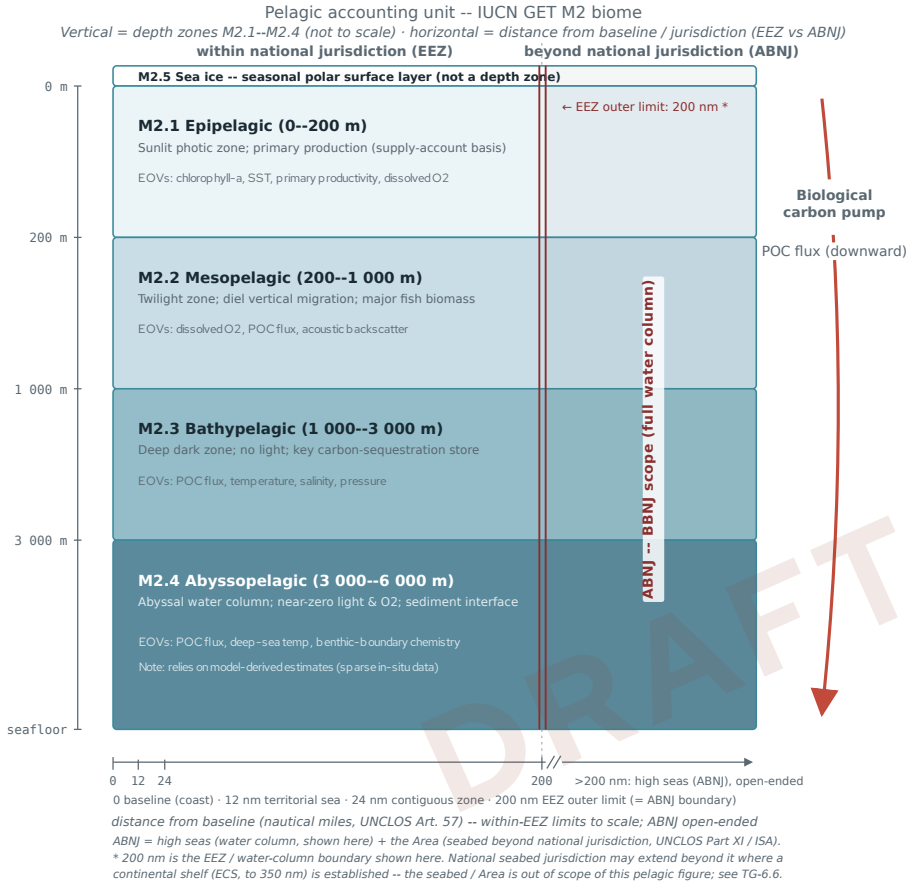


Figure 6.5.1 Vertical cross-section of four IUCN GET M2 pelagic depth zones as accounting units, crossed by the EEZ/ABNJ water-column boundary. M2.5 sea ice is a hatched surface band, not a depth zone. Depths: 200 m, 1 000 m, 3 000 m. Seabed/Area out of scope (TG-6.6).

Source: TG-6.5 (Pelagic Zone Ecosystem Accounts), Sections 2--3; IUCN Global Ecosystem Typology v2.1, M2 biome (Keith et al. 2022); SEEA CF 2012, Chapter 5 (ecosystem asset classification); BBNJ Agreement (adopted 19 June 2023; entered into force 17 January 2026), Art. 1 (area definitions).

Adapted from: IUCN GET v2.1 M2 biome schematic, with GOAP extensions: SEEA CF asset-account framing, EEZ/ABNJ jurisdictional divide, EOV annotation, biological carbon pump overlay, and depth-luminance fill encoding.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

FOOTNOTES

1. ¶1 This Circular carries the "Emerging" badge, indicating that accounting methodologies are less developed and uncertainties remain. Approaches should be considered provisional pending further international consensus.
2. ¶2 UNCLOS, Article 136. "The Area and its resources are the common heritage of mankind."
3. ¶3 Under the Paris Agreement, countries may include ocean-based climate mitigation measures in their nationally determined contributions (NDCs). Pelagic carbon sequestration quantification supports NDC formulation and tracking.
4. ¶4 Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ Agreement), adopted 19 June 2023. Entry-into-force date and implementation status are stated in Section 3.1.
5. ¶5 IUCN GET, M2 Pelagic ocean waters biome. "The Pelagic ocean biome is the largest on earth, comprising the open-ocean water column across all latitudes."
6. ¶6 IUCN GET, M2 Pelagic ocean waters biome classification.
7. ¶7 IUCN GET, M2.1 Epipelagic ocean waters.
8. ¶8 IUCN GET, M2.1 Distribution.
9. ¶9 IUCN GET, M2.2 Mesopelagic ocean waters. "The diverse organisms within this layer consume and reprocess allochthonous organic material sinking from the upper, photosynthetic layer."
0. ¶10 IUCN GET, M2.2 Distribution.
1. ¶11 IUCN GET, M2.3 Bathypelagic ocean waters. "Total biomass declines exponentially from an average of 1.45 mg.C.m-3 at 1,000 m deep to 0.16 mg.C.m-3 at 3,000 m."
2. ¶12 IUCN GET, M2.4 Abyssopelagic ocean waters. "Due to extreme conditions and limited resources, biodiversity is very low."
3. ¶13 IUCN GET, M2.5 Sea ice. "The seasonally frozen surface of polar oceans… is one of the most dynamic ecosystems on earth."
4. ¶14 IUCN GET, M2.1. "Autochthonous productivity in the epipelagic layer, largely by diatoms, accounts for around half of all global carbon fixation."
5. ¶15 SEEA EA, para 3.11.
6. ¶16 Longhurst, A.R. (2007). Ecological Geography of the Sea. Academic Press. Longhurst provinces are widely used biogeographic units for pelagic ecosystems.
7. ¶17 IUCN GET, M1.9. "The most productive upwelling zones are coastal, notably in four major eastern-boundary current systems (the Canary, Benguela, California and Humboldt)."
8. ¶18 UNCLOS, Parts II, V, VII.
9. ¶19 UNCLOS, Article 56(1)(a).
0. ¶20 UNCLOS, Article 87. "The high seas are open to all States, whether coastal or land-locked."
1. ¶21 SEEA CF, para 5.396-5.398 (EEZ asset boundary for aquatic resources). Para 5.395 concerns resource rents and fees and is cited separately in Section 3.5.
2. ¶22 Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ Agreement), adopted 19 June 2023; see Section 3.1 for entry-into-force date and accounting implications.
3. ¶23 SEEA CF, para 5.399.
4. ¶24 Alarcon Blazquez, M.G., van der Veeren, R., Gacutan, J. and James, P.A.S. (2023). 'Compiling preliminary SEEA Ecosystem Accounts for the OSPAR regional sea: experimental findings and lessons learned'. *One Ecosystem*, 8, e108030. doi:10.3897/oneeco.8.e108030. The accounts cover the OSPAR maritime area (over 13.5 million km² of the North-East Atlantic, including areas beyond national jurisdiction in the Wider Atlantic and Arctic Waters) and are, to the authors' knowledge, the first SEEA EA compilation for a regional sea.
5. ¶25 SEEA EA, para 5.32 and Table 5.1, on ecosystem condition characteristic classes.
6. ¶26 FDES 2013, Topic 1.3.3 on marine water quality indicators including chlorophyll-a.
7. ¶27 IUCN GET, M2.1 Epipelagic ocean waters, Ecological Traits.
8. ¶28 IUCN GET, M2.2. Mesopelagic fish biomass estimates remain uncertain.
9. ¶29 UNCLOS, Article 64(1).
0. ¶30 UNCLOS, Annex I Highly Migratory Species.
1. ¶31 UN Fish Stocks Agreement (1995). Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. Treaty Series, vol. 2167, No. 37924.
2. ¶32 SEEA CF, para 5.398.
3. ¶33 SEEA CF, para 5.399.
4. ¶34 UNCLOS, Article 65.
5. ¶35 SEEA AFF, Table 3.10 aquatic products classification.
6. ¶36 BBNJ Agreement (2023), Part II (Marine genetic resources) establishes benefit-sharing provisions.
7. ¶37 The biological pump refers to the suite of biologically mediated processes that transport carbon from the surface to the deep ocean, including sinking particles, vertical migration, and physical mixing.
8. ¶38 IUCN GET, M2.2 Mesopelagic ocean waters.
9. ¶39 SEEA Biophysical Guidelines, para 308.

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0. ¶40 See TG-4.1 Remote Sensing Data for detailed guidance on satellite data applications in ocean accounting.
1. ¶41 Sources: WCPFC Regional Observer Programme, Western and Central Pacific Fisheries Commission (https://www.wcpfc.int/regional-observer-programme (https://www.wcpfc.int/regional-observer-programme)); Perez Roda, M.A. et al. (2019), *A third assessment of global marine fisheries discards*, FAO Fisheries and Aquaculture Technical Paper No. 633, FAO, Rome (ISBN 978-92-5-131869-9); Kelleher, K. (2005), *Discards in the world's marine fisheries: An update*, FAO Fisheries Technical Paper No. 470, FAO, Rome. FAO global discards 2010-2014 are estimated at 9.1 million tonnes (95% CI: 6.7-16.1 million tonnes), with pelagic longline fisheries averaging a 6.7% discard rate.

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Deep Sea and ABNJ Accounting

Provides emerging guidance on accounting for deep sea ecosystems and areas beyond national jurisdiction (ABNJ).

Version 0.8.2 **Status** Draft **Stability** Emerging

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

Deep Sea and ABNJ Accounting (2026) (GOAP Technical Guidance on Ocean Accounting, TG-6.6, v0.8.2). GOAP Secretariat. https://guidance.oceanaccounts.org/circulars/TG-6.6-deep-sea-abnj/

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OUTCOME

This Circular provides emerging guidance on accounting for deep sea ecosystems and areas beyond national jurisdiction (ABNJ). ABNJ, comprising the high seas and the international seabed Area, fall outside exclusive economic zones (EEZs) and are governed by distinct international legal frameworks. Their treatment poses substantial challenges for the country-based structure of the System of National Accounts and SEEA.

This Circular supports four primary decision use cases. Deep-sea mining impact assessment requires baseline ecosystem accounts to evaluate environmental costs of seabed mineral exploitation against economic benefits, and those accounts inform national positions on International Seabed Authority (ISA) licensing decisions. BBNJ marine protected area designation depends on extent and condition accounts for deep-sea ecosystems to identify priority areas for area-based management tools under the Agreement on Biodiversity Beyond National Jurisdiction. Hydrothermal vent conservation needs accounts for chemosynthetic-based ecosystems to balance bioprospecting potential against preservation of unique genetic resources. ISA environmental management plans use ecosystem condition monitoring to set performance standards and track cumulative impacts across exploration contract areas. These decision contexts connect directly to TG-2.10 MEA Indicators and TG-1.3 Marine Spatial Management.

This Circular is classified as Emerging: methodology is still developing, and readers should anticipate that guidance will evolve as scientific understanding improves, governance frameworks mature, and practical implementation experience accumulates. The BBNJ Agreement creates new governance structures and information requirements that will shape ABNJ accounting in coming years. This Circular should be revised following COP1 (see Section 3.6 for review schedule).

Asset accounts for seabed minerals (described in TG-3.1 Asset Accounts) inform national natural capital budgets. Ecosystem extent accounts for deep-sea protected areas feed MEA indicator reporting against SDG 14.5.1 and GBF Target 3 (see TG-2.10 MEA Indicators). Condition accounts for chemosynthetic ecosystems connect to valuation frameworks in TG-1.9 Valuation. The conceptual framework is established in TG-0.1 General Introduction to Ocean Accounts and methodological foundations of asset accounting in TG-3.1 Asset Accounts.

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Framework Position

This Circular owns the accounts for IUCN GET biome M3 deep sea floors and, for the publication as a whole, the jurisdictional framework: the UNCLOS maritime zones, the SEEA CF asset boundary for areas beyond national jurisdiction, the extended continental shelf claim states, and the BBNJ Agreement provisions. Other circulars cross-refer here rather than restating them.

It cross-refers for the account structure (TG-3.1), condition measurement (TG-4.8, TG-4.9), seabed mineral asset accounts (TG-3.10) and MEA indicator derivation (TG-2.10).

Offshore energy activity within the EEZ and on the continental shelf is TG-6.9. The pelagic water column above these seabed types is TG-6.5.

1. Outcome

¶1 This Circular provides emerging guidance on accounting for deep sea ecosystems and areas beyond national jurisdiction (ABNJ). ABNJ, comprising the high seas and the international seabed Area, fall outside exclusive economic zones (EEZs) and are governed by distinct international legal frameworks. Their treatment poses substantial challenges for the country-based structure of the System of National Accounts and SEEA.

¶2 This Circular supports four primary decision use cases. Deep-sea mining impact assessment requires baseline ecosystem accounts to evaluate environmental costs of seabed mineral exploitation against economic benefits, and those accounts inform national positions on International Seabed Authority (ISA) licensing decisions. BBNJ marine protected area designation depends on extent and condition accounts for deep-sea ecosystems to identify priority areas for area-based management tools under the Agreement on Biodiversity Beyond National Jurisdiction. Hydrothermal vent conservation needs accounts for chemosynthetic-based ecosystems to balance bioprospecting potential against preservation of unique genetic resources. ISA environmental management plans use ecosystem condition monitoring to set performance standards and track cumulative impacts across exploration contract areas. These decision contexts connect directly to **TG-2.10 MEA Indicators** and **TG-1.3 Marine Spatial Management**.

¶3 This Circular is classified as Emerging: methodology is still developing, and readers should anticipate that guidance will evolve as scientific understanding improves, governance frameworks mature, and practical implementation experience accumulates. The BBNJ Agreement creates new governance structures and information requirements that will shape ABNJ accounting in coming years[1]. This Circular should be revised following COP1 (see Section 3.6 for review schedule).

¶4 Asset accounts for seabed minerals (described in **TG-3.1 Asset Accounts**) inform national natural capital budgets. Ecosystem extent accounts for deep-sea protected areas feed MEA indicator reporting against SDG 14.5.1 and GBF Target 3 (see **TG-2.10 MEA Indicators**). Condition accounts for chemosynthetic ecosystems connect to valuation frameworks in **TG-1.9 Valuation**. The conceptual framework is established in **TG-0.1 General Introduction to Ocean Accounts** and methodological foundations of asset accounting in **TG-3.1 Asset Accounts**.

¶5 **Framework Position**

¶6 This Circular owns the accounts for **IUCN GET biome M3 deep sea floors** and, for the publication as a whole, the **jurisdictional framework**: the UNCLOS maritime zones, the SEEA CF asset boundary for areas beyond national jurisdiction, the extended continental shelf claim states, and the BBNJ Agreement provisions. Other circulars cross-refer here rather than restating them.

¶7 It cross-refers for the account structure (**TG-3.1**), condition measurement (**TG-4.8**, **TG-4.9**), seabed mineral asset accounts (**TG-3.10**) and MEA indicator derivation (**TG-2.10**).

¶8 Offshore energy activity within the EEZ and on the continental shelf is **TG-6.9**. The pelagic water column above these seabed types is **TG-6.5**.

2. Requirements

¶1 This Circular requires familiarity with:

- ¶2
  TG-0.1 General Introduction to Ocean Accounts – provides the conceptual framework and key components of Ocean Accounts, including the relationship between accounting boundaries and jurisdictional frameworks essential for understanding the boundary challenges posed by ABNJ.
- ¶3
  TG-3.1 Asset Accounts – for the methodological foundations of physical and monetary asset accounts, ecosystem extent and condition accounts, and the concepts of depletion and degra-

dation that this Circular applies to deep sea and ABNJ contexts.

¶4 Readers may also benefit from **TG-0.2 Overview of Relevant Statistical Standards** for grounding in the international statistical standards context relevant to the UNCLOS and BBNJ legal frameworks discussed here.

¶5 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 The 2025 SNA explicitly acknowledges that "accounts are usually compiled for countries and hence the geographic scope is limited to the economic territory of a country including its Exclusive Economic Zone (EEZ)... there is a significant amount of natural capital, in particular concerning oceans, that may be excluded" [2]. Para. 35.129 adds that "where there is interest in organising data about these types of natural capital outside of the scope of the integrated framework of the SNA in a manner that can be directly related to country based measures, the accounting definitions and treatments of the integrated framework of the SNA and the SEEA can be applied" [3]. Paragraphs 35.128-35.129 represent new text in the 2025 revision and provide the primary conceptual justification for extending accounting frameworks to ABNJ.

3.1 Jurisdictional Framework

¶1 UNCLOS establishes the legal framework governing ocean jurisdiction and defines distinct maritime zones with different rights and obligations [4]. For countries that have not ratified UNCLOS, many key provisions are considered to reflect customary international law and remain relevant to accounting boundary determination.

¶2 As of 17 January 2026, the BBNJ Agreement has entered into force (UN Treaty Collection). That date is the single point of reference for the Agreement's operational status throughout this Circular.

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Maritime zones under UNCLOS

¶1 **Territorial Sea** extends up to 12 nautical miles from baselines. Coastal States exercise full sovereignty over the territorial sea, including the seabed and subsoil [5].

¶2 **Exclusive Economic Zone (EEZ)** extends up to 200 nautical miles from baselines. Coastal States have sovereign rights for exploration, exploitation, conservation and management of natural resources, both living and non-living [6]. The SEEA CF notes that "a country's EEZ may extend up to 200 nautical miles from the country's normal baselines" [7].

¶3 **Continental Shelf** may extend beyond 200 nautical miles to the outer edge of the continental margin, subject to limits defined in UNCLOS Article 76. Coastal States exercise sovereign rights for exploring and exploiting natural resources, including sedentary species [8]. The Commission on the Limits of the Continental Shelf (CLCS) reviews submissions from coastal States.

¶4 **The High Seas** comprise all parts of the sea not included in the EEZ, territorial sea, or internal waters of a State [9], and are open to all States subject to obligations for conservation of living resources [10].

¶5 **The Area** designates the seabed, ocean floor and subsoil beyond the limits of national jurisdiction [11], declared "the common heritage of mankind" [12] and administered by the ISA [13].

Implications for accounting boundaries

¶1 The SEEA CF states that "the SEEA Central Framework includes all natural resources, cultivated biological resources and land within a country of reference (including resources within a country's

exclusive economic zone)"[14]. Resources in ABNJ are explicitly excluded from individual country asset boundaries.

¶2 Several mechanisms nevertheless create accounting connections to national economies:

1. ¶3
   Quota-based fish stocks: Where international agreements allocate fishing quotas in ABNJ, the quota right itself may be recorded as a national asset where economic ownership is established. The 2025 SNA notes that "if economic ownership can be established for natural resources, for instance via internationally agreed quotas, these resources are within scope of the integrated framework of national accounts"[15]. SEEA CF paras. 5.397-5.400 distinguish the quota instrument (potentially recordable) from the underlying biological resource (which remains outside the national asset boundary)[16]. See **TG-6.7 Fisheries Stock Assessment** for guidance on recording quota-based fish stocks.
2. ¶4
   Seabed mining contracts: Entities holding ISA exploration or exploitation contracts conduct activities in the Area on behalf of sponsoring States, generating economic flows attributable to national economies. See **TG-3.10 Offshore Energy Accounts** for methodological parallels.
3. ¶5
   Flagged vessels: Production by vessels flagged to a country is attributed to that country's economy regardless of where in the ocean the activity occurs[17]. See **TG-6.10 Maritime Transport and Ports** for the residency and flag-attribution treatment.

¶6 The treatment of research vessels, environmental monitoring activities, and non-extractive uses in ABNJ remains an area requiring further methodological development.

¶7 Figure 6.6.1 shows ABNJ governance across six bodies spanning seabed minerals, fisheries, shipping, cetacean management, scientific research, and biodiversity — each generating data flows with distinct accounting implications[18].

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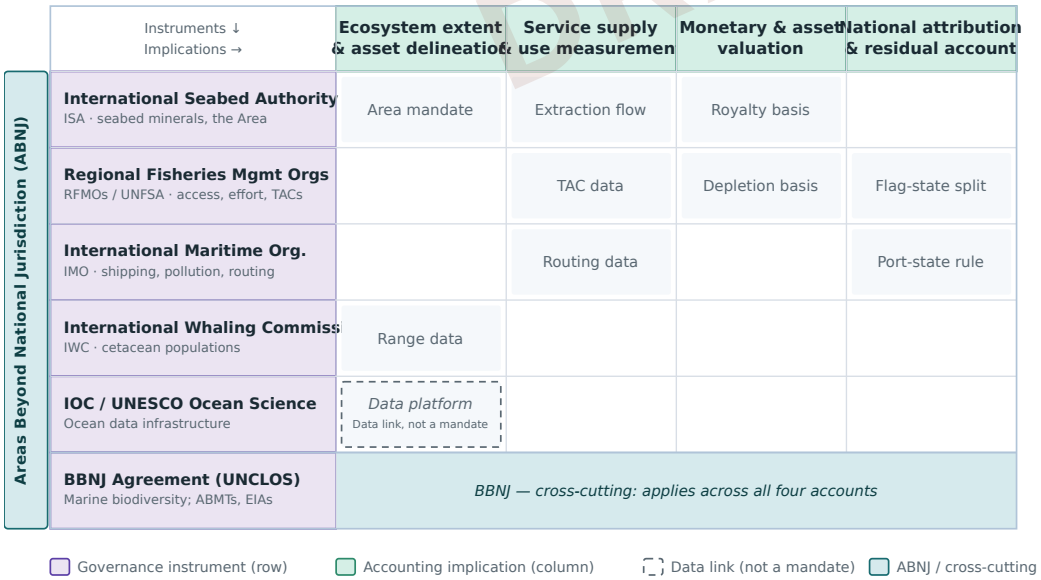


Figure 6.6.1 Sparse matrix mapping six ABNJ governance instruments to four accounting implications; filled cells name feed mechanisms; blanks mean none. Sparse (11 of 24); BBNJ is cross-cutting.

Source: TG-6.6 Deep Sea and ABNJ Accounting, Section 3.1; BBNJ Agreement (2023), Arts. 11-16 (ABMTs), 22-35 (EIAs); ISA Regulations on Prospecting and Exploration (2013); UNFSA (1995), Art. 10.

Extended continental shelf: accounting treatment of CLCS claim states

¶1 Compilers should distinguish three states of extended continental shelf (ECS) claims when delineating accounting boundaries. The distinction is a methodological choice made on prudential grounds, and it does not determine legal rights. UNCLOS Article 77(3) recognises that coastal-State rights exist ab initio and do not depend on a CLCS recommendation, and the accounting treatment recommended here does not contest that legal position. It reflects the principle that assets should be included in national balance sheets only when their extent is sufficiently certain to support reliable measurement and inter-country comparability. Pending final CLCS confirmation, compilers should apply a conservative framing and disclose the uncertainty per SEEA EA para 5.20.

- ¶2 **Approved CLCS recommendations**: The ECS area is included within the national accounting boundary in the same way as the EEZ seabed.
- ¶3 **Submitted but pending claims**: The ECS area should be excluded from the core national accounting boundary and disclosed only as a memorandum item with a clear note on jurisdictional uncertainty.
- ¶4 **No submission**: The area is treated as ABNJ for accounting purposes.

¶5 Compilers should seek legal advice on the status of any ECS claim before including the area in compiled accounts.

BBNJ Agreement implications

¶1 The BBNJ Agreement establishes new frameworks for conservation and sustainable use of marine biodiversity in ABNJ[19]. Key provisions relevant to ocean accounting are summarised in Table 3.1.1 below.

Provision	Description
Marine genetic resources	Mechanisms for access to and benefit-sharing from marine genetic resources of ABNJ, including digital sequence information[20]. Creates potential for recording benefit flows as resource rent equivalents.
Area-based management tools	Including MPAs in ABNJ, requiring delineation and condition monitoring[21]. MPA boundaries could serve as ecosystem accounting units.
Environmental impact assessments	Mandatory assessments for activities affecting ABNJ environments[22]. Generate baseline data potentially usable for accounting purposes.
Capacity-building and technology transfer	Supporting developing States' participation in ABNJ research and governance[23].

¶2 The development of monitoring frameworks for BBNJ-designated MPAs could provide baseline data for ecosystem extent and condition accounts in ABNJ. This Circular should be updated following COP1.

3.2 Deep Sea Ecosystems

¶1 Deep sea ecosystems are classified within the IUCN GET across two biomes: **M3 Deep Sea Floors** (benthic ecosystems)[24] and **M2 Pelagic Ocean Waters** (water column ecosystems extending to depth)[25]. For the GET realm/biome/EFG hierarchy and the national crosswalk obligation, see **TG-4.1 Remote Sensing and Geospatial Data** Section 3.2.4.

M3 Deep sea floors biome

¶1 **M3.1 Continental and island slopes** extend from the shelf break (~250 m) to abyssal basins (4,000 m), characterised by strong depth gradients in pressure, temperature, light and food availability[26], [27]. Continental slopes within EEZs fall within national accounting boundaries, whilst slopes on the extended continental shelf may also be attributable to coastal States.

¶2 **M3.2 Submarine canyons** function as "dynamic flux routes for resources between continental shelves and ocean basins" [28]. They enhance nutrient transport and support dense communities of cold-water corals and sponges.

¶3 **M3.3 Abyssal plains** extend between 3,000 and 6,000 m and are "covered by thick layers… of fine sediment" [29]. They host high biodiversity despite low productivity [30]. The vast majority of abyssal plains lie in ABNJ.

¶4 **M3.4 Seamounts, ridges and plateaus**: approximately 171,000 seamounts documented worldwide, covering 2.6% of the sea floor, with ridges covering approximately 9.2% [31]. Many seamounts are targets for fishing and potential mining activities.

¶5 **M3.5 Deepwater biogenic beds** are formed by sessile suspension-feeders such as cold-water corals, sponges, and bivalves that create structurally complex habitats [32]. These slow-growing systems are particularly vulnerable to physical disturbance. See **TG-6.1 Coral Reef Accounts** for cold-water coral characteristics. Energy source and growth dynamics differ between the two systems.

¶6 **M3.6 Hadal trenches and troughs** extend from 6,000 to 11,000 metres depth, comprising 27 disjoint deep-ocean trenches and 20 additional features [33]. Endemism in these systems is high.

¶7 **M3.7 Chemosynthetic-based ecosystems (CBEs)** include hydrothermal vents, cold seeps, and organic falls. These systems derive primary productivity from chemoautotrophy using reduced compounds such as hydrogen sulphide and methane [34], characterised by "high faunal biomass" but "low diversity and high endemism" [35]. CBEs are of particular interest for bioprospecting. The BBNJ Agreement's marine genetic resources provisions may alter how chemosynthetic-based ecosystems are valued.

M2 Pelagic ocean waters (deep component)

¶1 **M2.3 Bathypelagic ocean waters** (1,000-4,000 m depth) are characterised by permanent darkness, low temperatures (1-3C), and dependence on organic matter flux from surface waters [36].

¶2 **M2.4 Abyssopelagic ocean waters** (4,000 m to near the seafloor) receive "less than 1% of the primary production of the euphotic zone" [37] with low biological productivity [38]. For shallower pelagic ecosystems, see **TG-6.5 Pelagic and Open Ocean Accounts**.

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3.3 Extent and Condition Accounting

¶1 Compilers should treat this section as a target framework for structuring accounts as data become available. It is not operational guidance. The Emerging badge reflects the implementation gap between the account structures described and the data currently available to populate them. The measurement protocols for the variables themselves — how each is observed, at what frequency and to what tolerance — are owned by **TG-4.8 Physical Condition Measurement** and **TG-4.9 Biological Condition Measurement**; this Section selects and interprets them for deep sea ecosystems, where almost every protocol is constrained by platform access rather than by method.

Mapping challenges

¶1 "Less than 1% of the seafloor has been investigated biologically" [39]. Key challenges include:

1. ¶2 **Inaccessibility**: Most deep sea ecosystems cannot be observed directly except through expensive submersibles and ROVs.
2. ¶3 **Scale**: The deep sea floor covers approximately 300 million km², so full mapping is impractical with current technology.
3. ¶4 **Ecosystem delineation**: Many deep sea ecosystems grade into one another along environmental gradients, which complicates boundary definition.
4. ¶5 **Temporal variability**: Some features, particularly hydrothermal vents, are geologically ephemeral, with active venting occurring on timescales of years to decades.

¶6 For guidance on remote sensing and spatial data sources, see **TG-4.1 Remote Sensing Data**. The Seabed 2030 initiative aims to complete global bathymetric mapping by 2030.

Deep sea data priority assessment

Data Gap	Economic Importance	Data Availability	Priority
Seamount extent mapping	Medium	Low	High
Deep-sea mineral deposits	High	Medium	High
Hydrothermal vent extent	Low	Very low	Medium
Deep-sea fish stocks	Medium	Low	High
Abyssal plain condition	Low	Very low	Low

¶1 *Table 1: Indicative data priorities for deep sea accounting*

Extent account structure

¶1 For deep sea ecosystem types within national jurisdiction (EEZ and extended continental shelf), the extent account structure follows SEEA EA methodology as described in **TG-3.1 Asset Accounts**. For ABNJ, similar structures could be applied at regional or global scales.

Accounting entry	Abyssal plains	Seamounts	Hydrothermal vents	...	Total
Opening extent (km²)					
Additions					
– Natural expansion					
Total additions					
Reductions					
– Natural reduction					
– Anthropogenic reduction					
Total reductions					
Net change					
Closing extent (km²)					

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¶2 *Table 2: Structure of deep sea ecosystem extent account*

¶3 For hydrothermal vents and other ephemeral features, "natural expansion" and "natural reduction" may be substantial as geological processes create and extinguish active vent sites. Anthropogenic reductions may occur through seabed mining, bottom trawling (on seamounts), or other human activities.

¶4 The accounting treatment of ephemeral ecosystems raises classification questions under SEEA EA paras. 5.50-5.55, which classify extent changes along three axes: managed versus unmanaged, natural versus anthropogenic, and catastrophic versus gradual. Para. 5.54 reserves the "catastrophic loss" classification for sudden, large-scale events such as volcanic eruptions. Applying these criteria:

- ¶5 **Gradual decline in venting activity over years to decades** (the typical case) should be recorded as **natural unmanaged reduction**: geologically driven (natural), not the result of management action, and gradual rather than sudden.
- ¶6 **Sudden cessation of a large vent field** following a major tectonic or volcanic event within a single accounting period should be classified as **catastrophic loss** consistent with para. 5.54.

¶7 Compilers should document the basis for classification (rate of change, scale of affected field) in account metadata.

Condition variables

¶1 Relevant condition variables by ECT class include:

¶2 **Physical state**: hydrostatic pressure, temperature, substrate type and stability, sedimentation rates.

¶3 **Chemical state**: oxygen concentration, pH and carbonate saturation (relevant for cold-water corals), nutrient concentrations, pollutant concentrations.

¶4 **Compositional state**: species richness and endemism, community composition, presence/absence of indicator taxa, microbial diversity (particularly for CBEs).

¶5 **Structural state**: megafaunal biomass, structural complexity (coral framework, vent chimneys), bioturbation indicators.

¶6 **Functional state**: chemosynthetic productivity (for CBEs), organic matter flux and remineralisation rates, carbon sequestration in sediments.

¶7 For guidance on selecting condition variables and constructing indicators, see **TG-2.1 Biophysical Indicators**.

¶8 Establishing reference conditions is particularly challenging given limited historical baseline data. The SEEA EA concept of ecosystem integrity[40] may be operationalised by reference to undisturbed areas. Research on "natural laboratories", meaning areas protected from human impact, should be prioritised.

3.4 Compilation Procedure for Deep Sea Accounts

¶1 Due to the Emerging status of deep sea accounting, this procedure is aspirational and documents the workflow that would be followed as data become available.

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Step 1: Identify accounting area and jurisdictional boundaries

¶1 Define the spatial scope, distinguishing:

- ¶2 Deep sea areas within the EEZ (depths >250m)
- ¶3 Extended continental shelf areas subject to CLCS claims
- ¶4 Adjacent ABNJ areas (if compiling experimental accounts)

¶5 For ECS areas, apply the three-state CLCS treatment described in Section 3.1. Obtain legal advice on the status of any ECS claim before including the area in compiled accounts.

Step 2: Acquire bathymetric and geomorphology data

¶1 Obtain the best available bathymetric data. Priority sources:

- ¶2 National hydrographic surveys (where available)
- ¶3 GEBCO global compilation
- ¶4 Multibeam sonar surveys from research expeditions
- ¶5 Satellite-derived bathymetry for depths <1000m

¶6 Use geomorphometric analysis to delineate ecosystem types following IUCN GET categories: identify continental slopes (depth gradient analysis), detect seamounts and ridges (topographic prominence algorithms), delineate abyssal plains (slope <0.1 degrees, depth 3000-6000m), and map submarine canyons. For guidance on geospatial data processing, see **TG-4.1 Remote Sensing and Geospatial Data**.

Step 3: Compile ecosystem extent baseline

¶1 For each ecosystem type, measure opening extent in km². Assign a data quality rating following **TG-0.7 Quality Assurance** protocols:

- ¶2 High: Multibeam survey with ground-truthing
- ¶3 Medium: Satellite-derived bathymetry or predictive modelling validated by samples
- ¶4 Low: GEBCO compilation or unvalidated predictive models

¶5 Populate the opening stock row of the extent account (Table 2 structure).

Step 4: Identify and record extent changes

¶1 Classify changes as:

- ¶2 **Natural expansion**: New hydrothermal vent fields discovered and confirmed active
- ¶3 **Natural reduction**: Documented cessation of vent activity, seamount colonisation retreat
- ¶4 **Anthropogenic reduction**: Seabed disturbance from mining, trawling damage to seamounts, cable/pipeline impacts

¶5 For data-scarce environments, extent changes will commonly be zero or unobservable during typical accounting periods.

Step 5: Compile condition variable measurements

¶1 For ecosystem types where condition monitoring data exist, compile condition variables following the SEEA EA Ecosystem Condition Typology structure. Priority variables by ecosystem type:

¶2 **Seamounts (M3.4)**:

- ¶3 Physical: Substrate type, current speed
- ¶4 Chemical: Dissolved oxygen at summit depth
- ¶5 Compositional: Megafaunal taxa richness (from ROV transects)
- ¶6 Structural: Cold-water coral cover (%), sponge density

¶7 **Hydrothermal vents (M3.7)**:

- ¶8 Physical: Vent fluid temperature, flow rate
- ¶9 Chemical: H2S concentration, Fe/Mn concentrations
- ¶10 Compositional: Indicator taxa presence (vent-endemic species)
- ¶11 Structural: Chimney structure area, tubeworm aggregation density
- ¶12 Functional: Chemosynthetic productivity (where measured)

¶13 Where baseline data are insufficient to establish reference values, expert judgement or regional comparisons may be used, and the limitation should be documented.

Step 6: Calculate condition indices

¶1 Transform condition variables into standardised indicators following **TG-2.1 Biophysical Indicators** methodology. For each variable:

> *Indicator = (V - VL) / (VH - VL)*

¶2 Where V is the observed value, VH is the reference (high) value, and VL is the degraded (low) value. For inverse variables (e.g., pollutant concentrations, disturbance percentage): (VL - V) / (VL - VH), where the denominator must be evaluated using the actual reference value of VH for the variable in question (which is 0 only for variables whose reference state is zero). See Section 3.7 Table 4 for a worked example with VH explicitly stated.

¶3 Aggregate indicators into composite condition indices using equal weighting or expert-weighted aggregation. Document the aggregation method.

Step 7: Populate extent and condition accounts

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¶1 Enter compiled data into the account structures in Section 3.3. Ensure the closing stock = opening stock + additions - reductions. Document all data sources, measurement dates, quality ratings, and estimation methods in metadata.

Step 8: Link accounts to policy frameworks

¶1 Cross-reference compiled accounts to decision use cases:

- ¶2 For deep-sea mining assessment: highlight extent and condition for areas subject to ISA exploration contracts
- ¶3 For BBNJ MPA designation: identify ecosystem types with high endemism or low condition scores as priority conservation areas
- ¶4 For MEA reporting (via **TG-2.10 MEA Indicators**): extract protected area coverage and condition trends for SDG 14 and GBF indicators

3.5 Ecosystem Services from the Deep Sea

Provisioning services

¶1 **Genetic resources**: Deep sea organisms, particularly from extreme environments such as hydrothermal vents, harbour unique genetic resources with potential applications in biotechnology and pharmaceuticals [41]. The BBNJ Agreement establishes frameworks for access and benefit-sharing related to marine genetic resources from ABNJ, which may enable future monetary valuation. The CEPA classification includes "Scientific, cultural and educational services" (CEPA division 15) which may encompass genetic resources.

¶2 **Fisheries resources**: Some commercial fish stocks occur on or near deep sea features, particularly seamounts. High seas fish stocks subject to RFMOs may be attributed based on quota allocations [42]. See **TG-6.7 Fisheries Stock Assessment** and **TG-3.1 Asset Accounts** for detailed guidance.

¶3 **Mineral resources**: The Area contains large mineral deposits, including polymetallic nodules, cobalt-rich ferromanganese crusts, and seafloor massive sulphides [43]. UNCLOS defines "polymetallic nodules" as "one of the resources of the Area consisting of any deposit or accretion of nodules, on or just below the surface of the deep seabed, which contain manganese, nickel, cobalt and copper" [44]. The ISA has issued exploration contracts covering approximately 1.5 million km² of seabed, though no commercial exploitation has yet occurred. See **TG-3.10 Offshore Energy Accounts** for methodological parallels.

Regulating services

¶1 **Carbon sequestration**: Abyssal sediments are a major long-term carbon sink via the biological carbon pump. Deep sea carbon sequestration contributes to global climate regulation but is not currently quantified in ecosystem service accounts. For carbon-related accounting approaches, see **TG-6.2 Mangrove and Coastal Wetland Accounting**, which sets the blue carbon pricing rule for the publication.

¶2 **Climate regulation**: Deep water formation and thermohaline circulation influence global climate patterns at scales not readily attributed to specific ecosystem assets.

¶3 **Nutrient cycling**: Deep sea ecosystems contribute substantially to global biogeochemical cycles. Remineralisation of organic matter returns nutrients that eventually upwell to support surface productivity.

Challenges in service valuation

¶1 Monetary valuation of deep sea ecosystem services is at an early stage. The SEEA EA valuation chapters (8-11) are designated as "internationally recognized recommendations" rather than full

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statistical standard, and for deep sea ecosystems data scarcity adds further uncertainty to their application. Key challenges:

1. ¶2 **Spatial attribution**: Many deep sea services operate at global scales that cannot be attributed to discrete ecosystem assets. See **TG-2.2 Macro Dependencies** for macro-scale service flow approaches.
2. ¶3 **Temporal scales**: Carbon sequestration benefits may extend over millennia, challenging NPV discounting approaches. See **TG-1.9 Valuation** for discount rate selection.
3. ¶4 **Non-use values**: Much deep sea value may be non-use value (existence, bequest, option values) not captured in market transactions.
4. ¶5 **Irreversibility**: Deep sea ecosystems are slow to recover from disturbance, and losses may therefore be irreversible.

¶6 Monetary valuation of deep sea ecosystem services should be treated as experimental, with transparent documentation and appropriate caveats.

3.6 Accounting Challenges and Methodological Gaps

Attribution challenges

1. ¶1 **The commons problem**: ABNJ resources are not owned by any country. Whilst activities in ABNJ can be attributed to countries based on flag state, sponsoring state, or quota allocation, the underlying assets remain collective.
2. ¶2 **Migratory species**: Highly migratory species transit between EEZs and high seas areas. Current conventions attribute stocks to countries "during the period when those stocks inhabit its EEZ" [45], creating discontinuous records.
3. ¶3 **Transboundary flows**: Ecosystem services from ABNJ (e.g., carbon sequestration, nutrient cycling) benefit all countries but cannot be attributed to specific beneficiaries.

¶4 One partial treatment of the third challenge exists in practice. In the preliminary ecosystem accounts for the OSPAR maritime area, carbon sequestration was recorded in the use table against "government", defined for that purpose as the collective of OSPAR Contracting Parties, on the grounds that the service is non-exclusive and benefits the Contracting Parties as a whole [46]. The device records the flow without apportioning it, and keeps the use table balanced at the regional level. It does not resolve attribution to individual States, and the entry cannot be carried into a national account without a further allocation rule that the accounts themselves do not supply. Compilers adopting it should name the collective of parties as the accounting entity in the table header and state in metadata that no inter-State apportionment has been made.

Governance gaps

¶1 ABNJ governance is fragmented across ISA (mineral resources), regional fisheries management organisations (specific fish stocks), IMO (shipping and pollution), IWC (cetacean management), IOC/UNESCO (marine scientific research), and the BBNJ Conference of the Parties (biodiversity conservation). There is no single body responsible for integrated environmental-economic accounting for ABNJ.

Regional seas conventions as a compiling entity

¶1 Although no institution holds a global ABNJ accounting mandate, a regional seas convention whose convention area extends past the outer limit of member EEZs already has the three things a compiler needs: a standing accounting area that spans the jurisdictional boundary, a data platform, and a periodic reporting cycle. Where an ABNJ area falls inside such a convention area, compilers should treat the convention rather than any single coastal State as the natural compiling entity, consistent with the "regional sea" jurisdictional basis listed under *Experimental ABNJ accounts* below.

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¶2 The only published attempt to compile SEEA EA accounts across an area spanning both national jurisdiction and ABNJ is the preliminary account for the OSPAR maritime area [46]. That area covers over 13.5 million km² of the North-East Atlantic in five regions, comprising the internal waters, territorial seas and EEZs of fifteen Contracting Parties and the European Union, and extending into ABNJ across the Wider Atlantic (OSPAR Region V) and Arctic Waters (OSPAR Region I). Compilation was driven by an operational objective of the North-East Atlantic Environment Strategy 2030, which commits OSPAR to "start accounting for ecosystem services and natural capital" by 2025 [47]. Four findings from that exercise bear on the guidance in this Circular:

1. ¶3 **The deep sea dominated the accounted extent and contributed almost nothing to the accounted value.** Deep-sea bed habitat was the most extensive ecosystem type recorded, at 46% of the area for which seabed data existed, while extent coverage reached only 68% of the convention area. Of the services compiled, fish provisioning could not be assigned to individual ecosystem types at all — landings reported through FAO were attributable only to the seabed classes as a group — and the carbon sequestration estimate was built from littoral and sublittoral sediments alone. Compilers should expect the deep sea and ABNJ share of a regional accounting area to be large in extent and near-empty in service and monetary terms, and should report the unmapped residual as an explicit line rather than narrowing the accounting area to the mapped part.
2. ¶4 **A condition account could not be compiled from an abundant indicator series.** OSPAR holds long monitoring time series and publishes condition indicators through its Quality Status Reports, but those indicators are reported as aggregates for the convention area and its five regions and could not be disaggregated to the ecosystem types used in the extent account. Data abundance did not overcome the mismatch in spatial unit. This is the *Data scarcity* failure mode below arising from reporting geometry rather than from absent measurement, and it is the reason this Circular treats Section 3.3 as a target framework. See **TG-4.12 Transboundary Data Sharing**.
3. ¶5 **Regional habitat classifications did not align with the IUCN GET.** The exercise used EUNIS seabed classes from EUSeaMap rather than the GET typology endorsed by SEEA EA, because no GET-aligned dataset covered the area. EUNIS classes as then published described abiotic substrate, so extent could be recorded but the biotic ecosystem types to which services attach could not. A compiler working from a regional habitat map should record the crosswalk to the GET classes used in Section 3.2, and the residual that does not cross-walk, in account metadata rather than asserting equivalence.
4. ¶6 **A first compilation is worth producing before the data support it.** The accounts were published as a preliminary and experimental snapshot, with no extent time series (source seabed data were aggregated across years), service flows measured in different years from one another, and an asset value acknowledged as an underestimate. Their stated value was in locating the gaps and setting the data priorities, which is the same purpose served by the priority assessment in Section 3.3 above.

Data scarcity

¶1 Data scarcity is the principal challenge for deep sea accounting. Compilers should not attempt to produce deep sea accounts without first addressing data availability. Key gaps:

1. ¶2 **Baseline gaps**: For most deep sea ecosystems, no baseline inventory of extent or condition exists.
2. ¶3 **Monitoring gaps**: Ongoing monitoring is minimal, so changes over time are difficult to track.
3. ¶4 **Taxonomic gaps**: Many deep sea species remain undescribed, and biodiversity assessment is correspondingly limited.
4. ¶5 **Economic data gaps**: Limited information on economic activities occurring in ABNJ or their values.

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Experimental ABNJ accounts: presentation guidance

¶1 The 2025 SNA (para. 35.129) authorises application of SNA and SEEA accounting definitions and treatments to ABNJ [48]. Compilers preparing experimental ABNJ accounts should observe the following:

1. ¶2 **Satellite/supplementary status**: Experimental ABNJ accounts must be presented as clearly labelled satellite or supplementary tables, separate from the core national accounts. They should not be aggregated into headline natural capital, GDP, or NDP measures without explicit disclosure.
2. ¶3 **Recommended table headers**: Experimental ABNJ tables should display the accounting area (with geographic delineation), the jurisdictional basis for inclusion (e.g., flag state, sponsoring state, quota allocation, regional sea, ISA contract area), and a data quality rating consistent with **TG-0.7 Quality Assurance**.
3. ¶4 **Methodological labelling**: Each experimental table should carry a "supplementary — experimental ABNJ account" label and a footnote citing 2025 SNA para. 35.129 and SEEA EA para. 1.17 (satellite accounts).
4. ¶5 **International consultation**: Before publication, compilers should engage the SEEA technical working groups and the GOAP technical network to confirm methodology and align with concurrent country efforts.

Emerging opportunities

Development	Implication for accounting
BBNJ implementation	Monitoring, reporting, and assessment requirements will generate new data on ABNJ ecosystems.
Seabed mapping initiatives	Seabed 2030 aims to map the entire ocean floor by 2030, providing improved baseline data for extent accounts.
Remote sensing advances	New satellite and autonomous vehicle technologies are expanding observation capabilities. See **TG-4.1 Remote Sensing Data**.
ISA reporting requirements	Environmental impact assessments and monitoring under ISA contracts generate data on areas subject to mineral exploration.
Digital sequence information	Databases of genetic information from deep sea organisms may enable valuation of genetic resources.

¶1 This Circular should be reviewed on a 2-year cycle (next review: early 2028), with key triggers for interim updates including the adoption of monitoring frameworks at BBNJ COP, approval of a first commercial seabed mining contract by ISA, and publication of major deep sea mapping advances.

3.7 Worked Example: Deep-Sea Mining Impact Assessment

¶1 This worked example demonstrates compilation of deep sea ecosystem accounts for a hypothetical 200,000 km² deep-sea area (depths exceeding 1,000 m) within a coastal State's extended continental shelf and adjacent ABNJ. Given the Emerging status of this Circular and severe data limitations, compilers should treat the methods and values below as illustrative only.

Setting and decision context

¶1 **Accounting area**: A deep-sea accounting area of 200,000 km² spanning the continental slope and adjacent abyssal plain (bathymetry 1,000-4,500 m), including 12 mapped seamounts (M3.4, total area 3,200 km²), 3 confirmed active hydrothermal vent fields (M3.7, total area 8 km²), and extensive abyssal plain sediments (M3.3). Of the total, 140,000 km² lies within the State's extended continental shelf claim (approved by CLCS), and 60,000 km² lies in ABNJ. One seamount hosts an ISA exploration contract for polymetallic sulphides.

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¶2 **Decision context**: The sponsoring State is evaluating whether to support progression of the ISA exploration contract to the exploitation phase, requiring assessment of: (1) the economic value of mineral resources, (2) the environmental cost of ecosystem degradation from mining, and (3) the opportunity cost of foregone ecosystem services.

Step 1: Extent account (year t to t+1)

¶1 Extent data compiled from multibeam bathymetry (seamounts, abyssal plains) and ROV surveys (hydrothermal vents). Extent changes reflect discovery of a new vent field (natural expansion), cessation of one known vent (natural reduction confirmed by temperature monitoring), and seabed disturbance from mineral exploration test mining (anthropogenic reduction).

Accounting entry	Abyssal plains (M3.3)	Seamounts (M3.4)	Hydrothermal vents (M3.7)	Total
Opening extent (km²)	196,792	3,200	8	200,000
Additions				
– Natural expansion (new vent field discovered)	0	0	2	2
Total additions	0	0	2	2
Reductions				
– Natural reduction (vent cessation)	0	0	1	1
– Anthropogenic reduction (exploration disturbance)	3	0.5	0	3.5
Total reductions	3	0.5	1	4.5
Net change	-3	-0.5	+1	-2.5
Closing extent (km²)	196,789	3,199.5	9	199,997.5

¶2 *Table 3: Extent account for deep-sea accounting area*

¶3 **Interpretation**: The 3 km² abyssal plain reduction represents sediment disturbance from environmental baseline surveys and small-scale test mining under the ISA exploration contract. The 0.5 km² seamount reduction reflects localised disturbance from geological sampling on the seamount hosting the mineral deposit. The +1 km² net change in vent extent reflects discovery of a larger new vent field (2 km²) offset by cessation of a smaller known vent (1 km²). The vent cessation is recorded as natural unmanaged reduction (gradual geological process) consistent with the classification criteria in Section 3.3.

Step 2: Condition account

¶1 Condition indicators derived from ROV surveys (structural variables), water column sampling (chemical variables), and ISA exploration contract environmental monitoring data. Reference conditions drawn from undisturbed control sites within the same depth range and biogeographic province. Variables are classified against the SEEA EA Ecosystem Condition Typology (ECT) variable classes as set out in SEEA EA Chapter 5 [49].

Condition variable	ECT class	Observed value	VH (reference)	VL (degraded)	Indicator score
Benthic disturbance (% area with visible tracks)	Physical (inverse)	0.8%	0%	15%	0.95
Species discovery rate (new spp. per 100 samples)	Compositional	12	18	3	0.60
Water chemistry (dissolved oxygen, ml/L at 1500m)	Chemical	4.2	4.8	2.5	0.74

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Condition variable	ECT class	Observed value	VH (reference)	VL (degraded)	Indicator score
Connectivity index (larval dispersal potential)	Structure [50]	0.65	0.90	0.20	0.64

¶2 *Table 4: Condition account for deep-sea accounting area*

¶3 **Calculation notes**: For benthic disturbance (inverse variable), VH = 0% and the indicator is: (VL - V) / (VL - VH) = (15 - 0.8) / (15 - 0) = 14.2 / 15 = 0.95. The denominator reflects the actual reference value of VH and is not a default substitution. For variables whose reference value is non-zero, VH must be inserted explicitly. For species discovery rate: (V - VL) / (VH - VL) = (12 - 3) / (18 - 3) = 0.60.

¶4 **Composite condition index**: (0.95 + 0.60 + 0.74 + 0.64) / 4 = **0.73**

¶5 **Interpretation**: The composite index of 0.73 indicates relatively good condition (73% of reference condition), consistent with limited human disturbance to date. The species discovery rate indicator (0.60) suggests biodiversity may be less intact than other condition dimensions, potentially due to historical fishing impacts on seamounts. Compilers should note that even small condition reductions may be effectively irreversible on human timescales due to slow deep-sea recovery rates.

Step 3: Ecosystem services (annual flows)

¶1 Ecosystem service flows estimated from scientific literature, ISA environmental baseline reports, and expert judgement. Values carry substantial uncertainty and should be interpreted as illustrative orders of magnitude.

Service	Physical quantity	Monetary value (USD)
Genetic resources (bioprospecting potential)	~1-2 novel compounds/yr (annual discovery rate)	300,000-600,000 (estimated annual research/licensing value)
Carbon sequestration (sediment burial)	600,000 t CO2/yr (at 3.0 t CO2/km²/yr)	30,000,000-90,000,000 (at USD 50-150/t CO2e, market reference range)
Mineral potential (polymetallic sulphides, nodules)	ISA exploration phase — not yet exploited	— (potential future value)
Research and scientific use value — experimental (research expeditions, data generation)	4 research cruises/yr	3,200,000 (research expenditure; experimental — subject to methodological review, see note below)
Total valued services (midpoint)		**~63,650,000 (range: ~33.5M - ~93.8M)**

¶2 *Table 5: Ecosystem service flows from deep-sea accounting area*

¶3 **Valuation notes**:

- ¶4
  Genetic resources: The annual flow of approximately 1-2 novel compounds per year is extrapolated from cumulative expedition discoveries. Earlier drafts reported eight cumulative compounds, but using a cumulative stock as an annual flow conflates stock and flow concepts. Compilers should distinguish annual resource rent-equivalent flows (appropriate for ecosystem service accounting) from non-recurring research expenditure, per SEEA EA paras. 8.16 and 9.4. The BBNJ Agreement's benefit-sharing provisions may alter how these values are recorded in future accounts.
- ¶5
  Carbon sequestration: Estimated at 3.0 t CO2/km²/yr based on sediment trap studies in similar deep-sea environments. Total = 200,000 km² × 3.0 t CO2/km²/yr = 600,000 t CO2/yr. Valued

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using a market carbon price range of USD 50-150/t CO2e, consistent with SEEA EA paras. 9.23-9.31 (para. 9.31 on carbon prices) and Section 6.4.3 [51] . The social cost of carbon may be used only with explicit methodological justification and disclosure. The deep-sea sediment carbon sink operates over geological timescales, and attribution to discrete ecosystem assets is methodologically uncertain.

- ¶6
  Mineral potential: Recorded qualitatively only, as no commercial exploitation has commenced. Geologic surveys estimate 8 million tonnes of polymetallic sulphide ore (gross in-situ value approximately USD 3-4 billion at current commodity prices). Net present value to the State depends on extraction costs, ISA benefit-sharing arrangements, and discount rates. Detailed feasibility assessment is required.
- ¶7
  Research and scientific use value (experimental): Under SEEA EA paras. 8.16 and 9.4, research expenditure is not an ecosystem service flow in the strict sense. Compilers who follow SEEA EA strictly should reclassify this row as a memorandum item and exclude it from the ecosystem service total and from asset valuation inputs.

Step 4: Asset valuation

¶1 Asset values calculated as the net present value of expected future ecosystem service flows using a 4% real discount rate. For deep-sea ecosystems dominated by carbon sequestration, a single 25-year horizon understates the carbon benefit substantially. This example presents two horizons — 25 years (conventional) and 100 years (long-horizon sensitivity). Consult **TG-1.9 Valuation** on discount-rate and horizon choice.

¶2 The carbon sequestration component is held at the midpoint of the market reference range (USD 100/t CO2e × 600,000 t CO2/yr = USD 60,000,000/yr) to isolate horizon sensitivity.

¶3 **Conservative service flow (carbon sequestration midpoint + scientific value)** = USD 63,200,000/yr **Including genetic resource potential (midpoint)** = USD 63,650,000/yr

Scenario	Annual flow (USD)	Horizon	PV annuity factor (4%)	Asset value (USD)
A1 — Conservative	63,200,000	25 years	15.62	987,200,000
A2 — Conservative	63,200,000	100 years	24.50	1,548,400,000
B1 — Incl. genetic	63,650,000	25 years	15.62	994,200,000
B2 — Incl. genetic	63,650,000	100 years	24.50	1,559,400,000

¶4 *Table 6: Asset value sensitivity to projection horizon (4% real discount rate)*

¶5 **Sensitivity**: Extending the horizon from 25 to 100 years increases asset value by approximately 57% under either scenario. This reflects the dominant share of long-horizon carbon sequestration in total asset value. The difference between scenarios that include or exclude genetic resource potential (less than 1% at either horizon) is small relative to horizon sensitivity. The choice of valuation horizon, together with the underlying carbon price, is therefore the dominant driver for deep-sea asset values. If scientific value is reclassified as a memorandum item, the A-scenario annual flow drops to USD 60,000,000/yr and the B-scenario to USD 60,450,000/yr, with corresponding reductions in asset value.

Step 5: Decision support analysis

¶1 **Mining impact projection**: If the ISA exploration contract progresses to commercial exploitation, projected impacts over a 20-year mining operation include:

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- ¶2 **Extent loss**: 85 km² of abyssal plain directly disturbed (0.043% of total area), plus 120 km² indirect disturbance from sediment plume
- ¶3 **Condition decline**: Composite condition index projected to decline from 0.73 to 0.52 in mined area, and to 0.68 in indirectly affected area
- ¶4 **Service flow reduction**: Annual service losses of USD 61,500 (carbon sequestration in the 205 km² of disturbed sediments: 615 t CO2/yr at 3.0 t CO2/km²/yr and the USD 100 midpoint, an upper bound that assumes burial stops entirely) + USD 240,000 (lost scientific value from altered community composition) = approximately USD 301,500/yr

¶5 **Ecosystem degradation cost (SEEA EA-compliant method)**: SEEA EA paras. 6.44-6.48 define ecosystem degradation cost as the change in ecosystem asset value attributable to a decline in condition below a sustainable reference level. The correct measure is the NPV difference in service flows between the mining and no-mining scenarios, not the sum of a proportional asset share and a separately capitalised service loss (which would double-count, because the asset value is itself the NPV of those service flows. See SEEA EA para. 7.14).

¶6 Applying this method using the 25-year conservative horizon (Scenario A1):

¶7 Degradation cost (NPV of foregone flows, 4%, 25 years) = USD 301,500 × 15.62 ≈ **USD 4,700,000**

¶8 Under the 100-year horizon (Scenario A2): USD 301,500 × 24.50 ≈ USD 7,400,000. The "proportional asset share" term (85 km² / 200,000 km² × asset value) is omitted because it is derived from the same service flow stream as the asset value itself, and including both would double-count the loss.

> ¶9 ⓘ **Corrected 24 September 2026**
> ¶10 The carbon-service loss was given as USD 1.4 million/yr, which the stated inputs cannot reproduce (it implies about 68 t CO2/km²/yr against the stated 3.0); on those inputs the loss is at most USD 61,500/yr, so the degradation cost falls from USD 25.6 million to USD 4.7 million at 25 years and from USD 40.2 million to USD 7.4 million at 100 years.

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¶11 **Economic benefit from mining**: Gross in-situ ore value of USD 3-4 billion minus extraction costs (estimated 70% of gross value for deep-sea mining) yields net value of USD 900M-1.2B. The ISA's benefit-sharing regime for exploitation remains unadopted as of the publication date of this Circular [52]. Three illustrative State-share scenarios:

Scenario	State share (illustrative)	State benefit (USD, 20-year operation)
Low	20%	180M - 240M
Central	40%	360M - 480M
High	60%	540M - 720M

¶12 *Table 7: Illustrative State benefit from mining under hypothetical ISA benefit-sharing scenarios. No ISA benefit-sharing regime has been finalised, so figures are presented to support sensitivity analysis only.*

¶13 **Trade-off assessment**: Even under the high State-share scenario (USD 540M-720M), the ecosystem degradation cost on the 100-year horizon (~USD 7.4M) is small relative to mining revenue under standard cost-benefit analysis. Under the low State-share scenario the ratio narrows substantially. However, this comparison omits:

1. ¶14 **Irreversibility**: Deep-sea recovery timescales exceed 100 years, so the 25-year and 100-year degradation cost horizons are lower bounds. Under strict irreversibility, the perpetuity-equivalent degradation cost (USD 301,500/yr ÷ 4%) would be approximately USD 7,500,000 — consistent with the 100-year estimate. See SEEA EA paras. 6.44-6.48 and 7.20-7.22.

2. ¶15 **Option value**: Delaying mining preserves future options for genetic resource discovery or alternative uses.
3. ¶16 **Existence value**: Non-use values are not captured in service flow valuation.
4. ¶17 **Risk**: Sediment plume impacts may exceed projections.

¶18 The accounting framework transparently presents trade-offs but does not prescribe the decision.

Step 6: Upward connections to policy frameworks

¶1 **TG-1.1 National Ocean Budgets**: The degradation cost (USD 4.7M at 25-year horizon and USD 7.4M at 100-year horizon) informs natural capital budgeting. If mining proceeds, this cost should be deducted from gross mineral revenues when calculating environmentally adjusted NDP.

¶2 **TG-2.10 MEA Indicators**: Extent accounts feed SDG 14.5.1 (MPA coverage) if the deep-sea area includes protected zones. The 0.8% benthic disturbance metric supports SDG 14.2.1. Condition index trends inform BBNJ monitoring requirements.

¶3 **TG-1.3 Marine Spatial Management**: The spatial distribution of high-condition areas (seamounts, vent fields) versus disturbed areas guides MPA designation and mining exclusion zones. The connectivity index (0.65), classified as a structure ECT variable, informs network design for deep-sea MPAs.

¶4 **TG-3.1 Asset Accounts**: Mineral resources (USD 3-4B gross value) are recorded as non-renewable natural assets. The ecosystem asset value (Table 6, ~USD 1.0B at 25 years to ~USD 1.5B at 100 years under the conservative scenario) is recorded separately.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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FOOTNOTES

1. ¶1 The Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement), adopted June 2023; entry-into-force date is stated in Section 3.1 as the single reference point.
2. ¶2 2025 SNA, para 35.128
3. ¶3 2025 SNA, para 35.129
4. ¶4 United Nations Convention on the Law of the Sea (UNCLOS), 1982
5. ¶5 UNCLOS, Article 2
6. ¶6 UNCLOS, Article 56
7. ¶7 SEEA CF, footnote 63 (para 5.248)
8. ¶8 UNCLOS, Article 77
9. ¶9 UNCLOS, Article 86
0. ¶10 UNCLOS, Article 87
1. ¶11 UNCLOS, Article 1(1)
2. ¶12 UNCLOS, Article 136
3. ¶13 UNCLOS, Article 157. "The Authority is the organization through which States Parties shall… organize and control activities in the Area, particularly with a view to administering the resources of the Area."
4. ¶14 SEEA CF, para 29 (Preface)
5. ¶15 2025 SNA, para 35.128
6. ¶16 SEEA CF, paras. 5.397-5.400 (treatment of fishery quotas and underlying biological resources under the Central Framework — not an ecosystem-accounting treatment). The quota instrument may be recorded as a national asset where economic ownership is established; the underlying biological resource in ABNJ is not recorded as a national asset.
7. ¶17 SEEA CF, para 5.433. "Following the principles of the SNA, the location of the aquatic resource is not the key determinant of the attribution of economic production. Production is allocated instead to the country of residence of the harvesting operation."
8. ¶18 Figure adapted from UNCLOS Part XI, BBNJ Agreement, UNCLOS Part XIII (marine scientific research), UNCLOS Article 65 (cetaceans), and relevant institutional mandates.

9. ¶19 BBNJ Agreement, Article 1
0. ¶20 BBNJ Agreement, Part II (Marine Genetic Resources)
1. ¶21 BBNJ Agreement, Part III (Area-Based Management Tools)
2. ¶22 BBNJ Agreement, Part IV (Environmental Impact Assessments)
3. ¶23 BBNJ Agreement, Part V (Capacity-Building and Transfer of Marine Technology)
4. ¶24 IUCN GET, M3 Deep sea floors biome introduction
5. ¶25 IUCN Global Ecosystem Typology, Version 2.0
6. ¶26 IUCN GET, M3.1 Continental and island slopes
7. ¶27 IUCN GET, M3.1 Continental and island slopes, Ecological Traits
8. ¶28 IUCN GET, M3.2 Submarine canyons, Ecological Traits
9. ¶29 IUCN GET, M3.3 Abyssal plains, Ecological Traits
0. ¶30 IUCN GET, M3.3 Abyssal plains. "Many species have so far been sampled only as singletons (only one specimen per species) or as a few specimens."
1. ¶31 IUCN GET, M3.4 Seamounts, ridges and plateaus, Distribution
2. ¶32 IUCN GET, M3.5 Deepwater biogenic beds
3. ¶33 IUCN GET, M3.6 Hadal trenches and troughs, Key Ecological Drivers
4. ¶34 IUCN GET, M3.7 Chemosynthetic-based ecosystems
5. ¶35 IUCN GET, M3.7 Chemosynthetic-based ecosystems, Ecological Traits
6. ¶36 IUCN GET, M2.3 Bathypelagic ocean waters
7. ¶37 IUCN GET, M2.3 Bathypelagic ocean waters, Key Ecological Drivers
8. ¶38 IUCN GET, M2.4 Abyssopelagic ocean waters
9. ¶39 IUCN GET, M3.3 Abyssal plains
0. ¶40 SEEA EA, para 5.10
1. ¶41 BBNJ Agreement, Part II addresses access to and benefit-sharing from marine genetic resources
2. ¶42 SEEA CF, para 5.398
3. ¶43 UNCLOS Part XI and ISA regulatory framework
4. ¶44 UNCLOS Final Act, Resolution II, para. 1(d). See also UNCLOS Article 133(a), which includes polymetallic nodules within the definition of "resources of the Area."
5. ¶45 SEEA CF, para 5.398
6. ¶46 Alarcon Blazquez, M.G., van der Veeren, R., Gacutan, J. and James, P.A.S. (2023). 'Compiling preliminary SEEA Ecosystem Accounts for the OSPAR regional sea: experimental findings and lessons learned'. *One Ecosystem*, 8, e108030. doi:10.3897/oneeco.8.e108030.
7. ¶47 OSPAR Commission, *North-East Atlantic Environment Strategy 2030* (OSPAR Agreement 2021-01), Strategic Objective on ecosystem-based management. Quoted in full in Alarcon Blazquez et al. (2023), see [46].
8. ¶48 2025 SNA, para 35.129
9. ¶49 SEEA EA, Chapter 5 (Ecosystem Condition Typology). The ECT comprises six variable classes — physical, chemical, compositional, structure, function, and landscape state — organised under abiotic, biotic, and landscape-level groups (SEEA EA para. 5.32 and Table 5.1).
0. ¶50 Connectivity (larval dispersal potential) is classified here as a "structure" ECT variable, as a proxy for the structural integrity of the ecosystem network. The 0.20-0.90 reference range is illustrative, drawn from emerging deep-sea connectivity literature; this variable is treated as an experimental indicator pending consolidation of the underlying methodology.
1. ¶51 SEEA EA paras. 9.21-9.31 set the preference order for valuation methods; para. 9.31 covers prices from emission trading systems, marginal abatement costs and the social cost of carbon for global climate regulation services. The carbon sequestration component is defined in Section 6.4.3 (paras. 6.109-6.115).
2. ¶52 International Seabed Authority, Draft Regulations on Exploitation of Mineral Resources in the Area, Further Revised Consolidated Text, ISBA/31/C/CRP.1/Rev.2, 15 February 2026. Regulations remain unadopted as of the publication date of this Circular; the cited document supersedes earlier drafts (including ISBA/25/C/WP.1).

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Fisheries Accounting: Integrating Stock Assessment

Provides guidance on integrating fisheries stock assessment science with statistical accounting frameworks.

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides guidance on integrating fisheries stock assessment science with statistical accounting frameworks. Upon completion, readers will be equipped to compile fisheries asset accounts that draw on stock assessment outputs whilst maintaining accounting coherence.
Stock assessment and ocean accounting support three principal decision use cases:

- MSY-based quota verification (comparing actual catch against assessment-predicted sustainable harvest levels)
- depletion-adjusted fisheries GDP (indicating whether fisheries income derives from sustainable harvest or capital depletion)
- evidence for subsidy reform (quantifying the contribution of public subsidies to fishing capacity under SDG 14.6)

Policy applications are addressed in TG-1.5 Fisheries Management and TG-1.1 National Ocean Budgets. Derived indicators are compiled under TG-2.2 Productivity Indicators.
This Circular addresses how to transform stock assessment outputs into accounting entries, propagate uncertainty, accommodate multi-species and ecosystem considerations, and align with SDG indicator 14.4.1. Governance and policy aspects of fisheries management are addressed in TG-1.5 Fisheries Management.

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ABOUT THIS CIRCULAR

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¶1 **Framework Position**

¶2 TG-6.7 bridges fisheries science and the SEEA AFF physical asset account structure, providing the methodological interface between stock assessment outputs (biomass estimates, mortality rates, reference points) and the standardised account entries required by SEEA CF and SEEA AFF. It sits within Section 6 (Thematic Methods) and connects the general asset accounting framework in **TG-3.1 Asset Accounts** and the wild-capture/aquaculture boundary established in **TG-3.9 Aquaculture Accounts** to the fisheries governance and policy applications in **TG-1.5 Fisheries Management**.

1. Outcome

¶1 This Circular provides guidance on integrating fisheries stock assessment science with statistical accounting frameworks. Upon completion, readers will be equipped to compile fisheries asset accounts that draw on stock assessment outputs whilst maintaining accounting coherence.

¶2 Stock assessment and ocean accounting support three principal decision use cases:

- ¶3 **MSY-based quota verification** (comparing actual catch against assessment-predicted sustainable harvest levels)
- ¶4 **depletion-adjusted fisheries GDP** (indicating whether fisheries income derives from sustainable harvest or capital depletion)
- ¶5 **evidence for subsidy reform** (quantifying the contribution of public subsidies to fishing capacity under SDG 14.6)

¶6 Policy applications are addressed in **TG-1.5 Fisheries Management** and **TG-1.1 National Ocean Budgets**. Derived indicators are compiled under **TG-2.2 Productivity Indicators**.

¶7 This Circular addresses how to transform stock assessment outputs into accounting entries, propagate uncertainty, accommodate multi-species and ecosystem considerations, and align with SDG indicator 14.4.1[1]. Governance and policy aspects of fisheries management are addressed in **TG-1.5 Fisheries Management**.

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2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-4.10 Extending Fisheries Statistics for Ecosystem-Based Management** — the fisheries data pipeline this Circular consumes: which statistics a stock assessment is built from, and how they are extended for ecosystem-based management.
- ¶3 **TG-4.11 Aligning Research Statistical Modelling with Official Statistical Methods** — applies to Section 3.6, where assessment-model uncertainty is carried into an official statistic.
- ¶4 **TG-0.1 General Introduction to Ocean Accounts**
- ¶5 **TG-3.1 Asset Accounts** — general physical and monetary asset account structure, including the treatment of aquatic resources as environmental assets and the opening stock / additions / reductions / closing stock structure
- ¶6 **TG-3.9 Aquaculture Accounts** — distinction between cultivated and natural aquatic resources and the production boundary for wild-capture versus farmed fisheries

¶7 Supplementary references: **TG-2.1 Biophysical Indicators** (indicator framework for biomass and B/BMSY ratios), and **TG-0.7 Quality Assurance** (uncertainty documentation and data revisions).

¶8 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 Measuring fish stocks is challenging given the need to rely on biological models rather than direct observation[2], [3]. The SEEA CF and SEEA AFF provide the accounting framework for aquatic resources. Fisheries science provides the biological models and assessment methods that generate estimates of stock size, natural growth, mortality, and sustainable yield. Stock assessment is "the use of various statistical and mathematical calculations to make quantitative predictions about the reactions of fish populations to alternative management choices"[4]. The outputs of stock assessments (biomass estimates, recruitment indices, mortality rates, and reference points) are the raw material from which accounting entries for natural aquatic resources must be derived.

¶2 To illustrate the gap between fisheries science outputs and accounting requirements, consider a typical result: "B/BMSY = 0.75 with 95% confidence interval of 0.45–1.05". For the fisheries scientist, this result indicates that the stock is most likely below the level that can produce maximum sustainable yield, but the wide confidence interval means the stock could plausibly be anywhere from severely depleted to slightly above target. For the accountant, this result must be translated into a deterministic opening stock value (in tonnes), a sustainable yield estimate (to calculate depletion), and a sustainability classification (for SDG 14.4.1 reporting). Each requires explicit decisions about how to handle uncertainty.

¶3 This section examines stock assessment concepts (Section 3.1), their integration into asset accounts (Section 3.2), compilation procedures (Section 3.3), a worked example (Section 3.4), multi-species and ecosystem considerations (Section 3.5), uncertainty propagation (Section 3.6), and alignment with SDG 14.4.1 (Section 3.7).

3.1 Stock Assessment Concepts

¶1 Stock assessment science provides the biological foundation for fisheries accounting. For guidance on how these concepts relate to broader economic frameworks, see **TG-1.9 Valuation**.

Biomass and stock structure

¶1 **Biomass** refers to the total weight of fish in a stock or population. Stock assessments distinguish between the biomass concepts summarised in Table 3.1.0[5].

Biomass concept	Description
Total biomass (B)	The weight of all individuals in the stock, regardless of age or size.
Spawning stock biomass (SSB)	The weight of sexually mature individuals capable of reproduction, used to assess reproductive capacity.
Exploitable biomass	The portion of the stock available for harvest, typically excluding juveniles below minimum landing size.
Virgin biomass (B0)	The theoretical biomass that would exist in the absence of fishing pressure.

¶2 For asset accounting, the SEEA CF recommends SSB because "a primary purpose of fishery management is to maintain an adequate level of spawning stock so as to be able to generate natural growth and to minimize the probability of collapse"[6]. The SEEA AFF notes that the physical asset account "shows the total biomass of all species subject to harvesting or cultivation activity within a national boundary"[7], covering commercial, aquaculture, subsistence, and recreational harvesting.

¶3 Table 3.1.1 provides guidance on selecting the appropriate biomass concept for each accounting entry.

¶4 *Table 3.1.1: Biomass concept selection for accounting entries*

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Accounting Entry	Recommended Biomass Concept	Rationale
Opening/Closing stock	Total biomass (B)	Complete population
Sustainable yield calculation	Spawning stock biomass (SSB)	Reproductive capacity basis
Depletion assessment	SSB relative to BMSY	Management reference point
Extraction recording	Exploitable biomass	Harvestable portion
Monetary valuation	Exploitable biomass	Economic value basis
Condition indicator	B/BMSY or B/B0 ratio	Relative to reference

¶5 Compilers should use total biomass for opening and closing stock entries, SSB for sustainable yield calculations, and exploitable biomass for monetary valuation. Where only one biomass concept is available, document which concept is used and note implications for comparability.

Recruitment and natural growth

¶1 **Recruitment** is the process by which new individuals enter the fishable stock, typically defined as reaching a specified age or size[8]. **Natural growth** in asset accounting terms encompasses both recruitment (new individuals) and somatic growth (increase in size of existing individuals). The SEEA CF establishes that for renewable natural resources such as fish stocks, the primary addition to stock is natural growth, encompassing recruitment and somatic growth[9]. For the treatment of natural resource additions, see **TG-3.2 Flows from Environment to Economy**.

¶2 The two most common stock-recruitment models are the **Beverton-Holt** (recruitment increases with SSB towards an asymptotic maximum) and **Ricker** (recruitment declines at particularly high SSB due to density-dependent effects)[10]. High natural variability in recruitment creates substantial uncertainty in stock projections that must be acknowledged in asset account compilation.

Fishing and natural mortality

¶1 **Fishing mortality (F)** is the instantaneous rate of death due to fishing. **Natural mortality (M)** is the instantaneous rate of death from all other causes (predation, disease, senescence, starvation)[11]. Total mortality Z = F + M.

¶2 For asset accounting, normal losses correspond to natural mortality, and extraction corresponds to fishing mortality (gross catch)[12]. The Baranov catch equation, used in Step 4 of the compilation procedure (Section 3.3), relates catch, natural mortality, and fishing mortality.

Maximum sustainable yield and reference points

¶1 **Maximum sustainable yield (MSY)** is the largest average catch that can theoretically be removed from a stock on a sustained basis under prevailing environmental conditions[13]. The SEEA CF describes it as the point "where natural growth exactly replaces removal by fishing"[14].

¶2 Associated biological reference points:

- ¶3 **BMSY**: Biomass level at which MSY is achieved
- ¶4 **FMSY**: Fishing mortality rate that produces MSY
- ¶5 **B/BMSY ratio**: Current biomass relative to BMSY — a key sustainability indicator
- ¶6 **F/FMSY ratio**: Current fishing mortality relative to FMSY — indicates fishing pressure
- ¶7 **Blim / Bpa**: Limit and precautionary approach reference points providing buffer thresholds
- ¶8 **Flim / Fpa**: Corresponding fishing mortality limits

¶9 For accounting purposes, the directly relevant terms are MSY (which determines sustainable yield), BMSY (which determines the sustainability threshold for SDG 14.4.1[15]), and depletion (calculated as excess of catch over sustainable yield). Precautionary reference points (Blim, Bpa, Flim, Fpa) are management tools and may be recorded as supplementary metadata in the asset account.

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¶10 SDG Target 14.4 specifically references MSY: "restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics"[16].

Stock assessment methods

¶1 The choice of assessment method depends on data availability[17]:

¶2 **Data-rich methods** (integrated stock assessments, virtual population analysis) require catch-at-age data, abundance indices, and biological parameters. They provide absolute biomass and detailed population structure, and are applied to commercially important, well-studied stocks.

¶3 **Data-moderate methods** (surplus production models, catch-only models) require catch time series and relative abundance indices. They estimate biomass relative to reference points rather than absolute values.

¶4 **Data-poor methods** (length-based indicators, catch-curve analysis) require only basic catch or length-frequency data. They provide qualitative or semi-quantitative sustainability assessments.

¶5 The SEEA AFF acknowledges that a complete physical asset account "is most likely not possible under current circumstances" and that a more qualitative assessment using "various biological and bioeconomic models and catch statistics" may be appropriate[18]. Data-rich assessments can support full physical and monetary asset accounts. Data-moderate assessments may support physical accounts, but monetary valuation requires additional assumptions. Data-poor assessments can support only qualitative sustainability classifications, sufficient for SDG 14.4.1 reporting but not for complete asset accounts. Document the data tier for each stock and apply quality flags accordingly, following **TG-0.7 Quality Assurance**.

3.2 Asset Account Integration

¶1 For the general structure of asset accounts, see **TG-3.1 Asset Accounts**.

Mapping stock assessment outputs to account entries

¶1 *Table 3.2.1: Stock assessment output to account entry mapping*

Stock Assessment Output	Account Entry	Transformation Required
Bt (annual biomass)	Opening/Closing stock	None if same timing
Recruitment estimate	Natural growth (part)	Add to somatic growth
Natural mortality (M)	Normal losses	Convert rate to tonnes
Fishing mortality (F)	Extraction	Convert via Baranov equation
MSY estimate	Sustainable yield	Use directly
Retrospective revisions	Reappraisals	Current vs previous assessment

Opening and closing stocks

¶1 The opening and closing stock entries correspond to biomass estimates from stock assessments. The SEEA CF account structure is:

- ¶2 Opening stock of aquatic resources
- ¶3 Additions to stock (growth in stock, upward reappraisals, reclassifications)
- ¶4 Reductions in stock (gross catch/harvest, normal losses, catastrophic losses, downward reappraisals, reclassifications)
- ¶5 Closing stock of aquatic resources[19]

¶6 "Direct measurement of opening and closing stocks and elements of change in stocks usually cannot be observed or measured directly; an exception to this is the measurement of the harvest or gross catch. Accordingly, biological models and assumptions must be used to make estimates"[20].

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Entry	Source
Opening stock	Bt from stock assessment at year t
Closing stock	Bt+1 from stock assessment at year t+1
Consistency check	Closing = Opening + Additions - Reductions

¶7 The accounting identity must hold: any discrepancy between the stock assessment biomass trajectory and the sum of recorded additions and reductions indicates either model inconsistency or unrecorded flows.

¶8 When a revised assessment changes historical biomass estimates, record these changes as reappraisals in the current accounting period rather than revising historical accounts. Include metadata indicating the assessment vintage so users can distinguish "as-assessed" from "current-estimate" time series. See **TG-0.7 Quality Assurance** for data revision treatment.

¶9 Figure 6.7.2 shows a hypothetical fish-stock biomass trajectory[21]. The shaded band records 95% assessment confidence intervals used for asset-account uncertainty ranges, and the BMSY reference line marks the threshold below which depletion entries are required in the asset accounts.

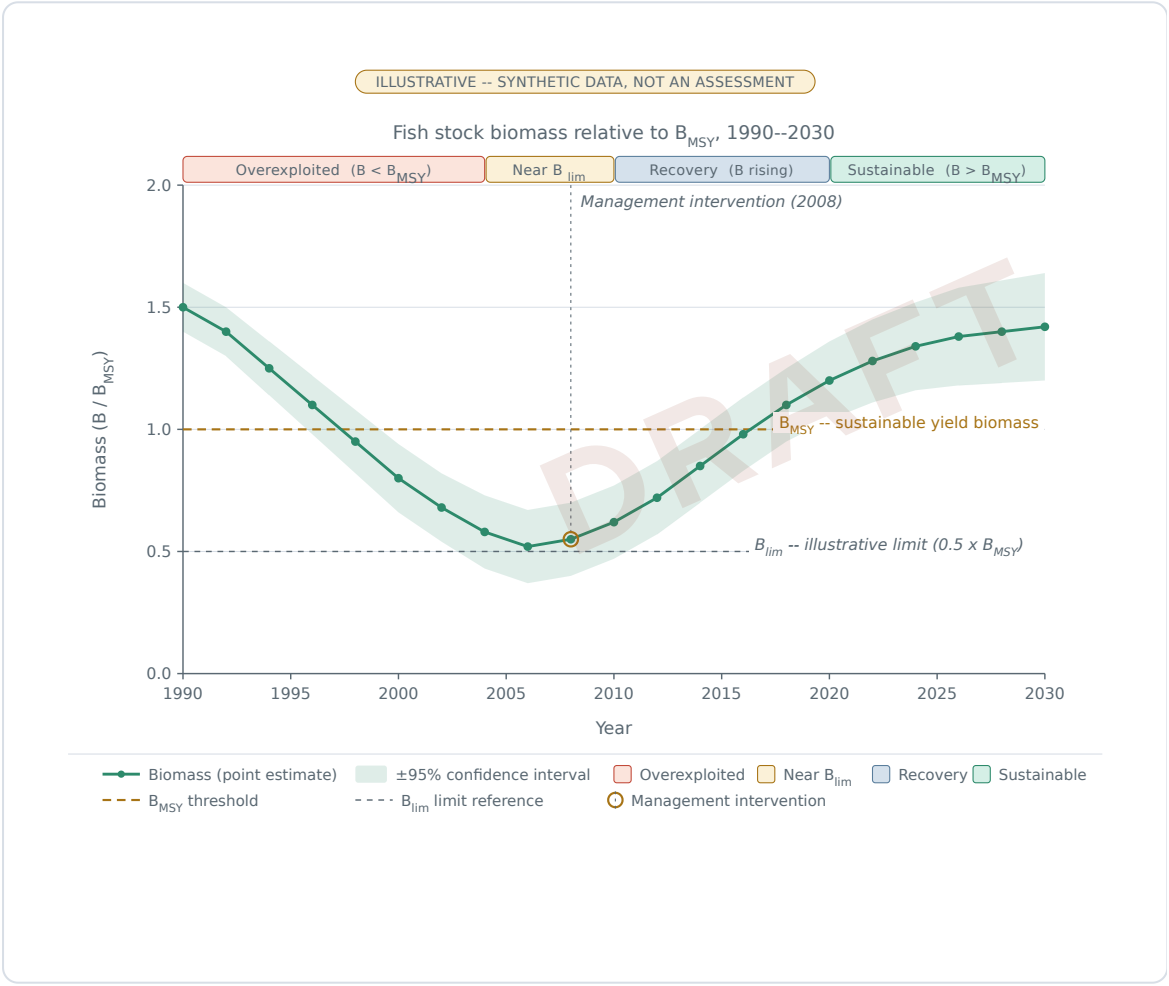


Figure 6.7.2 Illustrative fish-stock biomass trajectory (1990--2030) relative to BMSY, with four management states and a teaching-device intervention. Synthetic series with ±95% band; 0.5 × BMSY limit is illustrative, not a Guidance threshold.

Source: TG-6.7 (GOAP Technical Guidance, Section 6 -- Thematic Methods); reference point definitions per FAO Code of Conduct for Responsible Fisheries, Art. 7.5, and Hilborn & Walters (1992) *Quantitative Fisheries Stock Assessment*, Ch. 8.

Adapted from: SEEA EA 2024, Annex on fisheries asset accounts (stock depletion and recovery trajectories); FAO (2022) *The State of World Fisheries and Aquaculture*, reference point framework (B_{MSY}, B_{lim}).

¶10 The central trajectory (blue line) provides point estimates for opening and closing stock entries. The confidence bands represent assessment uncertainty. The trajectory records a stock that declined below BMSY in the early 2000s, reached a minimum around 2008, and subsequently recovered to approximately BMSY by 2020. During the decline phase, depletion is recorded. During the recovery phase, net additions exceed extractions and no depletion is recorded.

Sustainable yield and depletion

¶1 The SEEA CF establishes that "depletion of natural aquatic resources is derived following the approach... where depletion for renewable resources is shown to be equal to gross catch less sustainable yield" [22].

¶2 **Depletion** = Gross catch - Sustainable yield (if positive, otherwise zero)

> ¶3 ⓘ **Sign convention for recovering stocks**
> ¶4 Under this definition, a stock already below BMSY but whose current catch does not exceed its current-biomass sustainable yield records zero current depletion. The biomass deficit relative to BMSY is not a flow in the current period. It represents the cumulative effect of past over-harvesting. Readers familiar with SNA wealth accounting should note that no balance-sheet impairment entry is recorded for a recovering stock: the depletion flow is measured on catch, and the gap between current biomass and BMSY does not enter the calculation.

¶5 The SEEA CF notes that "depletion should therefore be recorded only when the extraction is beyond a normal level of natural growth (less natural losses)" [23].

¶6 Using the reference points defined in Section 3.1, the sustainable yield at current stock size equals MSY only when the stock is at BMSY. At other biomass levels, the current-biomass sustainable yield differs from MSY. For accounting purposes, compilers should calculate depletion using the sustainable yield corresponding to the current stock size, not MSY [24].

Recording catch and extraction

¶1 The SEEA CF recommends **gross catch** as the measure of extraction, noting that landings exclude "discards of organisms incidentally caught through harvesting activity (discarded catch) as well as the amount of the catch used for own consumption" [25]. For treatment of discards and residuals, see **TG-3.4 Flows from Economy to Environment**.

¶2 The FAO defines catch stages as follows [26]:

Stage	Definition
Gross removal	Total live weight of fish caught or killed during fishing operations.
Gross catch	Gross removal less pre-catch losses.
Retained catch	Gross catch less discarded catch.
Landings	Net weight of quantities landed at port.
Nominal catch	Live weight equivalent of landings.

¶3 For asset accounting, gross catch is preferred as it reflects the full impact on the fish stock. For monetary valuation, value typically derives from landings or retained catch.

¶4 Where subsistence catch represents more than approximately 10% of estimated total harvest, include it using household survey estimates, creel surveys, or regional benchmarks. If subsistence catch cannot be quantified, apply a quality flag per **TG-0.7 Quality Assurance** Section 3.6, document the omission in metadata, and note the likely direction of bias. This is consistent with SEEA AFF scope, which specifies that the physical asset account covers "subsistence and recreational harvesting" alongside commercial operations [7].

Monetary asset accounts

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¶1 For valuation methods, see **TG-2.4 Environmental (including Ecosystem) Goods and Services** Section 3.10. The SEEA CF provides two main valuation approaches [27]:

¶2 **1. Quota and licence valuation**: Where individual transferable quotas (ITQs) exist and are traded, "it is possible to estimate the value of the aquatic resources from the market prices of these entitlements" [28]. Where quotas cover only a portion of the stock, the ITQ-based value applies to the commercially quoted portion, and the unquoted portion should be estimated using the net present value of resource rent approach. Document the assumed quota coverage ratio as part of account metadata.

¶3 **2. Net present value of resource rent**: The operating surplus from harvesting is partitioned between user costs of produced assets (vessels, gear, equipment) and the resource rent attributable to the aquatic resource itself. The stock value is the NPV of expected future resource rents [29].

¶4 The 2025 SNA provides that "a total value of the fish stock can be calculated as the present value of the future resource rents estimated using the residual value method" where there is evidence of management [30]. Where "there is no effective management of the fish stock or an associated water body, then there is no legal owner and consequently no asset is recorded on the balance sheet" [31].

¶5 The recommended approach is to compile physical asset accounts for all commercially exploited stocks regardless of management status. Monetary asset accounts should follow 2025 SNA conventions for the core accounts (recording zero value for unmanaged stocks) but may include supplementary tables showing hypothetical resource rent values. See **TG-3.1 Asset Accounts** for the general treatment of asset boundary issues.

Catch per unit effort as a stock indicator

¶1 Where absolute stock estimates are unavailable, catch per unit effort (CPUE) may serve as a relative abundance indicator: "The ratio of catch per unit effort (CPUE) may provide a good indicator of the relative change in stock size, assuming that population density and population size are closely correlated" [32].

¶2 One limitation is **technological creep**: improvements in vessel technology and gear efficiency can cause fishing power to increase over time, so nominal CPUE can remain stable or rise even as the underlying stock declines [33]. Where technological creep is a concern, use **standardised CPUE** derived from generalised linear models (GLMs) or generalised additive models (GAMs) accounting for vessel characteristics, gear type, area, and temporal trends in catchability. Unstandardised nominal CPUE should not be used as a stock trend indicator without a quality flag per **TG-0.7 Quality Assurance** Section 3.6, specifying whether standardisation was applied and the likely direction of bias [34].

3.3 Compilation Procedure: From Assessment to Accounts

Step 1: Data assembly

¶1 Identify and assemble stock assessment outputs and catch statistics for the target species or stock complex:

- ¶2 **Stock assessment reports**: Obtain the most recent assessment from national fisheries agencies or international bodies. [35] Priority outputs: opening and closing biomass estimates (Bt, Bt+1), recruitment indices, natural and fishing mortality rates (M, F), and reference points (BMSY, FMSY, MSY).
- ¶3 **Catch statistics**: Collect reported landings from national agencies and international databases (FAO FishStatJ). Supplement with discard estimates from observer programmes where available.

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- ¶4 **Metadata documentation**: Record the assessment vintage, assessment method tier (data-rich, data-moderate, data-poor), primary data sources, and any caveats noted by the assessment scientists.

¶5 **Spatial apportionment of transboundary stocks.** For stocks assessed at RFMO or global scale, the recommended default is catch-based apportionment: the national share of total stock biomass is estimated as national reported catch divided by total assessed-area catch, applied to the total assessment biomass. Where fishery-independent survey data allow direct biomass estimation within the national EEZ, direct estimation is preferred. Document the apportionment method applied and note in metadata that the national account biomass represents an allocated share of a pooled assessment. Cross-country comparisons for transboundary stocks should acknowledge that countries using different apportionment methods will produce incompatible national totals [36].

Step 2: Unit standardisation

¶1 Standardise all values to a common unit:

- ¶2 **Mass units**: Convert to a consistent mass unit (e.g., tonnes) throughout the account.
- ¶3 **Number to mass**: Where assessments report abundance in numbers, apply mean weight-at-age to convert to biomass. Document conversion factors used.
- ¶4 **Wet weight to carbon**: For integration with ecosystem carbon accounts, apply species-specific wet weight to carbon conversion factors. For finfish, carbon content is typically 10–12% of wet weight [37]. Document the conversion factor applied. The 10–12% range reflects whole-body elemental analysis across multiple finfish species and can vary with condition, season, and body composition.

¶5 Fish biomass carbon is distinct from ecosystem carbon stocks held in seagrass meadows and mangrove forests, addressed in **TG-6.2 Mangrove and Coastal Wetland Accounting** and **TG-6.3 Seagrass Accounts**.

Step 3: Temporal alignment

¶1 Align stock assessment timing with the accounting period (typically calendar year):

- ¶2 **Opening stock**: Use biomass at 1 January of the accounting year (Bt). If the assessment provides mid-year or average biomass, extrapolate to 1 January using reported quarterly or monthly growth and mortality rates.
- ¶3 **Closing stock**: Use biomass at 31 December (Bt+1), or 1 January of the following year.
- ¶4 **Catch timing**: Sum reported catch over the accounting period by aggregating monthly or quarterly landing statistics to annual totals.

¶5 Where assessments use a different reference date, document the discrepancy and apply interpolation to align with the standard accounting period.

Step 4: Account entry calculation

¶1 **Opening stock**: Record Bt directly from the stock assessment as the opening biomass.

¶2 **Natural growth**: Calculate as recruitment plus somatic growth. Where the stock assessment provides age-structured population estimates, natural growth equals the sum of:

- ¶3 Recruitment (numbers at age-0 multiplied by mean weight-at-age-0)
- ¶4 Somatic growth (increase in weight of surviving individuals across all age classes)

¶5 Where only total biomass estimates are available, derive natural growth as a balancing item: Natural growth = Closing stock - Opening stock + Gross catch + Normal losses - Other additions + Other reductions. To avoid circular dependence between somatic growth and normal losses when both are residuals, solve for somatic growth first using survey-derived biomass change, then derive

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normal losses as the balancing item: Normal losses = Opening stock + Somatic growth - Gross catch - Closing stock.

¶6 **Gross catch**: Sum reported landings and estimated discards. Apply sector-specific discard rates where observer data are available. In particular, observer programmes typically cover large commercial vessels, whilst artisanal and small-scale fisheries frequently have lower discard rates. Applying a commercial observer discard rate to aggregate artisanal and commercial landings will overstate discards for mixed fisheries. Where discard data are unavailable, apply discard ratios from comparable fisheries for each sector separately, and document the estimation method and associated uncertainty.

¶7 **Normal losses**: Convert natural mortality rate (M) to absolute biomass loss. For age-structured models, apply M to each age class and sum. For biomass models, the Baranov-consistent derivation is:

¶8 Normal losses = (M / Z) × Opening biomass × (1 − e^(−Z))

¶9 where Z = F + M. For example, with F = 0.25, M = 0.18, Z = F + M = 0.43, and opening biomass of 42,000 t:

¶10 Normal losses = (0.18 / 0.43) × 42,000 × (1 − e^(−0.43)) = 0.419 × 42,000 × 0.349 ≈ 6,148 t

> ¶11 ⓘ **Why the simple M × average biomass approximation overstates normal losses**
> ¶12 A common approximation is M multiplied by average biomass (e.g., 0.18 × 40,250 = 7,245 t in the example above). This overstates natural mortality because it applies M to the full mid-year population without accounting for the simultaneous removal of individuals by fishing. In the Baranov model, natural and fishing mortality operate concurrently, so the population exposed to natural mortality at any point in time is smaller than the simple average suggests. The Baranov-derived formula corrects for this via the (M/Z) proportional allocation. Where M and F are not available separately, normal losses may be derived as a balancing item: Normal losses = Opening stock + Natural growth - Gross catch - Closing stock. Document which method was used.

¶13 **Sustainable yield**: Use the MSY estimate if the stock is at BMSY. If the stock is below or above BMSY, use the sustainable yield corresponding to current biomass. Stock assessments typically provide sustainable yield curves or tables as a function of stock size. Extract the value corresponding to current biomass. Where not explicitly provided, approximate from the surplus production function using the formula appropriate to the model form (Schaefer, Fox, or other)[24].

¶14 **Depletion**: Apply the depletion formula (Section 3.2).

¶15 **Closing stock**: Record Bt+1 from the stock assessment. Verify the accounting identity: Closing stock = Opening stock + Natural growth - Gross catch - Normal losses ± Other changes. Any discrepancy indicates unrecorded flows or assessment inconsistency and should be recorded as a reappraisal.

Step 5: Reappraisal treatment

¶1 When a new stock assessment revises historical biomass estimates:

- ¶2 **Retrospective revision**: Calculate the difference between the current assessment's estimate of opening stock and the previous assessment's estimate of the same point in time. Record this difference as a reappraisal.
- ¶3 **Metadata**: Document the assessment vintage for each entry, so users can distinguish "as-assessed" from "current-estimate" time series.

¶4 For example, if the 2025 assessment estimates 2024 opening stock at 50,000 tonnes but the 2024 assessment estimated it at 48,000 tonnes, record a +2,000 tonne upward reappraisal in the 2025 account.

Step 6: Quality assurance

¶1 Follow **TG-0.7 Quality Assurance**:

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- ¶2 **Accounting identity verification**: Confirm opening stock plus additions minus reductions equals closing stock.
- ¶3 **Consistency with catch data**: Compare assessment-predicted catch (derived from F and biomass via the Baranov equation) with reported catch. Large discrepancies may indicate unreported fishing or assessment misspecification.
- ¶4 **Trend plausibility**: Review biomass and depletion trends for plausibility. Sudden changes should correspond to documented events.
- ¶5 **Uncertainty documentation**: For data-moderate and data-poor assessments, document uncertainty magnitude and apply quality flags.

Step 7: Integration with broader accounts

- ¶1 **Link to TG-3.1 Asset Accounts**: Ensure consistency with monetary valuation methods and reappraisal treatment.
- ¶2 **Link to TG-3.2 Flows from Environment to Economy**: Record gross catch as a natural resource input.
- ¶3 **Link to TG-1.5 Fisheries Management**: Use depletion estimates and sustainability classifications to inform TAC decisions.
- ¶4 **Link to TG-2.2 Productivity Indicators**: Derive resource productivity and depletion intensity indicators from the asset account.

Which account entries each data tier supports

¶1 The table below maps each assessment tier to the physical asset account entries it can support, and is the operative rule for which cells a compiler may populate at a given data tier. Entries marked "proxy" require an indicative estimate rather than a model-based value. Entries marked "omit (document)" should be left blank with an explanatory metadata note.

¶2 *Table 3.3.1: Tier-to-account-entry mapping for physical asset accounts*

Account Entry	Tier 1 (CPUE index)	Tier 2 (Surplus production)	Tier 3 (Age-structured)
Opening stock (absolute tonnes)	Omit (document)	Computable	Computable
Natural growth	Proxy (CPUE trend)	Computable	Computable
Gross catch/harvest	Computable	Computable	Computable
Normal losses (natural mortality)	Omit (document)	Proxy	Computable
Uncompensated seizure (IUU)	Proxy	Proxy	Proxy
Closing stock (absolute tonnes)	Omit (document)	Computable	Computable
Sustainable yield	Omit (document)	Computable	Computable
B/B_MSY ratio	Qualitative only	Computable	Computable
Depletion (tonnes)	Qualitative signal only	Computable	Computable

¶3 At Tier 1, accounts can still support directional judgements (improving/stable/declining) useful for flagging potential sustainability concerns, even without absolute biomass estimates.

¶4 The management consequence — that a quota set at the lowest tier carries a wider error band than a single number implies — is set out in **TG-1.5 OA and Fisheries Management** Section 3.4.1.

3.4 Worked Example: Demersal Fish Stock Asset Account

Scenario description

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¶1 The accounting area is a coastal zone supporting a demersal fish stock harvested by commercial and artisanal fisheries. A data-rich stock assessment using age-structured analysis provides annual estimates of total biomass, spawning stock biomass, recruitment, natural mortality, and fishing mortality, as well as BMSY and MSY estimates. The accounting period is calendar year 2025. Commercial landings: 5,000 tonnes. Artisanal landings: 1,800 tonnes. Total landings: 6,800 tonnes.

Stock assessment outputs (2025 assessment)

Parameter	Value	Unit
Opening stock (1 Jan 2025)	42,000	tonnes
Spawning stock biomass (SSB)	28,000	tonnes
Recruitment (age-0 fish, 1 Jan)	120 million	individuals
Mean weight at recruitment	0.05	kg/individual
Natural mortality rate (M)	0.18	per year
Fishing mortality rate (F)	0.25	per year
Total mortality (Z = F + M)	0.43	per year
BMSY	38,000	tonnes
MSY	6,500	tonnes/year
Sustainable yield at current B	6,200	tonnes/year
Closing stock (31 Dec 2025)	38,500	tonnes

¶1 Note: Z = F + M = 0.25 + 0.18 = 0.43, which confirms internal consistency.

Catch statistics (2025)

¶1 Observer data from commercial vessels indicate an 8% discard rate by weight for the commercial sector: 5,000 × 8% = 400 tonnes of commercial discards. Artisanal discards are assumed negligible based on local fleet characteristics.[38] Gross catch = 6,800 + 400 = 7,200 tonnes.

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Compilation step-by-step

¶1 **Step 1:** Stock assessment and catch statistics assembled as above. Metadata: 2025 assessment conducted March 2026 using data through December 2025, age-structured model, data tier = data-rich.

¶2 **Step 2:** All values already in tonnes (wet weight). No conversion required.

¶3 **Step 3:** Assessment provides 1 January opening stock and 31 December closing stock, matching the calendar year. No adjustment required.

¶4 **Step 4: Account entry calculation**:

- ¶5
  Opening stock: 42,000 tonnes
- ¶6
  Gross catch: 7,200 tonnes (commercial landings 5,000 + artisanal landings 1,800 + commercial discards 400)
- ¶7
  Normal losses: Using the Baranov-consistent formula with F = 0.25, M = 0.18, Z = 0.43, opening biomass = 42,000 t:
  Normal losses = (0.18 / 0.43) × 42,000 × (1 − e^(−0.43)) = 0.4186 × 42,000 × 0.3495 ≈ 6,148 t
  The accounts table uses the **balancing-item value of 4,244 tonnes**, derived from the accounting identity: Normal losses = Opening stock + Natural growth − Gross catch − Closing stock = 42,000 + 7,944 − 7,200 − 38,500 = 4,244 tonnes. The balancing-item value is internally consistent with the assessment-provided opening and closing stocks.

The 1,904 t difference between the Baranov-formula estimate (6,148 t) and the balancing-item value (4,244 t) reflects a genuine biological divergence: the Baranov formula applies instantaneous mortality rates to opening biomass without accounting for the growth offset during the year, whilst the balancing item captures net mortality after somatic growth. New recruits (6,000 t) join the stock partway through the year and are not exposed to natural mortality for the full period. Use the balancing-item value for the accounts table. Present the Baranov estimate in a footnote as a biological cross-check. Document which method was used.

- ¶8
  Recruitment biomass: 120 million individuals × 0.05 kg/individual = 6,000 tonnes
- ¶9
  Somatic growth (balancing item): 38,500 - 42,000 + 7,200 + 4,244 - 6,000 = 1,944 tonnes
- ¶10
  Total natural growth: 6,000 + 1,944 = 7,944 tonnes
- ¶11
  Sustainable yield: 6,200 tonnes (at current spawning stock biomass of 28,000 t, below BMSY of 38,000 t, surplus production is below its maximum, so sustainable yield is below MSY of 6,500 t, see Section 3.2)
- ¶12
  Depletion: 7,200 - 6,200 = 1,000 tonnes

¶13 **Step 5: Verify accounting identity**: Closing = Opening + Natural growth - Gross catch - Normal losses 38,500 = 42,000 + 7,944 - 7,200 - 4,244 38,500 = 38,500 ✓

¶14 **Physical asset account table**:

¶15 *Table 3.4.1: Physical asset account for coastal demersal fish stock, 2025*

Accounting Entry	Value (tonnes)
Opening stock (1 Jan 2025)	42,000
Additions to stock	
Natural growth (recruitment + growth)	7,944
Upward reappraisals	0
Total additions	7,944
Reductions in stock	
Gross catch (landings + commercial discards)	7,200
Normal losses (natural mortality)	4,244
Catastrophic losses	0
Downward reappraisals	0
Total reductions	11,444
Closing stock (31 Dec 2025)	38,500
Metadata	
Assessment vintage (opening stock)	2025 assessment (March 2026)[39]
Derived measures	
Sustainable yield (at current B)	6,200
Depletion (catch - sustainable yield)	1,000
B/BMSY ratio (condition indicator, Table 3.1.1)	1.11
SSB/BMSY ratio (depletion assessment, Table 3.1.1)	0.74
Sustainability classification (SDG 14.4.1)	Unsustainable (overfished)

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¶16 **Interpretation**: The stock declined from 42,000 to 38,500 tonnes during 2025 (8.3% reduction). Gross catch (7,200 t) exceeded sustainable yield by 1,000 tonnes, indicating depletion. Spawning stock biomass is below BMSY (SSB/BMSY = 0.74, the measure Table 3.1.1 prescribes), so the stock is classified as overfished (unsustainable) under SDG 14.4.1, and continued overharvesting at this rate would drive it further below the sustainability threshold. The sustainable yield at current biomass (6,200 t) is below MSY (6,500 t) because the spawning stock is below BMSY (see Table 3.7.1, lower-right cell). A reduction in the TAC is therefore indicated.

¶17 ⓘ **Corrected 24 September 2026**

¶18 This example previously classified the stock as sustainable on total biomass (B/BMSY = 1.11); Table 3.1.1 prescribes spawning stock biomass for the assessment against BMSY, on which the ratio is 0.74, so the stock is now classified as overfished.

3.5 Multi-Species and Ecosystem Considerations

¶1 For ecosystem accounting approaches, see **TG-2.1 Biophysical Indicators** and **TG-3.1 Asset Accounts** Section 3.5 (Ecosystem Assets).

Multi-species fisheries

¶1 Many fisheries harvest multiple species simultaneously, which complicates catch allocation, aggregate stock indices, and bycatch treatment. The SEEA CF notes that "commonly, particularly in tropical areas, multiple species may be harvested at one time" [40]. For mixed-species fisheries, aggregate biomass indicators may be more practical than species-specific accounts: "accessing relevant indicators and models of the overall stock size consisting of multiple species that supports this harvest may be the most appropriate measurement approach" [41].

¶2 Bycatch discarded dead represents fishing-induced mortality that affects the stock but does not enter economic activity. Record discarded bycatch as part of gross catch (consistent with the SEEA CF definition) with a corresponding discard entry. Recording discarded bycatch in this way captures the full impact of fishing on the stock and keeps the treatment coherent with **TG-3.4 Flows from Economy to Environment**.

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Trophic interactions

¶1 Natural mortality rates implicitly incorporate predation. If fishing pressure on one species substantially alters predation mortality on another, this represents an indirect fishing impact that standard single-species accounts do not capture. The SEEA AFF refers to the **mean trophic index** as an indicator that may be used to understand the state of marine environments [42]. Declining mean trophic level in catches (fishing down the food web) can indicate ecosystem-level impacts.

Ecosystem-based approaches

¶1 Ecosystem-based fisheries management [43], [44] links fisheries asset accounts to broader ecosystem asset accounts. The SEEA AFF notes that "another approach is to consider indicators of the condition of marine and inland water ecosystems with a view to understanding the state of fish and other aquatic resources" [45]. Relevant ecosystem condition indicators include Ocean Health Index, mean trophic level, marine biodiversity indices, and habitat extent and condition (see **TG-2.1 Biophysical Indicators**).

¶2 A conceptual issue arises from the relationship between fish stocks as individual environmental assets and the marine ecosystems within which they exist. Under SEEA CF, fish stocks are recorded as individual environmental assets in physical asset accounts. Under SEEA EA, fish are components of marine ecosystem assets, and harvested fish represent provisioning services flowing from the ecosystem to the economy. Aggregating both individual asset values and ecosystem asset values creates a double-counting risk. The SEEA EA addresses this through the provisioning service

framework: fish are treated as an output (service flow) of the ecosystem asset rather than a component of its stock value [46].

¶3 **Procedural rule for compilers compiling both sets of accounts.** When both SEEA CF fish stock asset accounts and SEEA EA marine ecosystem accounts are compiled for the same spatial unit, the fish provisioning service value (annual flow) from the SEEA EA should be used in ecosystem wealth aggregates. The SEEA CF individual asset NPV should be compiled separately, clearly labelled as the stand-alone fisheries asset value, and excluded from total ecosystem asset values to avoid double-counting. Cross-reference this treatment in the metadata of both accounts. Ensure consistency with the treatment of ecosystem assets in **TG-6.1 Coral Reef Accounts**, **TG-6.2 Mangrove and Coastal Wetland Accounting**, and **TG-6.3 Seagrass Accounts**.

Carrying capacity and environmental limits

¶1 Fish stock productivity depends on environmental conditions and habitat availability. The SEEA AFF notes that "measures of water quality, for example, that take into account eutrophication, are likely to be important in understanding the sustainability of fisheries activities" [47]. Climate change is altering the environmental parameters that govern the potential productivity of marine areas and the distribution of fish stocks. Asset accounts should be interpreted in the context of changing environmental baselines.

3.6 Uncertainty Propagation and Quality Assurance

¶1 Stock assessment outputs carry substantial uncertainty from observation error, process error in biological parameters, model structural uncertainty, and parameter estimation uncertainty. For accounting purposes, uncertainty can be addressed through [48]:

- ¶2 **Central estimates**: Use point estimates (e.g., median biomass) for main accounts.
- ¶3 **Supplementary uncertainty ranges**: Report confidence intervals alongside point estimates.
- ¶4 **Sensitivity analysis**: Test how accounting entries change under alternative stock assessment scenarios.
- ¶5 **Quality indicators**: Flag entries derived from data-poor assessments.

¶6 The SEEA AFF acknowledges that "estimates of the absolute size of stocks can be imprecise" [49].

¶7 For species or areas without formal stock assessments, alternative approaches include:

- ¶8 extrapolation from assessed proxy species
- ¶9 indicator-based assessment using length-frequency or catch trends
- ¶10 catch-only production models
- ¶11 structured expert judgement on stock status categories

¶12 The SEEA CF notes that for multi-species tropical fisheries, aggregate stock indicators "may be the most appropriate measurement approach" [50].

3.7 Sustainability Status and Depletion

¶1 **SDG 14.4.1 is derived in TG-2.10 Multilateral Environmental Agreement Indicators Section 3.4**, which owns the indicator definition, the FAO custodian methodology and the reporting route [51]. This Section supplies what TG-2.10 draws on: which account entry carries the stock status, and how status interacts with the depletion entry. The two are easily conflated, because a stock can be classified sustainable and still record depletion in the same period.

Relationship to asset accounts

Asset account metric	SDG 14.4.1 alignment
Opening/closing stock (B)	Compared to BMSY to determine sustainability status

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Asset account metric	SDG 14.4.1 alignment
Depletion	Recorded when B < BMSY and/or catch > sustainable yield
Stock trajectory	Indicates movement toward or away from BMSY

¶1 The management decision framework that reads off this relationship — which TAC response follows from each combination of stock status and catch — is set out in **TG-1.5 OA and Fisheries Management** Table 3.4.1 and is normative for the publication. Table 3.7.1 below records the same four combinations from the compiler's side, stating what is entered in the accounts rather than what the manager should do.

¶2 The relationship between stock status and depletion recording requires careful interpretation. A stock below BMSY but recovering (catch below sustainable yield at current stock size) records no current depletion. A stock at or above BMSY (classified as sustainable) can experience depletion if catch temporarily exceeds MSY. Table 3.7.1 summarises all four combinations.

¶3 *Table 3.7.1: Stock status and depletion interaction*

	Catch <= Sustainable Yield	Catch > Sustainable Yield
B >= BMSY (Sustainable)	No depletion; SDG sustainable	Depletion recorded; SDG sustainable but at risk
B < BMSY (Unsustainable)	No current depletion; stock recovering; SDG unsustainable	Depletion recorded; stock declining further; SDG unsustainable

¶4 Both SDG status (stock-based) and the depletion flow (catch-based) should be compiled and reported as complementary measures.

Using the status classification inside the accounts

¶1 The status classification compiled under TG-2.10 is useful back inside the asset account: it stratifies the account by sustainability status, weights aggregate biomass by category, and lets depletion be reported separately for overfished and sustainably fished stocks [52]. Compilers should take the classification from the same source that feeds national SDG reporting rather than deriving a parallel one, so that the account and the indicator cannot diverge.

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Overfished stock treatment

¶1 For overfished stocks (B < BMSY), asset accounts should record:

1. ¶2 **Depletion**: When catch exceeds the sustainable yield corresponding to current (depressed) stock size
2. ¶3 **Sustainability deficit**: The cumulative impact of past overexploitation, measured as the difference between current biomass and BMSY — recorded as supplementary information rather than as an asset account entry, since it represents unrealised potential rather than a flow or stock change within the accounting period
3. ¶4 **Recovery trajectory**: Tracking progress towards BMSY through successive accounting periods

> ¶5 ⚠ **Analytical construct — not an accounting liability**
> ¶6 **Potential recovery value is an analytical construct for policy illustration only.** It is not an SEEA account entry, does not represent a recognised environmental liability, and should not be aggregated with or compared to balance-sheet asset values. The SEEA framework explicitly declined to include contingent or potential asset values in core accounts. Supplementary tables presenting this figure must carry a prominent label: *"Analytical estimate — not part of SEEA accounts."* Citing potential recovery value as an accounting liability figure would misrepresent its methodological status and is inconsistent with SEEA CF asset boundary conventions [53].

¶7 Potential recovery value may be recorded in supplementary tables alongside the main accounts to illustrate the economic cost of past overexploitation. The SEEA CF notes that "a total permissi-

ble catch resulting in earnings that are higher than this level will mean that some of those earnings should be regarded as depletion of the aquatic resources and not as income" [54] .

Climate-adjusted reference points

¶1 Where BMSY or MSY reference points are revised to reflect changed environmental productivity, the change in opening stock value arising solely from the reference point revision should be recorded as a reappraisal in the asset account, not as depletion [55] . SDG 14.4.1 time-series comparisons should note any years in which reference point changes drove stock reclassifications independently of changes in actual fishing pressure [56] . Metadata for each accounting period should record the BMSY and MSY reference point values in use.

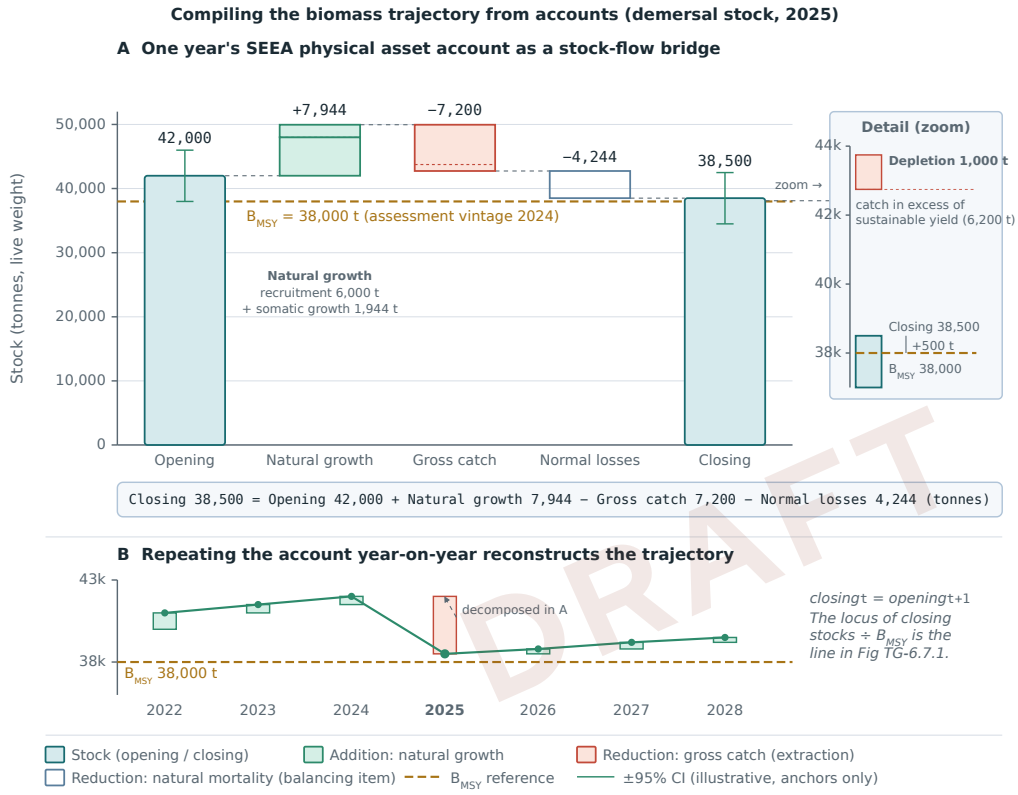


Figure 6.7.1 Two-panel bridge: Panel A compiles one year of the SEEA CF physical asset account; Panel B stacks years to reconstruct the biomass trajectory. Values are worked-example tonnes; depletion and normal losses are memorandum items.

Source: TG-6.7 Section 3.4 worked example (GOAP Technical Guidance, Section 6 -- Thematic Methods).

Adapted from: SEEA CF physical asset account structure (opening stock + additions − reductions = closing stock), Table 5.2 / paras 5.43--5.46; SEEA AFF physical asset account for aquatic resources; depletion per SEEA CF (gross catch less sustainable yield). Cf. Figure TG-3.1.1 (asset-account identity).

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

5. References

¶1 This Circular draws upon the following authoritative sources:

- ¶2 United Nations et al. (2014). *System of Environmental-Economic Accounting 2012: Central Framework*
- ¶3 United Nations et al. (2021). *System of Environmental-Economic Accounting—Ecosystem Accounting*
- ¶4 FAO (2020). *System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries (SEEA AFF)*
- ¶5 United Nations (2025). *System of National Accounts 2025*
- ¶6 FAO (2020). *The State of World Fisheries and Aquaculture (SOFIA)*
- ¶7 United Nations (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*

FOOTNOTES

1. ¶1 SDG Indicator 14.4.1, Proportion of fish stocks within biologically sustainable levels.
2. ¶2 FAO (2020), *The State of World Fisheries and Aquaculture*.
3. ¶3 SEEA AFF, para. 3.179.
4. ¶4 Hilborn, R. and Walters, C.J. (1992), *Quantitative Fisheries Stock Assessment*.
5. ¶5 SEEA Central Framework, para. 5.421.
6. ¶6 SEEA Central Framework, para. 5.421.
7. ¶7 SEEA AFF, para. 3.182.
8. ¶8 Haddon, M. (2011), *Modelling and Quantitative Methods in Fisheries*.
9. ¶9 SEEA Central Framework, para. 5.48(a) on growth in stock for biological resources; see also para. 5.82 on sustainable yield.
0. ¶10 Ricker, W.E. (1954), Stock and Recruitment, *Journal of the Fisheries Research Board of Canada*.
1. ¶11 Haddon, M. (2011), *Modelling and Quantitative Methods in Fisheries*, 2nd ed., Chapman and Hall/CRC. See also SEEA Central Framework, para. 5.437, for the accounting treatment of normal losses.
2. ¶12 SEEA Central Framework, para. 5.48(a) on growth in stock net of normal losses; see also para. 5.415 on natural mortality of aquatic resources.
3. ¶13 Schaefer, M.B. (1954), Some aspects of the dynamics of populations important to the management of commercial marine fisheries.
4. ¶14 SEEA Central Framework, para. 5.82.
5. ¶15 SDG Target 14.4.
6. ¶16 SDG Target 14.4.
7. ¶17 Carruthers, T.R. et al. (2014), Evaluating methods for setting catch limits in data-limited fisheries.
8. ¶18 SEEA AFF, para. 3.188.
9. ¶19 SEEA Central Framework, table 5.22.
0. ¶20 SEEA AFF, para. 3.186.
1. ¶21 Hypothetical illustration based on stock assessment trajectory patterns described in FAO (2020), *The State of World Fisheries and Aquaculture*.
2. ¶22 SEEA Central Framework, para. 5.431.
3. ¶23 SEEA Central Framework, para. 5.432.
4. ¶24 SEEA Central Framework, figure 5.2.
5. ¶25 SEEA Central Framework, para. 5.429.
6. ¶26 SEEA Central Framework, para. 5.428.
7. ¶27 SEEA Central Framework, para. 5.442.
8. ¶28 SEEA Central Framework, para. 5.448.
9. ¶29 SEEA Central Framework, para. 5.453.
0. ¶30 2025 SNA, para. 27.37.
1. ¶31 2025 SNA, para. 27.38.
2. ¶32 SEEA Central Framework, para. 5.425.
3. ¶33 SEEA AFF, para. 3.189.
4. ¶34 Maunder, M.N. and Punt, A.E. (2004), Standardizing catch and effort data: a review of recent approaches. *Fisheries Research*, 70(2-3), 141–159.
5. ¶35 For stocks managed by RFMOs (such as WCPFC, IOTC, or CCSBT), the RFMO stock assessment outputs provide the primary input. National compilers should coordinate with RFMO data teams to obtain stock-specific outputs apportioned to the national EEZ where relevant.
6. ¶36 FAO Fisheries Technical Paper y5438e, Conservation and management of shared fish stocks; SDG 14.4.1 indicator metadata, UN Statistics Division, unstats.un.org.

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7. ¶37 Czamanski, M., Nugraha, A., Pondaven, P., Lasbleiz, M., Masson, A., Caroff, N., Bellail, R. and Tréguer, P. (2011). Carbon, nitrogen and phosphorus elemental stoichiometry in aquacultured and wild-caught fish and consequences for pelagic nutrient dynamics. *Marine Biology*, 158(12), 2543–2556. https://doi.org/10.1007/s00227-011-1783-7 (https://doi.org/10.1007/s00227-011-1783-7)
8. ¶38 Quality flag: Artisanal discard rate assumed negligible. If artisanal discards are later quantified and found to be material, gross catch and depletion figures should be revised accordingly.
9. ¶39 Assessment vintage indicates the stock assessment used to derive the opening stock estimate. Non-zero reappraisal entries would arise if the 2025 assessment revised the estimate of the 1 January 2025 opening stock relative to the 2024 assessment. In this example the assessments agree, so reappraisals are zero. See Section 3.3 Step 5 for the reappraisal treatment.
0. ¶40 SEEA Central Framework, para. 5.426.
1. ¶41 SEEA Central Framework, para. 5.426.
2. ¶42 SEEA AFF, para. 3.190.
3. ¶43 FAO (2003), *Fisheries Management: The Ecosystem Approach to Fisheries*.
4. ¶44 Pikitch, E.K. et al. (2004), Ecosystem-Based Fishery Management.
5. ¶45 SEEA AFF, para. 3.190.
6. ¶46 SEEA EA, para. 5.19–5.22 (provisioning services and asset boundary).
7. ¶47 SEEA AFF, para. 4.108.
8. ¶48 ICES (2021), Guidelines for ICES advice on fishing opportunities.
9. ¶49 SEEA Central Framework, para. 5.424.
0. ¶50 SEEA Central Framework, para. 5.426.
1. ¶51 SDG Indicator 14.4.1.
2. ¶52 FAO (2020), *The State of World Fisheries and Aquaculture*, Methodology.
3. ¶53 SEEA Central Framework, para. 5.411–5.412 (asset boundary); SEEA EA, Chapter 5 (scope of ecosystem asset values).
4. ¶54 SEEA Central Framework, para. 5.452.
5. ¶55 SEEA Central Framework, para. 5.432 (reappraisals for improved information).
6. ¶56 IPBES (2019), *Global Assessment Report on Biodiversity and Ecosystem Services*, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

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Aquaculture Thematic Methods

Provides the site-level operational layer for aquaculture accounting, extending the physical asset account foundations established in TG-3.9.

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

Upon implementation, practitioners will be able to:

- Classify aquaculture systems according to their operational characteristics, species composition, and environmental setting, using ISIC and ISSCFC frameworks adapted for ocean accounting
- Compile site-level asset accounts tracking cultivated biological resources, production cycles, and stock changes, consistent with TG-3.1 Asset Accounts
- Quantify environmental interactions including nutrient loading, habitat modification, and genetic impacts on wild populations, complementing TG-3.4 Flows from Economy to Environment
- Account for feed and resource dependencies linking aquaculture production to wild fish stocks and terrestrial inputs, extending TG-3.9 Aquaculture Accounts
- Record disease-related losses and biosecurity costs as components of the aquaculture production account, with catastrophic losses treated consistently with SEEA AFF guidance
- Derive policy-relevant indicators for carrying capacity assessment, feed conversion efficiency monitoring, and environmental footprint analysis

Aquaculture thematic methods connect to economy-wide measurement through TG-2.5 Structure and Function of the Ocean Economy, pollution accounting through TG-2.7 Pollution and Other Flows to Environment, and social dependencies through TG-2.3 Social and Livelihood Dependencies on Ocean Ecosystems. Wild-capture methods are in TG-6.7 Fisheries Accounting: Integrating Stock Assessment.

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¶1 **Framework Position**

¶2 TG-6.8 sits within Section 6 (Thematic Methods) and provides the site-level operational layer for aquaculture accounting, extending the physical asset account foundations established in TG-3.9. It connects to the environmental flow accounts in TG-3.4, the ocean economy structure in TG-2.5, and the fisheries accounting methods in TG-6.7 to form a coherent thematic sub-system for aquatic food production.

1. Outcome

¶1 Upon implementation, practitioners will be able to:

- ¶2 **Classify aquaculture systems** according to their operational characteristics, species composition, and environmental setting, using ISIC and ISSCFC frameworks adapted for ocean accounting [1]
- ¶3 **Compile site-level asset accounts** tracking cultivated biological resources, production cycles, and stock changes, consistent with **TG-3.1 Asset Accounts** [2]
- ¶4 **Quantify environmental interactions** including nutrient loading, habitat modification, and genetic impacts on wild populations, complementing **TG-3.4 Flows from Economy to Environment** [3]
- ¶5 **Account for feed and resource dependencies** linking aquaculture production to wild fish stocks and terrestrial inputs, extending **TG-3.9 Aquaculture Accounts** [4]
- ¶6 **Record disease-related losses and biosecurity costs** as components of the aquaculture production account, with catastrophic losses treated consistently with SEEA AFF guidance [5]
- ¶7 **Derive policy-relevant indicators** for carrying capacity assessment, feed conversion efficiency monitoring, and environmental footprint analysis [6]

¶8 Aquaculture thematic methods connect to economy-wide measurement through **TG-2.5 Structure and Function of the Ocean Economy**, pollution accounting through **TG-2.7 Pollution and Other Flows to Environment**, and social dependencies through **TG-2.3 Social and Livelihood Dependencies on Ocean Ecosystems**. Wild-capture methods are in **TG-6.7 Fisheries Accounting: Integrating Stock Assessment**. [7]

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2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-4.3 Administrative Data Sources** — aquaculture licensing, site consent and production returns are the primary source for the site-level accounts in Section 3.2.
- ¶3 **TG-0.1 General Introduction to Ocean Accounts** — for environmental-economic accounting principles, asset boundaries, and production concepts.
- ¶4 **TG-3.9 Aquaculture Accounts** — for foundational physical asset account methods, including the cultivated versus non-cultivated biological resource distinction.

2.1 Data Requirements

Data source	Description
Aquaculture production statistics	Harvest quantities by species, production system, and site location, typically available from national fisheries agencies and FAO global aquaculture databases [8] .
Licence and site registration data	Permitted sites, lease areas, and production capacity limits, essential for carrying capacity analysis and spatial integration with ecosystem extent accounts [9] .

Data source	Description
Environmental monitoring data	Water quality parameters, nutrient concentrations, and benthic condition assessments, from regulatory agencies, industry reporting, or dedicated surveys [10] .
Feed and input records	Feed quantities, composition, and source materials; typically maintained by producers but may require survey collection for statistical purposes [11] .
Mortality and escape records	Stock losses from disease, escapes, and other causes; often required under regulatory frameworks though data quality varies across jurisdictions [12] .

2.2 Statistical Classifications

¶1 Aquaculture activities are classified according to:

- ¶2 **ISIC Division 03**: Specifically Group 032 (Aquaculture) with classes 0321 (Marine aquaculture) and 0322 (Freshwater aquaculture) [13]
- ¶3 **SEEA CF land use and water area categories**: Land used for aquaculture (1.3), including hatcheries (1.3.1) and managed grow-out sites (1.3.2), plus water area categories for inland and coastal waters [14]

¶4 Offshore aquaculture in EEZ waters has no discrete numeric sub-category in SEEA CF 2012 Annex I. Where offshore EEZ aquaculture is present, compilers should use the closest applicable coastal water area category and document the extension in supplementary tables, following the national extension guidance in **TG-0.1**. [15]

¶5 Marine spatial use classifications for aquaculture sites should be consistent with those applied in **TG-2.3** and the ecosystem extent accounting framework.

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3. Guidance Material

3.1 Aquaculture Systems Classification

¶1 The FAO defines aquaculture as:

> *"The farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants. Farming implies some form of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated."* [16]

¶2 This definition establishes the production boundary determining whether output is recorded as aquaculture or capture fisheries production. It is adopted in SEEA CF para. 5.409 and applied in **TG-3.9**. [17]

3.1.1 Marine Cage Systems

¶1 Marine cage aquaculture involves net-pen structures moored in coastal or offshore waters, typically for finfish such as salmon, sea bass, and cobia.

Characteristic	Description
Site boundaries	Defined by lease area coordinates; recorded under the applicable SEEA CF coastal water area category (see Section 2.2) [18] .

Characteristic	Description
Asset classification	Farmed fish are produced assets — inventories or fixed assets (broodstock) — per SEEA CF para. 5.441 [19] .
Environmental exposure	Open exchange with surrounding waters means nutrient and disease interactions extend beyond site boundaries; coordinate with **TG-3.4** [20] .

¶2 **BSU assignment for offshore aquaculture:** For fixed installations, the BSU should be determined by the centroid of the lease area polygon. For floating installations, by the lease area boundary. Where a lease area straddles two or more BSU boundaries, allocate production to the BSU containing the majority of the stocking area. See **TG-0.1** and **TG-1.2 Marine Spatial Planning** for BSU framework specifications. [21]

3.1.2 Coastal Pond Systems

¶1 Pond-based aquaculture uses constructed enclosures on land or in intertidal areas, commonly for shrimp, tilapia, and milkfish.

Feature	Description
Land area recording	Pond area classified under SEEA CF 1.3.2 (managed grow-out sites on land), enabling integration with terrestrial land use accounts [22] .
Water management	Controlled water exchange enables nutrient budgeting and site-level mass balance calculations [23] .
Production intensity	Semi-intensive to intensive systems require accounting for feed inputs and aeration costs; intensity affects environmental loading rates per unit production [24] .

3.1.3 Integrated Multi-Trophic Aquaculture

¶1 Integrated multi-trophic aquaculture (IMTA) co-cultures species at different trophic levels, where waste from fed species (e.g., finfish) provides nutrients for extractive species (e.g., seaweed, shellfish). Accounting considerations:

- ¶2 **Nutrient cycling**: Internal recycling reduces net environmental loading. Accounts should distinguish gross and net nutrient flows. Whether net loading is negative depends on site-specific mass balance data and should be verified empirically before recording negative residual flows. Where negative residual flows are recorded, apply the separate recording treatment in **TG-3.4**. [25]
- ¶3 **Multiple outputs**: Production accounts record outputs from each component species with appropriate allocation of shared inputs, following standard SNA treatment of joint production [26]

3.1.4 Production Boundary: Aquaculture versus Sea Ranching

¶1 Sea ranching, stock enhancement, and restocking programmes release juveniles into open water without continued ownership or active management. These programmes present a production boundary challenge distinct from the general aquaculture-versus-fisheries distinction.

¶2 The boundary should be determined by two sequential criteria:

1. ¶3 **Ownership after release**: Does the releasing entity retain individual ownership of the stock after it enters open water? Where ownership is held collectively (by a recognised producer association, statutory enhancement body, or public authority), criterion 1 is satisfied provided that (a) the collective holds legally enforceable harvest access rights and (b) maintains records of release quantities and harvest returns. Where neither individual nor collective enforceable

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ownership exists, the released stock is classified as a natural resource and excluded from cultivated asset accounts. [27]

2. ¶4 **Active grow-out intervention**: Does the entity undertake regular feeding, protection, health monitoring, or other active interventions during grow-out? If yes (and criterion 1 is also satisfied), the stock may be classified as a cultivated biological resource. If no, as is typical of open-water sea ranching, the stock is classified as a natural resource, regardless of ownership criterion 1.

¶5 Output released to open water without retained ownership should be classified as natural stock and excluded from cultivated asset accounts. A notation should be made in escape and release records (Section 3.2.4) indicating species, quantities, and intended enhancement purpose. This classification is consistent with SEEA AFF paras. 3.179–3.181 and FAO Technical Guidelines for Responsible Fisheries No. 5, Supplement 4 (2010). [27]

3.1.5 Species Coverage

¶1 *Table 3.1: Aquaculture species groups and key accounting considerations*

Species Group	Typical Systems	Key Accounting Considerations
Marine finfish	Cages, ponds	Feed-dependent; high nutrient loading
Crustaceans	Ponds, tanks	Disease vulnerability; habitat conversion
Molluscs	Rafts, longlines, on-bottom	Filter-feeding; minimal inputs
Seaweed	Rafts, ropes	Nutrient extraction; carbon sequestration
Other species	Various	Species-specific parameters required

3.2 Site-Level Accounting

3.2.1 Carrying Capacity Assessment

¶1 **Carrying capacity** represents the maximum production intensity that can be sustained without unacceptable environmental degradation. Four dimensions are assessed [28]:

Dimension	Description
Physical carrying capacity	Maximum stocking density based on water exchange, oxygen availability, and waste assimilation.
Production carrying capacity	Maximum yield achievable given infrastructure and resource constraints.
Ecological carrying capacity	Maximum production compatible with maintenance of ecosystem condition indicators.
Social carrying capacity	Maximum production acceptable to other users and stakeholders.

¶2 Physical, production, and ecological dimensions can be expressed in measurable physical units and recorded as supplementary physical data in the asset account. Social carrying capacity reflects stakeholder preferences and is not a standard SEEA account variable. Record it as a supplementary social indicator consistent with **TG-2.3**. [29]

¶3 The asset account for aquaculture sites should record carrying capacity estimates as context for stock and production data. The ecological dimension connects to condition accounting in **TG-2.3**, and residual flows should be recorded consistently with **TG-3.4**.

3.2.2 Production Cycle Accounting

¶1 Aquaculture production cycles vary by species and system, from several months (shrimp) to multiple years (salmon). The physical flow account should record: [30]

¶2 *Table 3.2: Aquaculture physical flow account structure*

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Flow Category	Description	Measurement
Opening stock	Biomass at period start	Tonnes live weight
Stocking (seed inputs)	Juveniles or seed transferred in	Numbers and biomass
Natural growth	Biological growth of stock	Tonnes gained
Harvest	Removal for sale	Tonnes live weight
Mortality	Normal and catastrophic losses	Tonnes and numbers
Escapes	Stock lost to environment	Numbers and biomass
Closing stock	Biomass at period end	Tonnes live weight

¶3 Output is measured in live weight equivalent consistent with FAO aquaculture production statistics. [31]

3.2.3 Mortality and Catastrophic Loss Recording

Mortality type	Description
Normal mortality	Predictable losses based on species and system characteristics; recorded as reductions in stock.
Disease outbreaks	Unexpected losses from pathogen events; recorded as catastrophic losses if exceeding normal thresholds (e.g., mortality exceeding two standard deviations above the historical average for the species and system type).
Environmental events	Losses from storms, harmful algal blooms, or temperature extremes; recorded as catastrophic losses.
Predation	Losses to predators (seals, birds); recorded under normal mortality or other reductions.

¶1 The SEEA AFF notes that "unexpected large losses from disease or natural disasters should be recorded as catastrophic losses" (para. 3.185). [32]

¶2 **Statistical parameters for the catastrophic loss threshold:**

1. ¶3 **Reference period**: Calculate historical average and standard deviation using a minimum of five accounting years of site-level mortality data. For sites with fewer than five years of records, use the full period of operation.
2. ¶4 **Reference population**: Use site-specific records where sufficient data are available. Where site-level records are insufficient (fewer than three years), apply a national species-and-system-type average.
3. ¶5 **New sites**: Apply the national species-and-system-type average threshold until a site-specific record is established. Where no national average is available, apply a documented expert judgement threshold and note this in account metadata.

¶6 For a production series with mean μ and standard deviation σ, the threshold is μ + 2σ (example: mean mortality 4.4%, σ = 0.49 pp, threshold = 5.38%, so observed mortality of 7.2% would be classified as catastrophic). Document the threshold derivation method following **TG-0.7 Quality Assurance**. [33]

3.2.4 Escape Recording

¶1 Escapes from aquaculture facilities require reclassification from cultivated to natural stocks. The SEEA AFF acknowledges this complexity:

> *"Challenges may arise when recording reclassifications of cultivated and natural fish stocks, for example when wild fish are introduced as breeding stock or when cultured seeds are released*

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> *into the wild; escapes by fish from aquaculture facilities in river and marine environments can also occur."*[34]

¶2 Escapes should be recorded as reductions in cultivated stock with corresponding entries in wild population accounts where these are maintained. For consistency with **TG-3.1 Asset Accounts** and **TG-6.7 Fisheries Accounting**, the record of each escape event should include species, estimated numbers and biomass, and whether the species is native to the receiving environment. Where escaped species are not subject to commercial fisheries, the wild stock account entry may be recorded as a supplementary table. [35]

3.3 Environmental Interactions

¶1 *Table 3.3: Aquaculture environmental interaction matrix*

Environmental Interaction	Direction	Account Recording	Measurement
Water abstraction	Input from environment	Natural input flow	m^3
Feed use (fish meal)	Input from economy	Intermediate consumption	tonnes
Fish/shellfish output	Output to economy	Production output	tonnes
Nutrient discharge	Output to environment	Residual flow	tonnes N, P
Escapees	Output to environment	Reclassification (to wild)	individuals
Sediment impact	Impact on condition	Condition account	benthic index

3.3.1 Nutrient Loading

¶1 Fed aquaculture systems release nutrients through uneaten feed, faeces, and metabolic excretion. Nutrient loading accounts should record: [36]

¶2 **Boundary with TG-6.13.** Catchment-derived nutrient loads reaching coastal waters are accounted for in **TG-6.13 Freshwater-Marine Interaction Accounting** Section 3.2. The two accounts partition on the **point of discharge**, not on the industry: a marine cage or other system discharging directly to coastal or marine waters is recorded here, and a land-based pond or hatchery discharging to a river or to sewer is a catchment source recorded under TG-6.13 and excluded from this account. Compilers running both accounts should record which convention each site falls under, so that a site converting from pond to cage production moves between accounts once rather than appearing in both.

¶3 *Table 3.4: Nutrient mass balance components for aquaculture*

Nutrient Flow	Source	Measurement
Nitrogen inputs	Feed, fertilizer	kg N per tonne production
Phosphorus inputs	Feed, fertilizer	kg P per tonne production
Nitrogen retained	Harvested biomass	kg N in product
Phosphorus retained	Harvested biomass	kg P in product
Net N discharge	Inputs minus retention	kg N released
Net P discharge	Inputs minus retention	kg P released

¶4 The SEEA AFF provides guidance on nutrient budgets: "The basis for measuring nutrient budgets is tracking the nitrogen and phosphorous [sic] cycles… Through consistent measurement of each part of those cycles, an overall indication of change can be obtained along with measures of surpluses or deficits of nitrogen and phosphorus" (para. 4.79). [37]

¶5 Aquaculture nutrient discharges should be recorded as emissions to water using the residual flow methods in **TG-3.4 Flows from Economy to Environment**.

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3.3.2 Habitat Modification

¶1 Aquaculture development can modify marine and coastal habitats through four pathways:

Pathway	Description
Direct conversion	Mangrove clearing for pond construction; seabed modification for on-bottom culture.
Shading effects	Light reduction beneath cage and raft structures affecting benthic communities.
Organic enrichment	Sediment accumulation beneath cage sites altering benthic fauna composition.
Structural provision	Cage structures and shellfish lines providing habitat for associated species.

¶2 Conversions of natural habitats (e.g., mangrove forest, seagrass beds) to aquaculture use should be recorded as land use change, consistent with SEEA EA extent accounting principles. Benthic condition beneath cage sites provides an indicator for the ecological carrying capacity dimension (Section 3.2.1).[38]

3.3.3 Genetic Impacts

¶1 Escaped farmed fish may interbreed with wild populations, potentially affecting genetic diversity and local adaptation.[39] Whilst quantitative genetic accounting methods remain under development, the following information supports qualitative assessment of genetic interaction risks.

Information element	Description
Escape volumes	Numbers and biomass of escaped stock by species, as recorded in Section 3.2.4.
Species overlap	Whether farmed species are native or non-native to the receiving region.
Breeding potential	Whether escapes are reproductively mature or sterile (e.g., triploid stock).

¶2 **Minimum genetic impact recording standard:** For each accounting period where escape events are recorded, compile the following supplementary table and cross-reference it from condition accounts. Cross-reference also from **TG-3.1 Asset Accounts** where condition account linkages are maintained.

¶3 *Table 3.5: Supplementary genetic impact recording template*

Species	Native / Non-native to receiving area	Number of escape events in period	Total estimated escaped biomass (kg)	Proportion with reproductive maturity	Monitoring outcome (interbreeding observed / not observed / not monitored)
[e.g., Atlantic salmon]	[Native / Non-native]	[N]	[kg]	[% or Unknown]	[Observed / Not observed / Not monitored]

3.4 Feed and Resource Use

3.4.1 Fishmeal and Fish Oil Dependency

¶1 Marine ingredients in aquafeed create linkages between aquaculture production and wild fish stocks. The SEEA AFF notes:

> *"Fish products... in granule or pellet form... provide nutrition in a stable and concentrated form... Many of the intensively farmed fish are carnivorous, including, among others, Atlantic salmon, trout, sea bass and turbot. In line with the emergence of modern aquaculture in the 1970s, fish meal and fish oil have become major components of feed for those species."*[40]

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¶2 *Table 3.6: Feed component recording for aquaculture accounts*

Feed Component	Source	Measurement
Fishmeal quantity	Reduction fisheries, processing by-products	Tonnes
Fish oil quantity	Reduction fisheries, processing by-products	Tonnes
Vegetable protein	Soy, other crops	Tonnes
Other ingredients	Various sources	Tonnes
Total feed use	All sources	Tonnes per tonne production

¶3 Feed ingredient sourcing should be linked to wild fish stock accounts in **TG-3.9** and **TG-6.7** to enable assessment of net contribution to fish supply.[41]

3.4.2 Fish-In Fish-Out Ratios

¶1 The **Fish-In Fish-Out (FIFO) ratio** measures the quantity of wild fish required (as feed ingredients) to produce one unit of farmed fish:

¶2

$$\text{FIFO} = \frac{(\text{Fishmeal quantity} \times \text{FCR}_{\text{meal}}) + (\text{Fish oil quantity} \times \text{FCR}_{\text{oil}})}{\text{Farmed fish output (tonnes)}}$$

¶3 where FCR_meal and FCR_oil are the species-specific wild-fish inclusion factors (kg wild fish per kg of meal or oil) derived from FAO reduction fishery yield ratios. Where fishmeal and fish oil are co-products of the same reduction fishery batch, allocate total wild-fish input between the two products based on their respective mass yield ratios to avoid double-counting.[42]

¶4 FIFO ratios vary substantially by species and system:

- ¶5 Salmon and marine carnivores: FIFO typically 1.5–3.0
- ¶6 Tilapia and herbivorous species: FIFO typically 0.3–0.8
- ¶7 Filter-feeding shellfish: FIFO = 0 (no feed inputs)

¶8 Declining FIFO ratios reflect increasing substitution of marine ingredients with terrestrial alternatives. For sustainability assessment, present both the ratio and the absolute quantities of wild fish used in feed: a declining ratio accompanied by expanding production may still increase absolute demand on wild fish stocks.[43]

3.4.3 Feed Sources and Sustainability

Category	Description
Reduction fisheries	Wild fish harvested specifically for fishmeal and fish oil; link to wild stock accounts and deduct from net fish supply contribution.
Processing by-products	Trimmings from fish processing; distinguish from dedicated reduction fishery catch in feed composition records.
Terrestrial inputs	Soy, wheat, and other crop-derived ingredients; link to agricultural accounts where available.

3.5 Disease and Biosecurity

3.5.1 Disease-Related Losses

¶1 *Table 3.7: Disease loss classification for aquaculture accounts*

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Disease Category	Examples	Recording Treatment
Endemic diseases	Routine bacterial, parasitic infections	Normal mortality within expected rates
Epidemic events	Viral outbreaks, ISA, VHS	Catastrophic loss if exceeding thresholds
Emerging diseases	Novel pathogens	Catastrophic loss; separate notation

¶2 Disease-caused losses are classified as catastrophic or normal using the two-standard-deviations rule defined in Section 3.2.3.

3.5.2 Treatment Chemical Use

¶1 *Table 3.8: Treatment chemical recording for aquaculture accounts*

Chemical Category	Purpose	Measurement
Antibiotics	Bacterial disease treatment	kg active ingredient
Antiparasitics	Sea lice, parasite control	kg active ingredient
Disinfectants	Biosecurity, equipment treatment	Litres or kg
Vaccines	Disease prevention	Doses administered

¶2 Treatment chemical emissions should be recorded consistent with **TG-3.4 Flows from Economy to Environment** for emissions to water.

3.5.3 Biosecurity Expenditure

Measure type	Description
Infrastructure	Nets, barriers, treatment systems (recorded as GFCF where representing durable investments).
Monitoring	Surveillance, testing, and certification programmes (recorded as intermediate consumption).
Management protocols	Fallowing, single year-class stocking, and area management agreements (costs as intermediate consumption).

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¶1 **GFCF boundary for biosecurity infrastructure:** Classification between GFCF and intermediate consumption follows 2025 SNA Chapter 11 capital boundary principles:[44]

- ¶2 **Service life exceeding 12 months**: Record as GFCF and depreciate over the asset's service life. Applies to purpose-built treatment systems, permanent barriers, and net structures with expected operational life of more than one accounting year.
- ¶3 **Service life of 12 months or less**: Record as intermediate consumption in the period of acquisition or replacement. Applies to biosecurity nets replaced on a cycle of 12 months or less.
- ¶4 **Rolling replacement**: Where nets or other biosecurity components are replaced on a rolling basis, record the full replacement cost in each period as intermediate consumption, regardless of the component's individual service life.

3.6 Compilation Procedure

Step 1: Data assembly and validation

¶1 Assemble aquaculture production data from fisheries agencies, site registration records from licensing authorities, and environmental monitoring data from regulatory programmes. Validate internal consistency between production records and site capacity data. Document data quality issues following **TG-0.7 Quality Assurance**.

Step 2: Site-level asset account compilation

¶1 For each aquaculture site or site cluster, compile a physical asset account (Table 3.2 format) recording opening stock, stocking (seed inputs), natural growth, harvest, mortality, escapes, and closing stock. Aggregate site-level accounts to species groups and production system types. Verify: Closing stock = Opening stock + Stocking + Natural growth - Harvest - Mortality - Escapes.

¶2 Stocking is a positive addition of cultivated biomass to the site, consistent with the SEEA AFF treatment of additions to cultivated biological resources; it is an entry in the physical asset account, not a revaluation. Where a cohort is stocked once at the start of a multi-year production cycle, the stocking term is zero in subsequent years of that cycle but should still be shown explicitly so that the identity is transparent.

Step 3: Environmental flow recording

¶1 Apply nutrient mass balance calculations (Table 3.4) to estimate nitrogen and phosphorus discharges from fed aquaculture systems. Record residual flows following **TG-3.4**. For coastal pond systems, record measured effluent volumes and nutrient concentrations where monitoring data are available.

Step 4: Feed dependency analysis

¶1 Compile feed use data by species and system type. Decompose feed into fishmeal, fish oil, vegetable protein, and other ingredients (Table 3.6). Calculate FIFO ratios using the mass-ratio allocation method (Section 3.4.2). Link fishmeal and fish oil use to wild fish stock accounts in **TG-6.7**.

Step 5: Integration with economy-wide accounts

¶1 Extract aquaculture output, intermediate consumption, and value added from national supply and use tables, following **TG-2.5** Section 3.7. Reconcile physical output quantities from asset accounts with monetary output, applying appropriate unit value factors. Record GFCF in aquaculture infrastructure and equipment.

Step 6: Indicator derivation

- ¶1 **Production efficiency and wild-fish dependency**: FCR and FIFO (Section 3.4.2)
- ¶2 **Environmental intensity**: Nutrient discharge per unit production (kg N per tonne harvest)
- ¶3 **Economic performance**: GVA per unit production, labour productivity, and capital intensity
- ¶4 **Carrying capacity utilisation**: Actual production as percentage of estimated site carrying capacity

3.7 Decision Use Cases

3.7.1 Sustainable Aquaculture Expansion Planning

¶1 **Account inputs**: Site-level asset accounts (Section 3.2), carrying capacity estimates (Section 3.2.1), nutrient loading data (Section 3.3.1), habitat modification records (Section 3.3.2).

¶2 **Analytical outputs**: Production potential by coastal zone, environmental loading relative to assimilative capacity, cumulative impact assessment, spatial optimisation of site allocation.

¶3 **Connection to other circulars**: Carrying capacity links to **TG-2.3**. GVA and employment projections link to **TG-2.5**.

3.7.2 Environmental Footprint Monitoring

¶1 **Account inputs**: Nutrient mass balance (Table 3.4), treatment chemical use (Table 3.8), escape records (Section 3.2.4), benthic condition indicators (Section 3.3.2).

¶2 **Analytical outputs**: Trends in nutrient loading intensity, chemical use per unit production, escape frequency, and benthic impact indices against regulatory limits.

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¶3 **Connection to other circulars**: Nutrient discharges aggregate into **TG-2.7 Pollution and Other Flows to Environment**. Habitat impacts connect to **TG-2.8 Climate Change Indicators**.

3.7.3 Feed Conversion Efficiency Tracking

¶1 **Account inputs**: Feed composition (Table 3.6), FIFO ratios (Section 3.4.2), feed conversion ratios, wild fish stock status from **TG-6.7**.

¶2 **Analytical outputs**: Trends in FIFO ratios, share of feed from by-products versus reduction fisheries, actual versus best-practice FCR, net contribution to fish supply.

¶3 **Connection to other circulars**: Wild fish use in feed links to **TG-6.7**. Protein supply links to **TG-2.3**.

4. Worked Example

¶1 This worked example illustrates compilation of a site-level aquaculture account for a hypothetical marine cage salmon farm. The example demonstrates the physical asset account, production flow recording, nutrient loading calculation, and feed use accounting described in Section 3.

4.1 Site Description

¶1 The example site comprises a marine cage salmon farm with 12 net-pen cages located in a coastal embayment. The farm operates on a 24-month production cycle, stocking smolts in Year 1 and harvesting market-size fish in Year 2. The site is classified under ISIC 0321 (Marine aquaculture) and occupies a lease area recorded under the applicable SEEA CF coastal water area category (see Section 2.2).

4.2 Physical Asset Account

¶1 *Table 4.1: Physical asset account — marine cage salmon farm (Year 2 of production cycle)*

Flow Category	Quantity (tonnes live weight)	Notes
Opening stock (1 January)	2,400	Carried from Year 1 closing balance
Stocking (seed inputs)	0	Cohort stocked in Year 1; no smolt input in Year 2
Natural growth	1,800	Biological growth during Year 2
Harvest	-3,600	Removal for sale (Oct–Dec)
Normal mortality	-180	4.5% of mid-year average biomass (estimated at ~4,000 tonnes live weight, reflecting growth before harvest)
Catastrophic loss	0	No disease or environmental events
Escapes	-20	Storm damage to one cage in March
Closing stock (31 December)	400	Remaining unharvested stock

¶2 **Accounting identity verification**: 2,400 + 0 + 1,800 - 3,600 - 180 - 20 = 400. The account balances.

4.3 Nutrient Loading Estimate

¶1 Using a mass balance approach for nitrogen:

- ¶2 **Feed input**: 4,320 tonnes of feed at 6.5% N content = 281 tonnes N
- ¶3 **Nitrogen retained in biomass gain**: 1,800 tonnes of growth at 2.8% N content = 50 tonnes N (retention is measured on growth, not harvest, because 2,000 tonnes of the harvest were stock carried from Year 1)

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- ¶4 **Mortality and escapes**: 200 tonnes, already within the biomass gain (3,600 harvest + 200 mortality and escapes - 2,000 stock drawdown = 1,800), so not deducted again
- ¶5 **Net N discharge to environment**: 281 - 50 = 231 tonnes N

¶6 This net nitrogen discharge of 231 tonnes would be recorded as a residual flow to the marine environment under **TG-3.4 Flows from Economy to Environment**.

¶7 **Loading intensity**: 231 tonnes N / 3,600 tonnes harvest = 64 kg N per tonne production.

4.4 Feed Use and FIFO Calculation

¶1 *Table 4.2: Feed composition and FIFO calculation*

Feed Component	Quantity (tonnes)	Share of Total
Fishmeal	648	15%
Fish oil	432	10%
Vegetable protein (soy)	1,296	30%
Other ingredients	1,944	45%
Total feed	**4,320**	**100%**

¶2 Wild fish equivalent in feed, using the mass-ratio allocation FIFO method (Section 3.4.2): fishmeal and fish oil are co-products of the same reduction fishery batch and must be treated as a single joint input. Combined fishmeal and fish oil: 648 + 432 = 1,080 tonnes. Using a combined mass yield of 22.5% (fishmeal) + 5.0% (fish oil) = 27.5% from live weight, following Tacon and Metian (2008)[45]:

- ¶3 Total wild fish attributed to this feed: 1,080 ÷ 0.275 = 3,927 tonnes
- ¶4 FIFO ratio: 3,927 / 3,600 = 1.09

¶5 This FIFO value reflects the standard mass-ratio allocation method following Tacon and Metian (2008)[45] and Jackson (2009)[46].

¶6 A FIFO ratio of approximately 1.0 indicates wild-fish input is roughly equivalent to farmed output by weight.

¶7 **Feed conversion ratio (FCR)**: 4,320 tonnes feed / 1,800 tonnes biomass gain = 2.4. FCR is computed on biomass gain, not harvest, because most of the harvested fish were grown in Year 1. The illustrative value is above the typical range for salmon cage culture (1.1–1.3); in a real compilation it would prompt a check of the feed and growth records (Step 1).

4.5 Integration with Supply-Use Framework

¶1 *Table 4.3: Integration with ocean economy supply-use table (ISIC 0321 – Marine aquaculture)*

Item	Physical (tonnes)	Monetary (000 USD)	Notes
Output (salmon harvest)	3,600	27,000	At USD 7.50 per kg farmgate price
Intermediate consumption (feed)	4,320	3,456	At USD 0.80 per kg feed price
Intermediate consumption (other)	–	2,160	Fuel, maintenance, services, etc. (excludes labour: compensation of employees is part of GVA)
Gross value added	–	21,384	Output minus intermediate consumption
Employment	–	48	Full-time equivalent workers
GFCF (cage replacement)	–	1,500	Annual capital investment

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¶2 The GVA of USD 21.4 million contributes to the aquaculture row in the ocean economy accounts. Labour productivity = USD 445,500 per worker, and capital intensity = 7.0% of GVA.

5. Compilation Considerations

5.1 Data Quality and Availability

¶1 Common data challenges by category:

- ¶2 **Production data**: Generally available from industry reporting and FAO aquaculture statistics, and typically the most complete data category. Verify consistency between national statistical agency records and industry association reports.
- ¶3 **Feed data**: Often commercially sensitive, and may require survey-based collection or estimation using species-specific feed conversion ratios. Document the estimation methodology and associated uncertainty where direct data are unavailable.
- ¶4 **Environmental data**: Variable availability depending on monitoring requirements. Some jurisdictions mandate site-level environmental monitoring, whilst others rely on ambient water quality monitoring that may not capture site-specific impacts.
- ¶5 **Disease data**: May be subject to confidentiality restrictions. Aggregate mortality rates and treatment chemical use statistics may be available where case-level data are restricted.

¶6 Minimum data requirements are production quantities by species and system type, and site location data. Additional data categories enable progressively more complete accounts as described in the phased implementation approach below.

5.2 Phased Implementation

¶1 The phases below define the widening content of an aquaculture account. They sit inside the general readiness and sequencing pathway at **TG-0.8 Implementation Readiness Assessment** Sections 3.1 and 3.2, which is not restated here.

¶2 **Minimum viable account:** A TG-6.8 aquaculture thematic account is considered complete at Phase 2 (environmental interaction accounting). Phase 1 alone represents a partial account consistent with TG-3.9. It does not constitute a complete TG-6.8 compilation. Compilers completing only Phase 1 should label their output "TG-3.9 consistent" and include a note on planned progress toward Phase 2. Document account completeness following **TG-0.7 Quality Assurance** completeness and comparability rating conventions.[47]

1. ¶3 **Phase 1 — Production and asset accounting**: Compile physical quantities of production, stock, and harvest by species and system type, drawing on existing aquaculture production statistics.
2. ¶4 **Phase 2 — Environmental interaction accounting**: Add nutrient loading estimates using mass balance calculations, habitat modification recording, and escape quantification. *Phase 2 represents the minimum complete TG-6.8 account.*
3. ¶5 **Phase 3 — Feed dependency and disease accounting**: Incorporate detailed feed composition, FIFO calculations, disease loss recording, and treatment chemical use.
4. ¶6 **Phase 4 — Full integration with ocean accounts**: Link aquaculture thematic accounts with **TG-3.1 Asset Accounts**, **TG-3.4 Flows from Economy to Environment**, and ecosystem condition accounts.

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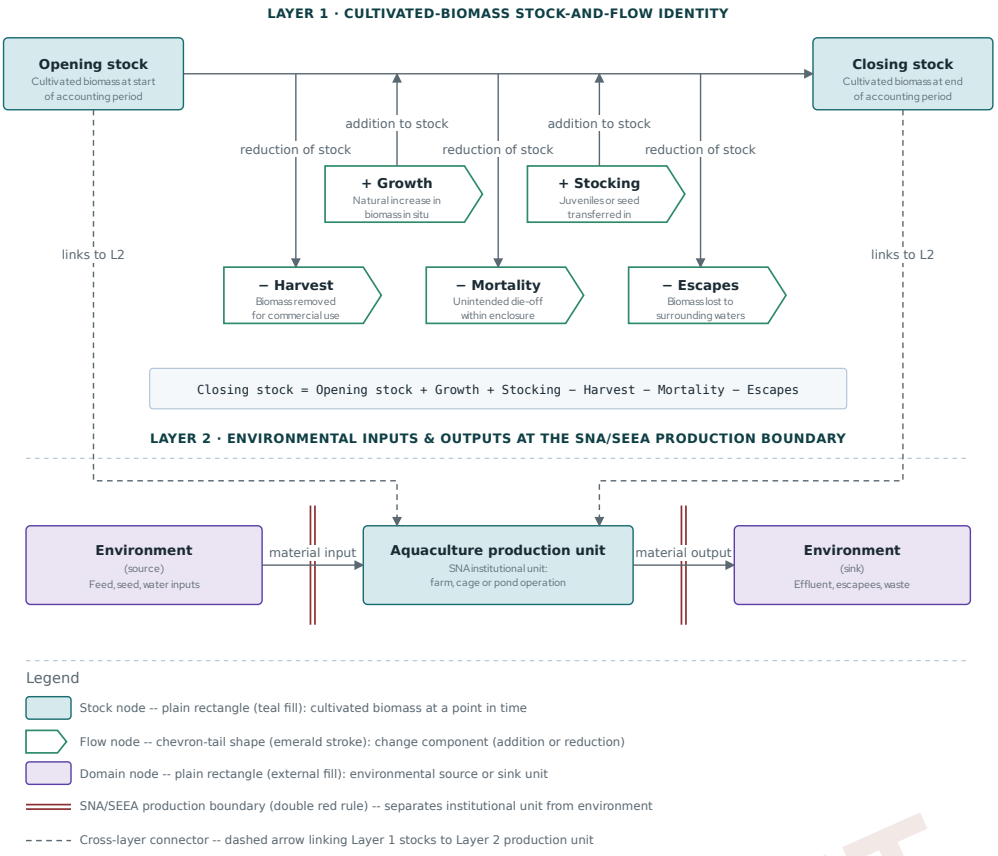


Figure 6.8.1 Two-layer aquaculture stock-and-flow: Layer 1 is the cultivated-biomass identity; Layer 2 places the unit at the SNA/SEEA production boundary. Stocks = plain rectangles; flows = chevron-tail. Mortality and escapes shown disaggregated.

Source: TG-6.8, Section 3 (aquaculture stock-and-flow accounts); SEEA AFF paras. 2.127--2.129; SEEA CF para. 5.1 (asset-account opening/closing stock identity).

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6. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

¶3 **Note:** This Circular addresses the thematic methods layer for aquaculture, and extends the foundational aquaculture accounting guidance in TG-3.9.

7. References

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- ¶2 FAO. 2008. *Glossary of Aquaculture*. Rome.
- ¶3 FAO. 2010. *Ecosystem Approach to Aquaculture*. FAO Technical Guidelines for Responsible Fisheries No. 5, Supplement 4. Rome.
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- ¶5 United Nations et al. 2021. *System of Environmental-Economic Accounting – Ecosystem Accounting*. New York.
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FOOTNOTES

1. ¶1 Classification enables consistent aggregation of aquaculture data across sites and jurisdictions, following ISIC and ISSCFC frameworks (SEEA AFF para. 3.156).
2. ¶2 Site-level accounts provide the foundation for national aquaculture statistics and enable analysis of production efficiency and environmental performance.
3. ¶3 Environmental interaction accounting supports assessment of cumulative impacts and sustainable development boundaries.
4. ¶4 Feed dependency tracking links aquaculture to wild fish stocks, addressing concerns about net contribution to fish supply (SEEA AFF para. 3.169).
5. ¶5 Disease and biosecurity accounting enables analysis of production risks and prevention investment returns (SEEA AFF para. 3.185).
6. ¶6 Indicator derivation connects site-level accounts to policy decisions on site allocation, environmental standards, and sustainability certification.
7. ¶7 Integration with broader ocean accounts requires consistent treatment of aquaculture as both an economic activity and source of environmental pressures.
8. ¶8 Production statistics typically available from national fisheries agencies and FAO global aquaculture databases.
9. ¶9 Licence data provides site boundaries and permitted production limits essential for carrying capacity analysis.
0. ¶10 Environmental monitoring data may be obtained from regulatory agencies, industry reporting, or dedicated surveys.
1. ¶11 Feed records typically maintained by producers for production management; may require survey collection for statistical compilation.
2. ¶12 Mortality and escape reporting often required under regulatory frameworks; data quality varies across jurisdictions.
3. ¶13 ISIC Rev.4 defines aquaculture as "the production process involving the culturing or farming (including harvesting) of aquatic organisms… using techniques designed to increase the production of the organisms in question beyond

the natural capacity of the environment."

4. ¶14 SEEA CF Annex I provides detailed definitions for each land and water use category.
5. ¶15 SEEA Central Framework (2012), Annex I. The SEEA CF water area categories in Annex I cover inland and coastal waters; no discrete EEZ aquaculture sub-category exists at the 4.x level in the published 2012 standard. Compilers developing national extensions for EEZ offshore aquaculture should follow the supplementary tables approach described in TG-0.1.
6. ¶16 FAO Glossary of Aquaculture (2008), adopted in SEEA CF para. 5.409.
7. ¶17 This distinction determines whether output is recorded as aquaculture (cultivated) or fisheries (natural) production (SEEA CF para. 5.409).
8. ¶18 Water area categories extend the SEEA CF land use classification to cover marine spatial use. See Section 2.2 and footnote 14a on EEZ classification.
9. ¶19 SEEA CF para. 5.441: "Aquatic resources farmed in an aquaculture facility are produced assets, either inventories or fixed assets (in the case of breeding stocks)."
0. ¶20 Open cage systems differ fundamentally from closed containment in their environmental interactions, necessitating coordination between site-level accounts and broader environmental flow accounts.
1. ¶21 TG-0.1 General Introduction to Ocean Accounts (Basic Spatial Unit framework); TG-1.2 Marine Spatial Planning (spatial data integration requirements). The centroid-of-lease-area rule for fixed installations is the standard approach in spatial environmental accounting; the majority-area rule for straddling sites follows the SEEA EA recommended allocation principle for account boundaries.
2. ¶22 Land area recording enables integration with terrestrial land use accounts (SEEA CF Annex I).
3. ¶23 Controlled water exchange enables nutrient mass balance calculations at the site level.
4. ¶24 Intensity classification affects environmental loading rates and resource requirements per unit production.
5. ¶25 Integrated systems may show reduced net nutrient loading under specific site conditions; see Nederlof et al. (2022) for empirical evidence on nitrogen retention efficiencies in IMTA systems, which vary widely (up to 56% by retention method) and are highly site- and species-specific. Net uptake exceeding fed-species outputs is most plausible in seaweed-dominant systems at low feed input densities. Compilers should verify this empirically before recording negative residual flows. Negative residual flows (net environmental inputs) require separate recording treatment under TG-3.4 from positive discharges.
6. ¶26 Multiple output recording follows standard SNA treatment of joint production.
7. ¶27 SEEA AFF paras. 3.179–3.181 (boundary between cultivated and natural aquatic resources); FAO Technical Guidelines for Responsible Fisheries No. 5, Supplement 4 (2010).
8. ¶28 Carrying capacity concepts parallel those used for livestock (SEEA AFF para. 3.90) and tourism (SF-MST). Four-dimension framework following McKindsey et al. (2006).
9. ¶29 Social carrying capacity reflects community and stakeholder tolerance levels. It is not a standard SEEA account variable and should be recorded as a supplementary social indicator rather than as part of the formal asset account. See TG-2.3 for social indicator conventions.
0. ¶30 Production cycle accounting follows SEEA AFF physical flow account structure (para. 3.158).
1. ¶31 Live weight equivalent measurement ensures consistency with FAO reporting standards (SEEA AFF para. 3.159).
2. ¶32 SEEA AFF para. 3.185.
3. ¶33 The five-year minimum reference period is consistent with standard statistical practice for rare-event threshold estimation. Site-specific reference populations are appropriate given high variation in mortality rates across system types. Threshold derivation methods should be documented following TG-0.7 Quality Assurance.
4. ¶34 SEEA AFF, paras. 3.185-3.187.
5. ¶35 Cross-reference corrected per EL6.8-05. Cultivated-to-wild reclassification entries belong in TG-3.1 (asset accounts) and TG-6.7 (wild stock implications). Where escaped species are not subject to commercial fisheries, a supplementary table is the appropriate recording vehicle rather than a formal account.
6. ¶36 Nutrient loading calculations adapted from SEEA AFF nutrient budget methodology (Section 4.4).
7. ¶37 SEEA AFF para. 4.79. Note: the quoted SEEA AFF text uses "phosphorous" — this is a misspelling in the source document; the correct noun is "phosphorus" (IUPAC). The [sic] notation indicates the error originates in the cited source.
8. ¶38 Habitat modification recording supports ecosystem extent and condition accounting per SEEA EA.
9. ¶39 Fleming, I.A. et al. (2000). Lifetime success and interactions of farm salmon invading a native population. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 267, 1517–1523. doi:10.1098/rspb.2000.1173.
0. ¶40 SEEA AFF para. 3.169.
1. ¶41 Cross-reference to fisheries and aquaculture accounting circulars ensures consistent treatment of wild fish use in feed across the ocean accounting framework.
2. ¶42 Tacon, A.G.J. and Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: trends and future prospects. *Aquaculture* 285: 146–158. doi:10.1016/j.aquaculture.2008.08.015. This paper establishes the mass-allocation FIFO methodology including separate fishmeal and fish oil yield fractions. See also Jackson, A. (2009) for the formalised split-allocation formula.
3. ¶43 Declining FIFO ratios are a positive sustainability signal, but absolute quantities of wild fish in feed should also be tracked to account for the effect of production volume growth.

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4. ¶44 2025 SNA, Chapter 11 (capital boundary; expected service life criterion for fixed assets). The one-year service life criterion is carried forward from SNA 2008 para. 10.7. Specific 2025 SNA paragraph numbers for the capital boundary criterion should be confirmed against the Chapter 11 PDF (available at: https://unstats.un.org/unsd/nationalaccount/snaupdate/2025/2025SNA_CH11_V5.pdf (https://unstats.un.org/unsd/nationalaccount/snaupdate/2025/2025SNA_CH11_V5.pdf)) before this citation is finalised.
5. ¶45 Tacon, A.G.J. and Metian, M. (2008). *Aquaculture* 285: 146–158. doi:10.1016/j.aquaculture.2008.08.015.
6. ¶46 Jackson, A. (2009). Fish in fish out ratios explained. *Aquaculture Europe*, 34(3). IFFO/EAS conference paper. Available at: https://www.iffo.com/system/files/downloads/EAS%20FIFO%20September2009%202_0.pdf (https://www.iffo.com/system/files/downloads/EAS%20FIFO%20September2009%202_0.pdf). Grey literature; Tacon & Metian (2008) is the primary peer-reviewed citation.
7. ¶47 TG-0.7 Quality Assurance (completeness and comparability standards); TG-3.9 Aquaculture Accounts (foundational account scope).

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Offshore Energy Thematic Methods

Provides methodological guidance for accounting for offshore energy activities within ocean accounts.

Version 0.8.1 **Status** Draft **Stability** Emerging

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides methodological guidance for accounting for offshore energy activities within ocean accounts, extending TG-3.10 Offshore Energy Accounts with thematic methods for cumulative impacts, decommissioning, and energy transition.

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ABOUT THIS CIRCULAR

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1. Outcome

¶1 This Circular provides methodological guidance for accounting for offshore energy activities within ocean accounts, extending **TG-3.10 Offshore Energy Accounts**[1] with thematic methods for cumulative impacts, decommissioning, and energy transition.

1.1 Decision Use Cases and Policy Links

¶1 **Offshore wind site selection and spatial planning**. Marine spatial planning authorities require spatial footprint data, exclusion zone mapping, and ecosystem condition baselines to evaluate competing offshore wind proposals, feeding into **TG-1.2 Marine Spatial Planning**.

¶2 **Oil and gas decommissioning accounting**. Asset accounts for offshore energy infrastructure (Section 3.5.1) enable tracking of decommissioning liabilities. The rigs-to-reefs framework (Section 3.5.2) provides accounting treatment for partial decommissioning. Asset valuations also support **TG-1.8 OA and Project-Level Finance**.

¶3 **Energy transition and climate policy**. The energy transition accounting framework (Section 3.6) supports reporting on the shift from offshore oil and gas to marine renewables, including NDC progress and avoided-emissions tracking. Climate indicators feed into **TG-2.8 Climate Indicators**. Section 3.6.3 provides the accounting linkage.

¶4 **Renewable energy target monitoring**. Physical energy accounts (Section 3.2) record installed capacity and generation by technology type. These data support comparison against policy targets and link to **TG-2.5 Ocean Economy Structure**.

¶5 **Asset accounts integration**. Treatment of renewable energy resources and terminal costs for offshore infrastructure is governed by **TG-3.1 Asset Accounts**.

1.2 Emerging Methodological Issues

¶1 Methods for offshore renewable energy accounting and cumulative impact assessment are not yet standardised within the SEEA framework. Specific areas of emerging methodology are summarised below.

Methodological area	Description
Income attribution for floating offshore wind installations	Accounting treatment for mobile offshore installations (floating production units, floating wind turbines) without fixed seabed attachment. See Section 3.1.2.
Carbon capture and storage (CCS) accounting	Recording of carbon dioxide stored in depleted offshore reservoirs, pending resolution of whether stored carbon is negative extraction, a new asset type or an environmental protection service. See Section 3.6.3.
Infrastructure repurposing accounting	Treatment of oil and gas infrastructure converted for renewable energy use (platforms as wind turbine bases, pipelines for hydrogen transport). See Section 3.6.1.
Electromagnetic field (EMF) impact accounting	Recording of electromagnetic fields from subsea power cables and their effects on electroreceptive species. See Section 3.4.2.
Ecosystem service valuation	Valuation of artificial reef ecosystem services created by offshore structures. See Section 3.4.3.
Cumulative impact thresholds	Frameworks for assessing when combined impacts exceed ecosystem carrying capacity. See Section 3.4.
Cross-border accounting	Treatment of offshore installations in shared maritime zones or areas beyond national jurisdiction. See Section 3.1.1.

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Methodological area	Description
Emerging offshore activities	Offshore hydrogen production, offshore desalination, and marine data centres represent emerging ocean uses. Record pilot installations in supplementary tables where they occur.

¶2 Reclassification to Applied may be considered once international guidance on these topics is formally adopted through the UN Statistical Commission process or the UNCEEA work programme. The spatial scope covers offshore energy activities within the Exclusive Economic Zone and on the continental shelf as defined by UNCLOS, including both fixed and floating installations. Activities within areas beyond national jurisdiction are addressed in **TG-6.6 Deep Sea and Seabed Accounting**. **TG-6.11 Coastal Infrastructure** addresses cable landfall infrastructure and onshore grid connections.

¶3 **Framework Position**

¶4 This Circular specialises **TG-3.10 Offshore Energy Accounts** for cumulative impacts, decommissioning and the energy transition. TG-3.10 owns the supply and use tables, the mineral and energy resource asset accounts and the activity classification; this Circular adds what those do not reach.

¶5 It also owns, for the publication as a whole, the treatment of **submerged artificial structures (IUCN GET M4.1)** at Section 3.5.2 — the write-down, the M4.1 extent entry at footprint plus ecological halo, and its reversal. That rule applies wherever the structure sits, including inside the territorial sea (**TG-6.11**) and to structures colonised by reef-building corals (**TG-6.1**).

¶6 Spatial scope is the EEZ and continental shelf. Activity in areas beyond national jurisdiction is **TG-6.6**; cable landfall and onshore grid connection are **TG-6.11**.

2. Requirements

¶1 This Circular requires familiarity with:

- ¶2
  TG-0.1 General Introduction to Ocean Accounts — conceptual framework for ocean accounting, including the Basic Spatial Unit framework for georeferencing offshore activities.
- ¶3
  TG-3.10 Offshore Energy Accounts — foundational accounting structure for offshore energy, including supply and use tables, asset accounts for mineral and energy resources, and activity classification.

2.1 Related Circulars

- ¶1
  TG-3.1 Asset Accounts — general methodology for environmental asset accounts applicable to seabed mineral resources and ecosystem condition accounting.
- ¶2
  TG-3.3 Economic Activity Relevant to the Ocean — industry classification guidance for distinguishing offshore from onshore energy extraction.
- ¶3
  TG-4.1 Remote Sensing Data — methods for mapping offshore energy infrastructure using satellite imagery and AIS data.
- ¶4
  TG-6.5 Pelagic and Open Ocean — accounting for offshore renewable installations in pelagic environments.
- ¶5
  TG-6.6 Deep Sea and Seabed Accounting — relevant for deep-water energy developments and activities beyond national jurisdiction.
- ¶6

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TG-6.11 Coastal Infrastructure — export cable landfall, onshore substations, and grid connection infrastructure.

2.2 International Standards Alignment

¶1 This guidance aligns with four standards:

- ¶2 SEEA Central Framework (2012)[2] for mineral and energy resource treatment and decommissioning costs
- ¶3 SEEA-Energy (2019)[3], [4] for physical and monetary supply and use tables and fossil fuel asset accounts
- ¶4 2025 SNA[5] for renewable energy resource classification and terminal cost treatment
- ¶5 UNCLOS (1982)[6] for the offshore installation legal framework[7]

2.3 Data Sources

Source	Data provided
National petroleum and energy regulatory authorities	Licence areas, production data, reserves estimates, and decommissioning schedules for offshore oil and gas fields.
Environmental agencies	Impact assessments, monitoring data for ecosystem condition variables, and discharge permits.
Maritime authorities	Infrastructure locations, safety zone coordinates, and vessel tracking data (AIS).
Energy companies	Financial reports, sustainability disclosures (following IFRS S2 and TNFD frameworks), and operational data.
Research institutions	Ecological studies, technology assessments, and condition monitoring results.
International sources	IEA *World Energy Balances*[8] for bilateral production data; IRENA for renewable energy capacity and cost data; 4C Offshore and Global Wind Energy Council for offshore wind farm registries.

¶1 Data quality should be assessed following **TG-0.7 Quality Assurance**, with particular attention to temporal consistency, spatial coverage, and measurement uncertainty.

¶2 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

3.1 Energy Type Classification

3.1.1 Fossil fuel extraction (oil and gas)

¶1 Offshore oil and gas platforms extract mineral and energy resources classified within ISIC Division 06 (Extraction of crude petroleum and natural gas)[9]. ISIC Division 06 does not distinguish onshore from offshore extraction at the four-digit level, so compilers should use location-based coding or national satellite industry codes where available. See **TG-3.3 Economic Activity Relevant to the Ocean**.

¶2 **Physical asset accounts** record stocks using the United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources (UNFC-2009)[10]:

Class	Description
Class A: Commercially Recoverable Resources	Deposits where extraction and sale has been confirmed economically viable (UNFC categories E1, F1, G1-G3).
Class B: Potentially Commercially Recoverable Resources	Deposits expected to become economically viable in the foreseeable future (UNFC categories E2, F2.1/F2.2, G1-G3).
Class C: Non-Commercial and Other Known Deposits	Resources not expected to become economically viable with current technology and prices.

¶3 **Monetary asset accounts** record the net present value of commercially recoverable resources, with revaluations reflecting changes in commodity prices, extraction costs, and discount rates[11]. For foundational supply-use and asset-account structures, see **TG-3.10 Offshore Energy Accounts**.

¶4 **Transboundary reservoirs**. Where offshore reservoirs straddle maritime boundaries, the SEEA Central Framework requires that "only the country's share of the resource should be recorded in its asset accounts" (SEEA CF para. 5.93)[12]. Share allocation rules:

- ¶5 The **primary basis** is a *unitisation agreement* specifying production shares. Where one is in force, compilers should use its production share for national asset account entries.
- ¶6 Where no unitisation agreement exists, use the most recent **bilateral production data sharing arrangement**, or IEA *World Energy Balances*[8] as an interim basis.
- ¶7 UNFC classification should be applied **independently in each jurisdiction** using that jurisdiction's economic parameters. Where the sum of national reserves exceeds an independently assessed reservoir total, document this divergence in a cross-boundary consistency footnote.

¶8 Transboundary reservoir methodology has been flagged as a candidate issue for future UNSD guidance development.

3.1.2 Offshore wind energy

¶1 The 2025 SNA and SEEA-Energy classify wind energy resources as a type of renewable energy resource distinct from mineral and energy resources[13].

¶2 Key accounting considerations:

- ¶3 **Income attribution — floating wind installations**. By convention, income streams from offshore renewable energy capture are attributed to the value of underlying seabed assets[14]. For floating installations without fixed seabed attachment, this convention is methodologically problematic. Compilers should distinguish two treatments:
  - ¶4 *Provisional recording convention (workaround)*: Record floating installations in the spatial unit corresponding to the licence or lease area, and attribute income streams to seabed assets within that area. This is **explicitly a workaround**, not a settled method.
  - ¶5 *Preferred future treatment*: Attribute floating wind income to a distinct "offshore wind resource" asset class reflecting the wind resource and licence. This treatment is not yet standardised.

  Compilers must document in account metadata which treatment has been applied. A formal issue has been submitted to the UNSD SEEA expert group. Compilers should monitor outcomes through UNSD and UNCEEA.
- ¶6 **Fixed asset accounts** — Wind turbines, foundations, and transmission infrastructure are recorded as produced fixed assets with depreciation over their operational life.
- ¶7 **Capacity factors** — Physical accounts should record both installed capacity (MW) and actual generation (MWh), as capacity factors for offshore wind typically range from 35–50%.

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- ¶8
  Cable infrastructure and indicative useful lives — Array cables and export cables have different asset lives and ownership structures and should be recorded as separate asset classes where data permit. Table 3.1 provides indicative useful life parameters [5], [15].
  Table 3.1: Indicative useful life parameters for offshore wind asset classes

Asset class	Indicative useful life (years)
Wind turbine and tower	20–25
Monopile / jacket foundation	25–30
Array cable	20–25 (aligned with turbine life)
Export cable	30–40 (may serve multiple wind farm generations)
Offshore substation	25–30

(References to be confirmed — see Section 5.)

3.1.3 Wave and tidal energy (emerging)

¶1 The FDES defines renewable energy sources to include "tidal action, wave action, marine (non-tidal currents, temperature differences and salinity gradients)" [16].

¶2 Two distinct tidal energy technologies should be distinguished. **Tidal range** (barrages and lagoons) creates large spatial footprints and significant estuarine ecosystem impacts. **Tidal stream** (underwater turbines) has smaller spatial footprints but potential collision and noise impacts on marine fauna. These technologies differ substantially in their spatial, ecological, and economic characteristics and should be recorded separately.

¶3 Accounting for emerging marine energy technologies should:

- ¶4 Track pilot and demonstration installations separately from commercial operations
- ¶5 Record research and development expenditure as gross fixed capital formation per SEEA-Energy guidance
- ¶6 Monitor installed capacity growth to inform energy transition scenarios

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3.2 Compilation Procedure for Offshore Energy Accounts

Step 1: Data collection and source identification

¶1 Assemble the data sources catalogued in Section 2.3 to measure opening stocks, production flows, additions, reductions, and closing stocks for each energy type. Data quality should be assessed following **TG-0.7 Quality Assurance**, with particular attention to temporal consistency, spatial coverage, and measurement uncertainty.

Step 2: Classification and mapping to asset categories

¶1 Map source data to SEEA CF asset categories:

- ¶2 **Mineral and energy resources** (offshore oil and gas) — Class A (commercially recoverable), Class B (potentially commercial), and Class C (non-commercial)
- ¶3 **Renewable energy resources** (wind, wave, tidal) — classified separately from mineral resources following 2025 SNA treatment

¶4 Physical accounts record stocks in natural units (barrels, cubic metres, MW installed capacity, MWh generation). Monetary accounts record net present value of expected resource rents (for oil and gas) or income streams attributed to seabed assets (for renewable installations).

Step 3: Physical supply and use table compilation

¶1 Physical energy supply and use tables (PSUT) follow SEEA-Energy Chapter 3 [4].

¶2 **Supply table** records: (1) production from offshore oil and gas fields (by spatial unit and field), (2) production from offshore renewable installations (by technology and location), and (3) imports of offshore-produced energy where relevant for transboundary accounting.

¶3 **Use table** records: (1) intermediate consumption within offshore operations (platform electricity, flaring losses), (2) exports of offshore-produced oil, gas, and electricity, and (3) final consumption of offshore renewable electricity by domestic users.

¶4 The balanced PSUT provides the foundation for deriving energy self-sufficiency indicators, emission intensity by fuel type, and renewable energy share indicators feeding into **TG-2.8 Climate Indicators**.

Step 4: Monetary supply and use table compilation

¶1 Monetary supply and use tables enable calculation of gross value added, compensation of employees, and gross operating surplus for offshore energy industries. These measures feed into **TG-2.5 Ocean Economy Structure**.

¶2 Key valuation considerations:

- ¶3 Oil and gas production is valued at wellhead prices (excluding transport and processing margins)
- ¶4 Offshore renewable electricity is valued at wholesale market prices or feed-in tariff rates
- ¶5 Gross value added is calculated as output minus intermediate consumption
- ¶6 For non-renewable resources, **resource rent should be calculated separately** from consumption of fixed capital on produced assets, using the net price or user cost method per SEEA-Energy Chapter 6[11]. See Section 3.7 for a worked example.

Step 5: Asset account compilation

¶1 Asset accounts track opening stocks, additions, reductions, reappraisals, and closing stocks. For offshore oil and gas, depletion of the mineral resource is recorded **separately** from consumption of fixed capital on produced assets. Conflating the two is a methodological error that SEEA-Energy Chapter 6 explicitly cautions against[11]. For offshore renewable resources, there is no depletion, and asset value derives from the stream of future income attributed to the seabed lease or licence.

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Step 6: Integration with national accounts and balance sheets

¶1 Integration ensures that:

- ¶2 **Depletion entries** in asset accounts correspond to depletion costs in production accounts and adjustments to net domestic product (see **TG-1.1 National Ocean Budgets**)
- ¶3 **Extraction entries** correspond to natural resource inputs in physical supply-use tables
- ¶4 **Investment in offshore infrastructure** is recorded as gross fixed capital formation in produced assets
- ¶5 **Environmental impact entries** in ecosystem condition accounts are consistent with offshore energy spatial footprints

3.3 Spatial Footprint Accounting

3.3.1 Seabed occupation

¶1 Spatial accounts should record:

¶2 **Direct footprint** — The physical area occupied by: (1) platform jackets and foundations (oil/gas), (2) monopile, jacket, or floating foundations (wind), (3) anchoring systems and mooring lines, and (4) subsea infrastructure (wellheads, manifolds, templates).

¶3 **Cable corridors** — Export cables require seabed rights-of-way. UNCLOS Article 79 establishes that all States are entitled to lay submarine cables on the continental shelf, subject to coastal State jurisdiction over cables connected to installations [17]. Cable landfall and onshore substation accounting are addressed in **TG-6.11 Coastal Infrastructure**.

3.3.2 Exclusion and safety zones

¶1 UNCLOS Article 60 permits coastal States to establish safety zones extending up to 500 metres from each point of the outer edge of offshore installations [18]. These zones effectively exclude commercial fishing, navigation, anchoring, and other seabed development.

¶2 Spatial accounts should record both the **statutory exclusion area** (defined by regulatory designation) and the **effective exclusion area** (observed through AIS vessel tracking data showing actual avoidance patterns). For guidance on using AIS and satellite data to delineate effective exclusion zones, see **TG-4.1 Remote Sensing Data**.

¶3 **Tier 1 fallback (no AIS processing capacity)**. Compilers may estimate the effective exclusion area by applying an empirical multiplier to the statutory 500 m safety zone area. The AIS-derived method remains preferred. Compilers must document in account metadata which method has been used and, where the multiplier is applied, the assumed value.

3.3.3 Integration with marine spatial planning

¶1 Offshore energy spatial data should be compiled as georeferenced polygon layers showing lease/licence boundaries, infrastructure locations, cable routes, safety/exclusion zones, and planned development areas, consistent with formats in **TG-1.2 Marine Spatial Planning**.

3.4 Environmental Impact Recording

¶1 The quantitative treatment below links physical impact measurements to the condition variables defined in SEEA Ecosystem Accounting, so cumulative impacts flow through to ecosystem condition assessments. For general ecosystem condition accounting methodology, see **TG-3.1 Asset Accounts**.

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¶2 *Table 3.2: Offshore energy environmental impact comparison*

Impact Type	Oil & Gas	Offshore Wind	Tidal/Wave
Seabed disturbance	Platform footprint	Foundation footprint	Device anchoring
Underwater noise	Drilling, operation	Construction (piling)	Operation (low)
Collision risk	Low (platforms visible)	Bird/bat collision	Marine mammal
Pollution risk	Spills, discharges	Low (no fuel)	Low
Decommissioning	Complex, costly	Simpler	Emerging
Account treatment	Depletion of minerals	No depletion	No depletion

3.4.1 Underwater noise

¶1 Offshore energy activities generate underwater noise during construction (pile driving), operation (machinery, vessel traffic), and decommissioning [19].

¶2 **Source characterisation** — Record noise source levels, frequencies, and temporal patterns by activity type and location as supplementary physical data tables linked to the relevant spatial unit and time period.

¶3 **Receptor mapping** — Identify noise-sensitive marine species, particularly marine mammals and fish. UNCLOS Article 65 requires States to cooperate for the conservation of marine mammals, with cetaceans receiving particular attention [20].

¶4 **Impact pathways** — Link noise exposure to ecological outcomes including behavioural disturbance, masking, temporary or permanent hearing threshold shifts, and physical injury. Document as condition indicators within ecosystem condition accounts.

¶5 **Data sources**. Use **regulatory monitoring data** (where available under national marine noise management frameworks) or **published acoustic modelling results** from environmental impact assessments. For European jurisdictions, EU Marine Strategy Framework Directive descriptor D11 (Commission Decision (EU) 2017/848 [21]) provides the regulatory baseline.

¶6 TNFD metrics for noise pollution [22] are designed for corporate site-level disclosure and should **not be aggregated directly across operators to derive national-level indicators**, for three reasons:

- ¶7 measurement methodologies are not standardised across companies
- ¶8 "noisiest part of day" is a peak rather than period-average metric
- ¶9 TNFD disclosures are voluntary and incomplete

3.4.2 Electromagnetic fields (EMF)

¶1 Subsea power cables generate electromagnetic fields that may affect electroreceptive marine species (sharks, rays, some crustaceans). Research remains limited. Current accounting practice should:

- ¶2 Record cable specifications (voltage, current, burial depth, shielding) as supplementary physical data
- ¶3 Map cable routes in relation to sensitive habitats using georeferenced data
- ¶4 Monitor and report any observed behavioural effects as condition indicators where monitoring data are available

3.4.3 Habitat modification

¶1 **Substrate introduction** — Hard structures create artificial reef habitat in otherwise soft-sediment environments. The IUCN Global Ecosystem Typology classifies "Submerged artificial structures" (M4.1) as a distinct ecosystem type [23]. Compilers should record the introduction of hard substrate as a change in ecosystem type within extent accounts (from soft-sediment benthic to M4.1), whilst noting that the ecological value of artificial habitat may differ substantially from natural reef. For general guidance on ecosystem extent accounting, see **TG-3.1 Asset Accounts**. For coral reef regions, see **TG-6.1 Coral Reef Accounts**.

¶2 **Sediment disturbance** — Installation and cable burial activities disturb seabed sediments, potentially releasing contaminants and altering benthic communities. Record as condition changes in affected spatial units.

¶3 **Hydrodynamic changes** — Large arrays of offshore structures may alter local currents, wave patterns, and sediment transport [24]. Compilers should record observed hydrodynamic changes in the minimum supplementary table below, drawing on satellite altimetry, HF radar, and in situ monitoring described in **TG-4.1 Remote Sensing Data**.

¶4 *Table 3.3: Minimum supplementary table for offshore wind hydrodynamic impact recording*

Field	Description
Installation ID	Unique identifier for the wind array
Monitoring period	Reporting year and reference baseline period
Current velocity change	% change from baseline at specified depth
Wave height reduction	% change in lease area
Sediment transport indicator	Qualitative: increased / reduced / unchanged
Source	Model output or in situ observation

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Field	Description
Uncertainty rating	Low / medium / high

3.4.4 Collision risk

¶1 **Seabirds** — Offshore wind turbines present collision risk for migratory and foraging seabirds. Empirical evidence suggests mortality rates for offshore installations are generally lower than for onshore wind, though considerable uncertainty remains in population-level estimates. Impact assessment should adopt precautionary approaches, clearly distinguishing observed mortality from modelled estimates.

¶2 **Marine mammals** — Vessel traffic associated with offshore energy operations increases collision risk for cetaceans and pinnipeds. Record as pressure indicators in ecosystem condition accounts.

¶3 **Fish and invertebrates** — Entrainment in cooling water intakes may impact fish populations. Tidal stream devices present potential collision risk for marine mammals and large fish species.

3.5 Decommissioning Accounting

3.5.1 Asset retirement framework

¶1 The SEEA Central Framework distinguishes between terminal costs and remedial costs for fixed asset disposal [25]:

¶2 **Terminal costs** are anticipated during production periods and should be provisioned through consumption of fixed capital allowances over the asset's life. Examples include removal of platform topsides and jackets, plugging and abandonment of wells, cable removal or burial, and site clearance surveys.

¶3 **Remedial costs** are incurred after operations cease, often by parties other than the original operator: cleanup of contaminated seabed sediments, long-term monitoring of residual structures, and rehabilitation of impacted habitats.

¶4 The 2025 SNA glossary defines terminal costs as "costs incurred on the disposal of an asset or at the end of its service life" covering "de-installation and decommissioning costs (in case of oil rigs or nuclear power stations) or rehabilitation costs of land sites" [26].

¶5 **Orphaned infrastructure**. For account purposes, an installation is classified as **orphaned** where:

¶6 (a) the registered operator or licence holder no longer exists as a legal entity; or (b) the operator exists but has formally disclaimed decommissioning responsibility, and a court or regulatory determination has assigned liability to the state; or (c) the installation has been abandoned without regulatory notification and the operator cannot be located.

¶7 Orphaned installations should be identified separately in supplementary tables and recorded as **government-held contingent liabilities**, consistent with the 2025 SNA treatment of contingent liabilities [27]. Where the liability is **probable and the remediation cost can be reliably estimated**, the estimated cost should be recorded as a government provision. Where the government subsequently incurs remediation expenditure, record as gross fixed capital formation (land improvement asset) or intermediate consumption (ongoing environmental protection), as applicable.

3.5.2 Rigs-to-reefs programmes

¶1 Some jurisdictions permit partial decommissioning where platform structures are left in place as artificial reefs. Research indicates that "more than 500 oil and gas platforms were decommissioned and left as artificial reefs in US waters since 1940" with "more than 600 in the Asia-Pacific alone" as candidates for reefing [28].

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¶2 **This Section owns the treatment of submerged artificial structures for the publication.** The rule below is written for rigs-to-reefs conversions but applies to any placed structure that acquires confirmed ecological function, wherever it sits: breakwaters, groynes and artificial reefs inside the territorial sea are recorded the same way (**TG-6.11 Coastal Infrastructure Accounting** Section 3.4.1), and a structure colonised by reef-building corals is still M4.1 and not an addition to M1.3 photic reef extent (**TG-6.1 Coral Reef Accounting** Section 3.1).

¶3 Accounting treatment follows a three-step recording sequence consistent with SEEA EA extent account transition rules [29]:

1. ¶4 **On legal decommissioning**: Record write-down of the oil and gas infrastructure asset as an **other change in volume of produced assets**, removing the platform from the produced asset stock.
2. ¶5 **On regulatory confirmation of reef designation**: Record introduction of an **IUCN GET M4.1** ecosystem extent entry, with area equal to the **structure footprint plus a defined ecological halo** (typically 50–100 m radius from the structure). The statutory 500 m exclusion zone must not be used as the M4.1 extent area, as it substantially overstates the area of active ecological function.
3. ¶6 **In subsequent periods**: Update ecosystem condition variables (species diversity, biomass density, structural integrity) as monitoring data become available. No circular in this edition covers M4.1 condition measurement: select variables under **TG-4.8 Physical Condition Measurement** and **TG-4.9 Biological Condition Measurement**. The benthic cover and structural complexity metrics in **TG-6.1 Coral Reef Accounting** Section 3.2 are a usable analogue for the biological variables, but the reference condition for a submerged artificial structure is not a natural reef and must be set on its own terms.

¶7 If reef designation is subsequently revoked or the structure fails to develop confirmed ecological function, the M4.1 extent entry should be **reversed** as an other change in volume of ecosystem assets in the period of revocation.

¶8 In addition, compilers should:

- ¶9 record the reduction in decommissioning liability (terminal cost avoided)
- ¶10 track any payments to or from regulatory authorities
- ¶11 account for any ongoing maintenance or monitoring obligations

¶12 Note that oil and gas infrastructure left as artificial reefs "is more exposed to light/noise/chemical pollution associated with operations as well the spread of invasive species" compared to purpose-built artificial reefs [30]. This pollution legacy should be reflected in the condition assessment of converted structures.

3.5.3 Remediation expenditure

¶1 Where decommissioning reveals contamination or environmental damage, remediation expenditure should be recorded as:

- ¶2 **Gross fixed capital formation** when creating a land improvement asset (remediated site)
- ¶3 **Intermediate consumption** when representing ongoing environmental protection activities

¶4 SEEA-Energy notes that expenditures on decommissioning represent one area where economic response to environmental issues can be highlighted [31]. The same principle applies to offshore oil and gas decommissioning, which may be recorded as environmental protection expenditure within thematic and extended accounts.

3.6 Energy Transition Accounting

3.6.1 Fossil to renewable transition

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¶1 **Asset revaluation** — Declining demand for fossil fuels may reduce the economic value of oil and gas reserves, recorded as downward reappraisals in physical asset accounts and revaluations in monetary accounts.

¶2 **Infrastructure repurposing** — Some offshore oil and gas infrastructure may be converted for renewable energy use (platforms as wind turbine bases, pipelines for hydrogen transport, wellbore infrastructure for geothermal extraction). Record the reclassification as other changes in volume of assets, noting both the write-down of the original asset and the acquisition of the repurposed asset.

¶3 **Workforce transition** — Employment shifts from fossil fuel to renewable sectors should be tracked through labour accounts linked to ISIC industry classifications. See **TG-3.5 Social Accounts**.

3.6.2 Stranded asset treatment

¶1 The IFRS S2 Climate-related Disclosures standard requires disclosure of "the amount and percentage of assets or business activities vulnerable to transition risks" [32]. In SEEA terms, stranded assets are recorded as:

- ¶2 **Downward reappraisals** (Class A to Class B/C) for resource reclassification
- ¶3 **Other changes in volume of assets** for unexpected retirements
- ¶4 **Write-offs** for exploration expenditure on abandoned projects

¶5 **Recognition timing**. The SEEA Central Framework requires that revaluations be recorded "when the event causing the change is recognized" (para. 5.94) [33]. Table 3.4 sets out recognition criteria by trigger type.

¶6 *Table 3.4: Stranded asset recognition criteria by trigger type*

Trigger type	Period of recording	Supporting documentation
Policy announcement	Period in which **binding legislation or regulation is enacted** (not at consultation or political announcement stage) [34]	Citation of enacted legislative or regulatory instrument
Market signal	Period after the commodity price has been **below the cost of extraction for two consecutive annual average periods** and no recovery is expected [35], [36]	Annual average price series and extraction cost reference
Physical event	Period of the physical event [37]	Incident report and reference to asset condition assessment

¶7 Documentation should follow **TG-0.7 Quality Assurance** standards.

3.6.3 Carbon and climate accounting

¶1 **Emissions** — Fossil fuel extraction generates direct emissions (flaring, venting, fugitive methane) and enables downstream emissions from combustion. For recording these flows, see **TG-3.4 Flows from Economy to Environment**.

¶2 **Carbon storage (CCS)** — Some depleted offshore reservoirs may be repurposed for carbon capture and storage. CCS accounting remains an open methodological question awaiting UNSD resolution, including whether stored carbon represents negative extraction, a new asset type, or an environmental protection service. Compilers in jurisdictions with operating offshore CCS projects (notably Norway, the UK, and Australia) should populate the provisional supplementary table below, drawing on the OSPAR CCS reporting framework [38] and IEA CCUS Projects Database [39].

¶3 *Table 3.5: Provisional supplementary table for offshore CCS recording (pending standardisation)*

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Field	Unit / format
Reservoir ID	Unique identifier
Location (BSU)	Basic Spatial Unit reference
Storage capacity	Mt CO2
Cumulative injections to period start	Mt CO2
Injections during period	Mt CO2
Monitoring / verification expenditure	USD
Ownership structure	Operator, equity shares, public/private

¶4 **Avoided emissions** – Offshore renewable energy displaces fossil fuel generation, contributing to emission reductions counted in national inventories. For SDG indicator 12.c.1 compilation from offshore energy accounts, see **TG-2.10 MEA Indicators**[40].

3.7 Worked Example: Synthetic Offshore Energy Account

Scenario description

¶1 The accounting area is a coastal State's EEZ containing one mature offshore oil field and one operational offshore wind farm. The accounting period is calendar year 2025.

¶2 **Offshore oil field parameters:**

- ¶3 Total recoverable reserves (Class A): 200 million barrels
- ¶4 Development cost (GFCF): USD 15,000 million
- ¶5 Annual extraction rate: 20 million barrels
- ¶6 Expected production life: 10 years
- ¶7 Oil price (central case): USD 85/barrel; sensitivity range USD 70–100/barrel
- ¶8 Annual operating expenditure: USD 800 million
- ¶9 Estimated decommissioning cost: USD 2,000 million

¶10 **Offshore wind farm parameters:**

- ¶11 Installed capacity: 500 MW
- ¶12 Capacity factor: 0.42
- ¶13 Annual generation: 1,839,600 MWh
- ¶14 Design life: 25 years
- ¶15 Construction cost (GFCF): USD 2,500 million
- ¶16 Annual O&M expenditure: USD 50 million
- ¶17 Wholesale electricity price: USD 80/MWh

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Physical asset account for oil field (stock in million barrels)

Accounting entry	Value
Opening stock (1 Jan 2025)	200
Additions to stock	
Discoveries	0
Upward reappraisals	0
Total additions	0
Reductions in stock	
Extraction	20
Downward reappraisals	0

Accounting entry	Value
Total reductions	20
Closing stock (31 Dec 2025)	180
Derived measures	
Depletion (extraction for non-renewable resource)	20

¶1 *Table 3.6: Physical asset account for offshore oil field, 2025*

Resource rent calculation (net price method, central case USD 85/barrel)

Item	Value (USD million)
Gross output (20M bbl × USD 85)	1,700
less: Intermediate consumption (operating costs)	800
less: CFC on development infrastructure (USD 15,000M / 10 yr)	1,500
less: Return to produced capital (assumed 4% of net capital stock, indicative)	300
Resource rent (net price method)	**-900**
Memo: Unit resource rent per barrel	-45.0

¶1 *Table 3.7: Resource rent supplementary calculation, oil field 2025 (central case USD 85/barrel)*

¶2 At the central case price, resource rent is negative, as the mature field's development cost is high relative to current gross output. Where resource rent is non-positive, depletion is recorded as zero and the field's monetary asset value is held under review for downward reappraisal.

Monetary account for oil field (values in million USD, annual; central case USD 85/barrel)

Monetary flow	Annual value
Gross output (20M bbl × USD 85)	1,700
Intermediate consumption (operating costs)	800
Gross value added	900
Consumption of fixed capital and depletion	
of which: CFC on development infrastructure (USD 15,000M / 10 yr)	1,500
of which: Decommissioning provision (USD 2,000M / 10 yr)	200
of which: Mineral resource depletion (per resource rent, Table 3.7)	0
Total CFC and depletion	1,700
Net value added	-800

¶1 *Table 3.8: Production account for offshore oil field, 2025 (central case USD 85/barrel)*

Price sensitivity for net value added

¶1 *Table 3.9: Price sensitivity — net value added, oil field 2025 (USD million)*

Oil price (USD/bbl)	Gross output	GVA	CFC + depletion	Net value added
70	1,400	600	1,700	-1,100
85 (central)	1,700	900	1,700	-800
100	2,000	1,200	1,700	-500

¶2 Mature offshore fields with high development cost may report negative net value added across a wide range of price assumptions. This reflects depreciation of large past development capital,

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decommissioning provisioning, and a mature-life production profile. Compilers should report results alongside the resource rent calculation and price-sensitivity range.

¶3 **Decommissioning provision**: Terminal costs of USD 2,000 million are provisioned over the 10-year production life at USD 200 million per year, recorded as part of consumption of fixed capital. If actual decommissioning costs in Year 11 exceed the provision (e.g., USD 2,500 million due to unexpected contamination), the excess USD 500 million is recorded as remedial costs in the period incurred.

Physical supply account for offshore wind (energy in MWh)

Physical flow	Year 1	Year 2	…	Year 25
Installed capacity (MW)	500	500	…	500
Actual generation (MWh)	1,839,600	1,839,600	…	1,839,600
Capacity factor	0.42	0.42	…	0.42

¶1 *Table 3.10: Physical supply account for offshore wind, 2025*

Monetary account for offshore wind (values in million USD, annual)

Monetary flow	Annual value
Gross output (1,839,600 MWh × USD 80)	147.2
Intermediate consumption (O&M)	50.0
Gross value added	97.2
Consumption of fixed capital (USD 2,500M / 25 yr)	100.0
Net value added	-2.8

¶1 *Table 3.11: Production account for offshore wind, 2025*

¶2 Any subsidies received (feed-in tariffs, renewable energy certificates) should be recorded as current transfers in the distribution of income account.

¶3 **Wind wholesale price sensitivity**. The USD 80/MWh central case sits at the lower end of European 2024–25 offshore wind strike prices (USD 90–130/MWh typical). Benchmark prices should be sourced from IRENA LCOE data or published Contracts for Difference (CfD) strike prices for the relevant jurisdiction [41].

¶4 *Table 3.11a: Price sensitivity — net value added, offshore wind farm 2025 (USD million)*

Wholesale price (USD/MWh)	Gross output	GVA	CFC	Net value added
70	128.8	78.8	100.0	-21.2
80 (central)	147.2	97.2	100.0	-2.8
90	165.6	115.6	100.0	15.6
110	202.4	152.4	100.0	52.4

¶5 At USD 90/MWh or above the wind farm reports positive net value added, and compilers should document the price source in account metadata.

Spatial footprint summary

Spatial measure	Oil field	Wind farm
Lease area	25 km²	120 km²
Direct seabed footprint	0.15 km²	0.25 km²
Statutory safety zones (500m)	0.79 km²	62.8 km²

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Spatial measure	Oil field	Wind farm
Export cable corridor	0 km² (subsea pipeline)	20.0 km²
Effective exclusion area (from AIS)	1.2 km²	140.0 km²

¶1 *Table 3.12: Spatial footprint account for offshore energy installations, 2025. Safety-zone derivation: wind farm ~80 turbines × π × (0.5 km)² ≈ 62.8 km²; oil field 1 platform × π × (0.5 km)² ≈ 0.79 km².*

Environmental impact summary

Impact category	Oil field	Wind farm
Seabed disturbance	0.15 km²	0.25 km²
Underwater noise (construction)	180 dB re 1 µPa @ 1m (drilling)	190 dB re 1 µPa @ 1m (piling)
Pollution risk	2.5 million m³ produced water	Low
Exclusion zone	0.79 km²	62.8 km²
GHG emissions (direct)	450,000 tonnes CO2-eq	<5,000 tonnes CO2-eq

¶1 *Table 3.13: Environmental impact account for offshore energy installations, 2025*

¶2 These impact indicators feed into the ecosystem condition accounts described in Section 3.4, and support cumulative impact assessment across multiple installations within a spatial unit.

Integration and upward connections

¶1 **Upward linkages to policy**:

- ¶2 **TG-1.1 National Ocean Budgets**: The USD 200 million decommissioning provision represents a fiscal liability. Monetary depletion of oil reserves (calculated via resource rent applied to the 20 million barrels extracted) represents natural capital drawdown deducted from gross income to calculate environmentally adjusted net domestic product.
- ¶3 **TG-2.8 Climate Indicators**: Direct emissions of 450,000 tonnes CO2-eq from the oil field contribute to national greenhouse gas inventories. The 1.84 TWh of offshore wind generation displaces approximately 900,000 tonnes CO2-eq of fossil generation (assuming grid emission factor of 0.5 kg CO2/kWh).
- ¶4 **TG-1.8 Project Finance**: Total investment of USD 2,500 million against annual revenue of USD 147 million illustrates project finance challenges where long payback periods and policy support requirements create financing gaps addressable through blue bonds or sustainability-linked loans.

¶5 **Cross-account consistency**:

- ¶6 Oil extraction of 20 million barrels corresponds to extraction recorded in physical supply-use tables
- ¶7 Monetary depletion of oil reserves corresponds to adjustments in monetary asset accounts
- ¶8 Offshore wind generation of 1.84 TWh flows into national energy balance tables
- ¶9 Spatial footprints are consistent with marine spatial planning databases

4. Worked Example Cross-References

¶1 Cross-references for the worked example (Section 3.7) and integration with upstream and downstream circulars are provided in the relevant subsections of Section 3 and Section 1.2. The compilation procedure (Section 3.2) and the data sources (Section 2.3) define the practical workflow for compiling offshore energy accounts.

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5. Coordination Considerations

¶1 Effective offshore energy accounting requires coordination between national statistical offices, energy ministries, environment ministries, maritime authorities, industry associations, and regional bodies (including bilateral coordination on unitisation of transboundary reservoirs as set out in Section 3.1.1).

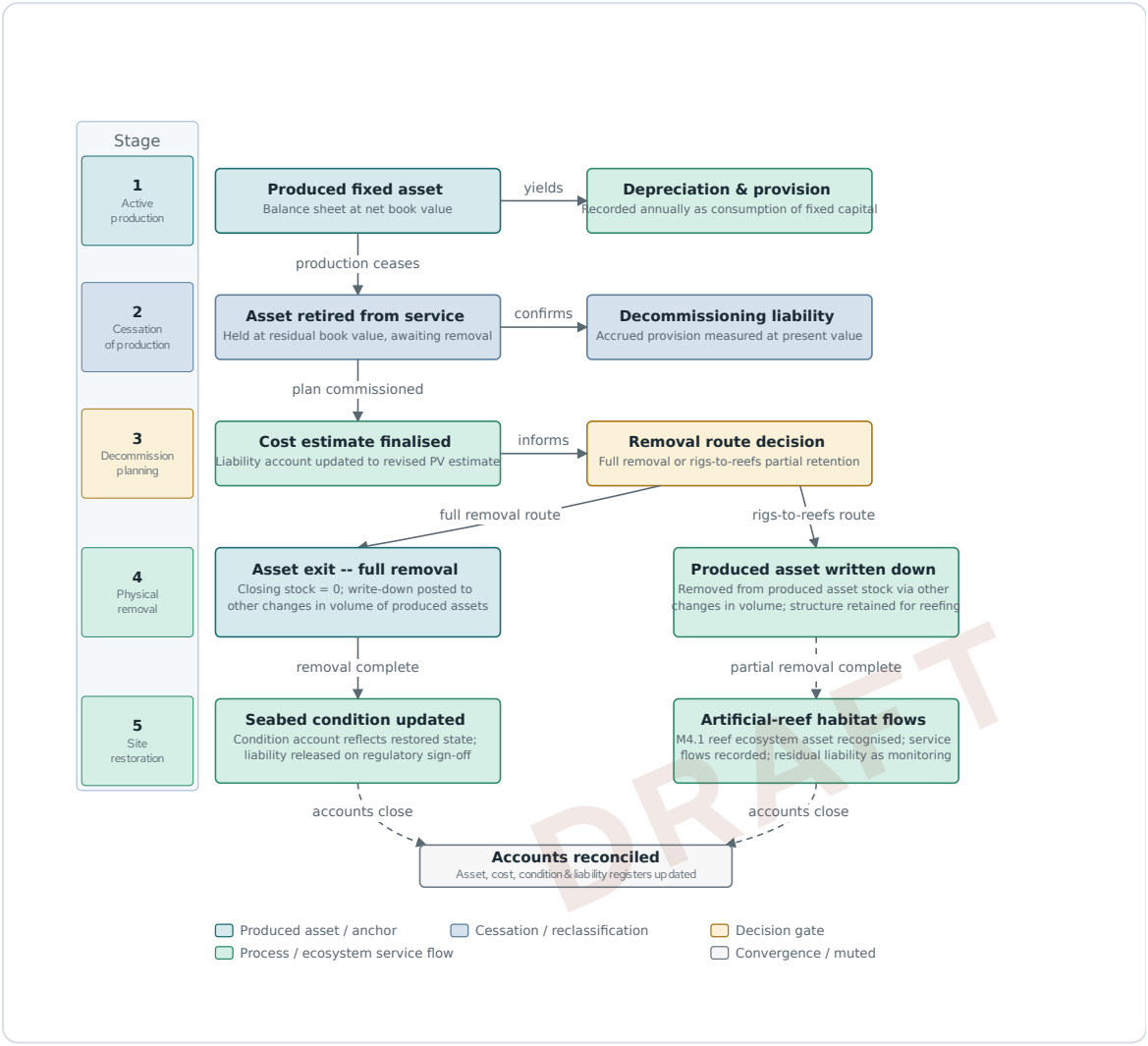


Figure 6.9.1 Five-stage offshore decommissioning sequence linking each stage to produced-asset exit, liability recognition, or artificial-reef reclassification.

Source: TG-6.9 draft, decommissioning treatment (stages, account entries, and liability provisions); 2025 SNA Glossary (definition of terminal costs); SEEA CF (2012) §4.194--4.209 (terminal vs remedial costs); IMO Resolution A.672(16) (guidelines for abandonment of offshore installations); OSPAR Decision 98/3 (disposal of disused offshore installations in the OSPAR maritime area); SEEA EA (2021) Ch. 4 (ecosystem extent transitions) and condition accounts (restoration).

6. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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4. ¶4 SEEA-Energy (2019), Chapters 3–6. Physical and monetary accounts for energy flows and stocks.
5. ¶5 2025 SNA, paragraphs 11.199–11.202 (renewable energy resource classification) and paragraph 11.85 (other structures including offshore installations). *Paragraph numbers to be verified against the final published 2025 SNA text.*
6. ¶6 UNCLOS (1982), Articles 56, 60, 76–79. Sovereign rights over continental shelf resources and regulation of offshore installations.
7. ¶7 Additional regulatory context is provided by: IMO MARPOL Convention and London Protocol (discharge accounting and decommissioning at sea); OSPAR Convention (North-East Atlantic offshore installation management); IFRS S2 and TNFD frameworks (corporate sustainability disclosures); and IEA, IRENA, and UNSD/UNCEEA work programmes.
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0. ¶10 SEEA Central Framework (2012), paragraphs 5.170–5.185 (application of UNFC-2009 for categorizing mineral and energy resources) and paras 5.170–5.195 on monetary valuation of mineral and energy resources. *Upper bound of paragraph range to be verified against the published SEEA CF PDF.*
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2. ¶12 SEEA Central Framework (2012), paragraph 5.93. Treatment of shared mineral and energy resources in national asset accounts.
3. ¶13 2025 SNA, paragraph 11.202. "For renewable energy resources, the following breakdown is recommended: (i) wind energy resources; (ii) solar energy resources; (iii) water energy resources; (iv) geothermal energy resources; and (v) other renewable energy resources."
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5. ¶15 IRENA offshore wind asset-life data. *Document title and section/annex reference to be confirmed — IRENA (2023) "Offshore Wind Energy: Technology Overview" was not verified by websearch; correct IRENA source to be identified before final publication.*
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0. ¶40 SDG Indicator 12.c.1. “Amount of fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels.”
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Maritime Transport and Ports

Provides thematic methodology for compiling ocean accounts relating to maritime transport and port activities.

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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OUTCOME

This Circular provides thematic methodology for compiling ocean accounts relating to maritime transport and port activities. Maritime transport carries more than 80 per cent of global merchandise trade by volume. The compilation of maritime transport accounts supports port investment planning, shipping decarbonisation tracking, and trade facilitation assessment.

Upon completion, users will be able to:

- Identify and classify maritime transport and port activities according to ISIC Revision 4 Division 50 (Water Transport) and Class 5222 (Service Activities Incidental to Water Transportation), applying the ocean economy thematic and extended account framework described in TG-3.3 Economic Activity Relevant to the Ocean
- Compile physical and monetary accounts for shipping emissions, including greenhouse gases and air pollutants, following the SEEA Central Framework air emissions accounting approach detailed in TG-3.4 Flows from Economy to Environment
- Measure the economic contribution of maritime transport through value added, employment, and trade flows using SNA 2025 production account methods, integrating these measures with the ocean economy structural indicators in TG-2.5 Structure and Function of the Ocean Economy
- Account for port infrastructure, including land use, dredging, and capital formation, within the asset accounting framework established in TG-3.1 Asset Accounts and extended in TG-6.11 Coastal Infrastructure Accounting
- Record environmental interactions including ballast water, hull biofouling, anchoring impacts, and underwater noise as residual flows and ecosystem condition impacts, linking to the emissions methodology in TG-2.8 Climate Indicators

This Circular connects maritime transport accounts to broader ocean economy measurement (TG-2.5), climate policy (TG-2.8), infrastructure investment (TG-6.11), and labour accounts (TG-3.5 Social Accounts: see Section 3.4.2 for the operational employment-to-social-accounts linkage).

Framework Position

This Circular specialises the ocean-economy identification method of TG-3.3 Economic Activity Relevant to the Ocean for one sector: maritime transport and ports, ISIC Revision 4 Division 50 and Class 5222. TG-3.3 owns the general method for identifying ocean-related industries and the ISIC concordance; this Circular adds the sector-specific apportionment, the port asset treatment, and the vessel-activity basis for emissions.

It cross-refers for the residual-flow and air-emissions framework (TG-3.4), produced asset accounting (TG-3.1), employment and social accounts (TG-3.5) and indicator derivation (TG-2.5, TG-2.8).

Port infrastructure as a produced coastal asset is TG-6.11; this Circular records it as sector capital formation. Vessel-sourced litter is TG-6.12.

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1. Outcome

¶1 This Circular provides thematic methodology for compiling ocean accounts relating to maritime transport and port activities. Maritime transport carries more than 80 per cent of global merchandise trade by volume.[1] The compilation of maritime transport accounts supports port investment planning, shipping decarbonisation tracking, and trade facilitation assessment.

¶2 Upon completion, users will be able to:

- ¶3 Identify and classify maritime transport and port activities according to ISIC Revision 4 Division 50 (Water Transport) and Class 5222 (Service Activities Incidental to Water Transportation), applying the ocean economy thematic and extended account framework described in **TG-3.3 Economic Activity Relevant to the Ocean**[2]
- ¶4 Compile physical and monetary accounts for shipping emissions, including greenhouse gases and air pollutants, following the SEEA Central Framework air emissions accounting approach detailed in **TG-3.4 Flows from Economy to Environment**[3]
- ¶5 Measure the economic contribution of maritime transport through value added, employment, and trade flows using SNA 2025 production account methods, integrating these measures with the ocean economy structural indicators in **TG-2.5 Structure and Function of the Ocean Economy**[4]
- ¶6 Account for port infrastructure, including land use, dredging, and capital formation, within the asset accounting framework established in **TG-3.1 Asset Accounts** and extended in **TG-6.11 Coastal Infrastructure Accounting**[5]
- ¶7 Record environmental interactions including ballast water, hull biofouling, anchoring impacts, and underwater noise as residual flows and ecosystem condition impacts, linking to the emissions methodology in **TG-2.8 Climate Indicators**[6]

¶8 This Circular connects maritime transport accounts to broader ocean economy measurement (**TG-2.5**), climate policy (**TG-2.8**), infrastructure investment (**TG-6.11**), and labour accounts (**TG-3.5 Social Accounts**: see Section 3.4.2 for the operational employment-to-social-accounts linkage).

¶9 **Framework Position**

¶10 This Circular specialises the ocean-economy identification method of **TG-3.3 Economic Activity Relevant to the Ocean** for one sector: maritime transport and ports, ISIC Revision 4 Division 50 and Class 5222. TG-3.3 owns the general method for identifying ocean-related industries and the ISIC concordance; this Circular adds the sector-specific apportionment, the port asset treatment, and the vessel-activity basis for emissions.

¶11 It cross-refers for the residual-flow and air-emissions framework (**TG-3.4**), produced asset accounting (**TG-3.1**), employment and social accounts (**TG-3.5**) and indicator derivation (**TG-2.5**, **TG-2.8**).

¶12 Port infrastructure as a produced coastal asset is **TG-6.11**; this Circular records it as sector capital formation. Vessel-sourced litter is **TG-6.12**.

2. Requirements

¶1 This Circular builds upon the following prerequisites:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** — foundational framework for GOAP Technical Guidance, including core concepts, terminology, and accounting principles.
- ¶3 **TG-3.3 Economic Activity Relevant to the Ocean** — general approach to compiling accounts for ocean-related economic activity, including industry classifications, supply and use tables, and the ocean economy thematic and extended account framework. The maritime transport accounts compiled under this Circular are a sector-specific application of the methods in TG-3.3.

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¶4 **Related Circulars (optional but recommended):**

- ¶5 **TG-2.5 Structure and Function of the Ocean Economy** – indicator derivation methodology for transport GVA shares, employment intensity, and export contribution.
- ¶6 **TG-2.8 Climate Indicators** – GHG emission indicators and integration into climate monitoring frameworks.
- ¶7 **TG-3.1 Asset Accounts** – produced asset accounting framework underlying valuation of port infrastructure and vessel capital stock.
- ¶8 **TG-3.4 Flows from Economy to Environment** – detailed emissions accounting methodology, including classification of residual flows underpinning the shipping emissions accounts in Section 3.3.
- ¶9 **TG-4.1 Remote Sensing** – port area spatial delineation using satellite imagery and GIS, supporting land use mapping in Section 3.2.1.
- ¶10 **TG-6.9 Offshore Energy** – accounting treatment of offshore support vessels and maritime logistics of offshore energy installations.
- ¶11 **TG-6.11 Coastal Infrastructure Accounting** – broader infrastructure accounting framework within which port capital formation is situated.

¶12 **Readiness and sequencing.** Whether a country is positioned to compile this account at all – mandate, data architecture, capacity and the order in which to build – is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

3.1 Maritime Transport Activities

3.1.1 Industry Classification Framework

¶1 Maritime transport activities are classified according to ISIC Revision 4.[7]

¶2 **Division 50 – Water Transport**

¶3 This division encompasses the transport of passengers or freight over water, whether scheduled or not, distinguishing between sea-going vessels and inland waterway vessels based on vessel type.[8]

ISIC Code	Description	Scope
501	Sea and coastal water transport	Transport on sea-going vessels
5011	Sea and coastal passenger water transport	Ferries, cruises, water taxis on sea-going vessels
5012	Sea and coastal freight water transport	Container ships, tankers, bulk carriers, general cargo
502	Inland water transport	Transport on vessels not suitable for sea transport
5021	Inland passenger water transport	Rivers, canals, lakes, harbours
5022	Inland freight water transport	Inland freight on waterways and ports

¶4 These codes have been verified against the official ISIC Rev.4 publication.[9] Compilers should also note the correspondence with the Central Product Classification (CPC) Ver.2.1 for product-level analysis of transport services, which aligns with the supply and use table approach described in **TG-3.3 Economic Activity Relevant to the Ocean**.

¶5 **Inland waterway transport (ISIC 502).** For inland navigation emissions, compilers should refer to the IPCC 2006 Guidelines, Volume 2, Chapter 3, which provides default emission factors for wa-

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ter-borne navigation including inland vessels.[10] Vessels operating in both inland and coastal environments should be classified by predominant area of operation. Compilers should document the classification rule in metadata and apply it consistently across the time series.

¶6 **Supporting Activities (Division 52)**

ISIC Code	Description	Scope	Coverage
5222	Service activities incidental to water transportation	Harbour operations, pilotage, lighterage, vessel salvage, navigation services, berthing	Mandatory
5224	Cargo handling	Loading and unloading of vessels (port portion)	Mandatory (apportioned by maritime ratio)
5229	Other transportation support activities	Freight forwarding, customs agencies	Supplementary

¶7 The "Coverage" column distinguishes ISIC classes that are mandatory components of maritime transport accounts (ISIC 5222 and the maritime-attributable share of ISIC 5224) from those that are supplementary. ISIC 5224 (Cargo Handling) covers both maritime and non-maritime cargo handling. Compilers should apply a maritime ratio to apportion the maritime share, as illustrated in the worked example in Section 3.7 using an illustrative 0.70 ratio.[11]

¶8 *(Note: ISIC Division 30, ship building [3011] and pleasure boats [3012], is excluded from TG-6.10 scope. Record these under general industry accounts.)*

3.1.2 Vessel Categories

¶1 For accounting purposes, the commercial fleet may be disaggregated by vessel type. Table 3.1.1 below summarises the principal categories[12].

Vessel category	Description
Container vessels	Carry standardised cargo containers.
Bulk carriers	Dry bulk cargo (grains, ores, coal).
Tankers	Liquid bulk cargo (oil, chemicals, liquefied gas).
General cargo vessels	Non-containerised cargo.
Roll-on/roll-off (Ro-Ro) vessels	Wheeled cargo.
Passenger vessels	Ferries and cruise ships.
Fishing vessels	Commercial fishing (cross-reference **TG-6.7 Fisheries Accounting: Integrating Stock Assessment**).
Service vessels	Tugs, dredgers, offshore support vessels (cross-reference **TG-6.9 Offshore Energy** for vessels supporting offshore installations).

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¶2 This disaggregation is important for emissions accounting because emission factors vary by vessel type, size, and engine configuration. The vessel classification should be used consistently across physical activity accounts, economic accounts, and emissions accounts. The Fourth IMO GHG Study (2020) provides emission factor data by vessel type and operating mode that can serve as a starting point where country-specific factors are not available.[13]

3.1.3 Trade Flow Measurement

¶1 Maritime trade flows are measured through:

- ¶2 **Volume (physical):** Tonnes loaded and unloaded at ports
- ¶3 **Value (monetary):** Value of goods transported (CIF/FOB basis)[14]

- ¶4 **Activity (operational):** Vessel movements, port calls, cargo handling operations

¶5 Data sources include port authority records, customs declarations, automatic identification system (AIS) tracking, and shipping company reports. Satellite AIS covers most commercial vessels over 300 gross tonnes in major shipping lanes, though coverage in remote ocean areas, smaller vessel classes, and terrestrial AIS-predominant regions remains incomplete.[15] Compilers should cross-check AIS-derived activity data against vessel registry sources such as UNCTAD's *Review of Maritime Transport* and document coverage limitations in metadata.

3.2 Port Infrastructure

3.2.1 Port Areas and Land Use

¶1 Port infrastructure accounting requires spatial delineation of port areas. Table 3.2.1 below summarises the main land-use components of a port[16].

Component	Description
Quays and berths	Vessel mooring facilities.
Storage areas	Container yards, warehouses, tank farms.
Intermodal connections	Rail terminals, road connections.
Administrative areas	Offices, customs facilities.
Ancillary facilities	Ship repair, bunkering stations.

¶2 Port areas should be mapped using consistent spatial references (see **TG-4.1 Remote Sensing**) and linked to the SEEA land cover and land use classifications.[17] The port boundary should encompass the full operational area including anchorages, fairways, and approach channels.

3.2.2 Dredging and Land Reclamation

¶1 Dredging activities modify the seabed to maintain or create navigational channels and berthing areas. The distinction between capital and maintenance dredging determines SNA treatment:[18]

Type	Definition	SNA treatment
Capital dredging	Creates new channel/berth capacity or enlarges existing capacity beyond previous design depth or width	Gross fixed capital formation (GFCF)
Maintenance dredging	Restores a channel or berth to its original design depth and width following sedimentation	Intermediate consumption

¶2 Compilers should apply this rule to dredging expenditure records from port authorities and contractor invoices. Where invoices do not clearly distinguish the two, compilers should document the criterion used. For the fuller treatment of capital versus maintenance distinctions for coastal works, cross-reference **TG-6.11 Coastal Infrastructure Accounting** Section 3.2.4.

¶3 **Physical measures:**

- ¶4 Volume of sediment removed (cubic metres)
- ¶5 Disposal location (ocean dumping, beneficial reuse, confined disposal)
- ¶6 Channel depth and width specifications

¶7 **Dredge spoil as a material flow.** Dredged sediment should be recorded as a material flow in the SEEA Central Framework physical flow accounts. SEEA CF paragraph 3.267 treats dredging material flows under physical flow accounting, with contaminated spoil recorded as a residual flow within waste accounts and unpolluted spoil excluded from the waste-flow boundary.[19] Compilers should record dredge spoil volumes by disposal pathway and sediment quality classification.

¶8 **Environmental considerations:**

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- ¶9 Sediment quality (contaminant levels)
- ¶10 Impacts on benthic habitats
- ¶11 Turbidity and sedimentation effects

¶12 Land reclamation for port expansion should be recorded as a transformation of marine extent to land (cross-reference **TG-3.1 Assets**). [20] Port expansion through reclamation may also trigger requirements under coastal infrastructure accounting (see **TG-6.11 Coastal Infrastructure Accounting**).

3.2.3 Port Capital Formation

¶1 Gross fixed capital formation in ports includes investment in: [21]

- ¶2 Breakwaters and seawalls
- ¶3 Quay structures and berths
- ¶4 Container handling equipment (cranes, straddle carriers)
- ¶5 Warehouses and storage facilities
- ¶6 Navigational aids and vessel traffic systems
- ¶7 Environmental protection infrastructure (oil spill response, waste reception)

¶8 Capital formation should be recorded following SNA 2025 principles, distinguishing new construction and major improvements (gross fixed capital formation) from routine maintenance (intermediate consumption). Depreciation schedules vary by asset type: quay structures may have useful lives of 50 years or more, whilst handling equipment typically depreciates over 15–25 years. The perpetual inventory method (PIM) is the standard approach for compiling port capital stock. [22]

3.2.4 Vessel Capital Stock

¶1 Vessels are produced assets that should appear in national balance sheets as transport equipment under SNA 2025 asset classification AN1131. [23] Vessel capital stock is required for: (i) calculating consumption of fixed capital used to derive net value added in Table 3.7.1, and (ii) supporting complete asset accounting for the maritime transport industry.

¶2 **Data sources for vessel capital stock:**

- ¶3 National vessel registries and maritime administration records (acquisition costs, vessel age, type)
- ¶4 Lloyd's Register / IHS Markit (now LSEG/Clarksons) maritime fleet databases (vessel characteristics, valuation benchmarks)
- ¶5 Customs records on vessel imports and exports
- ¶6 Shipping company financial statements (book values, depreciation schedules)

¶7 **PIM application.** Compilers should apply the perpetual inventory method to vessel acquisition costs using vessel-type-specific service lives and depreciation profiles (container vessels typically 20–30 years, bulk carriers and tankers 25–30 years, and passenger ferries 30–40 years). For the general PIM framework, see **TG-3.1 Asset Accounts**. The depreciation entry for ISIC 501 in Table 3.7.1 represents vessel depreciation derived through this PIM approach.

3.3 Emissions Accounting

3.3.1 Greenhouse Gas Emissions

¶1 Following the SEEA Central Framework, air emissions accounts record the generation of emissions by resident economic units by type of substance. [24]

¶2 **GHG emissions from shipping include:**

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Substance	Chemical Symbol	Primary Source	GWP100 (AR6)
Carbon dioxide	CO2	Fuel combustion	1
Methane (fossil)	CH4	Fuel combustion, LNG slip	29.8
Methane (biogenic)	CH4	Biofuel combustion	27.0
Nitrous oxide	N2O	Fuel combustion	273

¶3 GWP100 values are taken from IPCC AR6 WGI Chapter 7 Supplementary Material Table 7.SM.7.[25] Compilers should align the GWP cycle (AR5 vs. AR6) used in maritime transport accounts with the cycle adopted in their country's national GHG inventory under UNFCCC reporting. AR5 GWP100 values may be retained for historical comparability in time series where the national inventory has not yet transitioned.

¶4 **Estimation methodology:**

¶5 Shipping emissions are typically estimated using activity-based methods:[26]

¶6

$$E = \sum_{v} \sum_{m} (A_{v,m} \times EF_{v,m})$$

¶7 Where:

- ¶8 E = Total emissions
- ¶9 A = Activity (fuel consumption or distance travelled)
- ¶10 EF = Emission factor
- ¶11 v = Vessel type
- ¶12 m = Operating mode (cruising, manoeuvring, at berth)

¶13 **Data sources:**

- ¶14 Ship fuel consumption records
- ¶15 AIS-derived activity data
- ¶16 Port call statistics
- ¶17 National fuel sales data with maritime allocation

¶18 The Fourth IMO GHG Study (2020) provides emission factor data by vessel type and operating mode. Compilers may also draw on the IPCC 2006 Guidelines, Volume 2, Chapter 3.[27]

¶19 *Table 3.3.1: Shipping emission calculation methods*

Emission Source	Calculation Basis	Data Source	Account Entry
Main engines	Fuel consumption x EF	Fuel sales, voyage reports	Residual flow (air)
Auxiliary engines	Activity hours x load factor x EF	Port records	Residual flow (air)
Underwater noise	Vessel type x speed	AIS data	Condition impact
Oil discharge	Incident reports	Coast guard	Residual flow (water)

¶20 Ballast water discharge is not an air emission or a SEEA residual air flow. It is a biological pressure with ecosystem condition implications. The accounting treatment for ballast water is set out in Section 3.5.1.

¶21 **Residence principle application:**

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¶22 Following the SEEA CF residence principle, emissions should be attributed to the country where the operating enterprise is resident, not the flag state of the vessel.[28] In practice, emissions from a vessel flagged in one country but operated by an enterprise resident in another should be attributed to the country of the operator.

¶23 **Reconciliation with IPCC national inventories.** The SEEA-based residence attribution will differ from IPCC national inventory treatment, which excludes international marine bunker fuels from national totals and reports them as a memo item.[29] Compilers should prepare a bridging table in metadata distinguishing SEEA-attributed shipping emissions from IPCC memo-item international marine bunker fuel quantities. For broader reconciliation between thematic emissions accounts and national climate reporting, see **TG-2.8 Climate Indicators**.

¶24 **Flag-of-convenience and complex vessel ownership.** Compilers should apply the following decision tree for residence attribution:

Case	Situation	Attribution rule
1	Vessel flagged and operating enterprise resident in same country	Attribute emissions and output to that country
2	Flag state differs from operating enterprise's country of residence	Attribute to the operator's country of residence
3	Complex multinational ownership through shell companies and multiple flag states	Apply the ultimate beneficial ownership chain consistent with SNA 2025 guidance; document the chain in metadata

¶25 Practical sources include the IMO Global Integrated Shipping Information System (GISIS) and Lloyd's Register / IHS Markit (LSEG/Clarksons) maritime databases. Open or international registries account for the majority of global gross tonnage, so most compiling countries will encounter Case 2 or Case 3 in practice.

3.3.2 Air Pollutants

¶1 Beyond GHGs, maritime transport releases air pollutants with local and regional health impacts:[30]

Pollutant	Symbol	Impact	Mitigation
Sulphur oxides	SOx	Acid rain, respiratory health	Low-sulphur fuel, scrubbers
Nitrogen oxides	NOx	Smog, respiratory health	Emission control areas (ECAs)
Particulate matter	PM	Cardiovascular, respiratory	Engine efficiency, fuel quality
Black carbon	BC	Arctic warming, health	Operational measures

¶2 IMO MARPOL Annex VI regulates these emissions and has established Emission Control Areas. The 2020 global sulphur cap of 0.50 per cent m/m has had a material effect on fuel composition and emissions profiles that should be reflected in time series accounts.[31]

¶3 For linkage to health impacts, see **TG-2.7 Pollution and Other Flows**. For integration of shipping GHG emissions into national climate indicator frameworks, see **TG-2.8 Climate Indicators**.

3.3.3 Underwater Noise

¶1 Shipping is a major source of chronic underwater noise pollution, particularly at low frequencies (10–1000 Hz) that overlap with marine mammal communication bands.[32]

¶2 Noise emissions can be characterised by:

- ¶3 **Source level** (dB re 1 microPa at 1 m)
- ¶4 **Frequency spectrum**
- ¶5 **Temporal patterns** (continuous vs. intermittent)

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¶6 Accounting for underwater noise requires:

- ¶7 Vessel traffic density data (AIS)
- ¶8 Source level models by vessel type and speed
- ¶9 Propagation modelling for spatial distribution
- ¶10 Overlay with sensitive habitats and species distributions

¶11 Underwater noise accounting is an emerging area where data availability and standardised methods remain under development. The IMO Guidelines for the Reduction of Underwater Noise from Commercial Shipping (MEPC.1/Circ.833) provide a voluntary framework, whilst regional initiatives such as JOMOPANS are developing monitoring methodologies.[33] Compilers should record noise indicators where feasible and note limitations in metadata. For linkage to ecosystem condition assessment, see **TG-2.1 Biophysical Indicators**.

3.4 Economic Measurement

3.4.1 Value Added

¶1 Maritime transport value added is calculated according to SNA 2025 principles:[34]

¶2 **Gross Value Added (GVA)** = Output − Intermediate Consumption

¶3 For maritime transport industries (ISIC 50, 5222):

- ¶4 **Output** = Freight revenue + passenger revenue + charter income + ancillary services
- ¶5 **Intermediate consumption** = Fuel, port fees, insurance, maintenance, provisions

¶6 **Net Value Added** = GVA − Depreciation

¶7 **Illustrative calculation structure:**

Component	ISIC 501	ISIC 502	ISIC 5222	Total Maritime
Output (P.1)	[value]	[value]	[value]	[sum]
Intermediate consumption (P.2)	[value]	[value]	[value]	[sum]
GVA (B.1g)	[value]	[value]	[value]	[sum]
Depreciation (P.51c)	[value]	[value]	[value]	[sum]
NVA (B.1n)	[value]	[value]	[value]	[sum]

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¶8 For countries with material transshipment activity, care should be taken to correctly attribute output to resident enterprises, consistent with the balance of payments treatment of freight transport described in BPM6.

3.4.2 Employment

¶1 Employment in maritime transport includes:[35]

¶2 **Seafarers:**

- ¶3 Officers and ratings on commercial vessels
- ¶4 Measured by nationality (flag state vs. residence state considerations)

¶5 **Shore-based employment:**

- ¶6 Port workers (stevedores, crane operators)
- ¶7 Port authority and maritime agency staff
- ¶8 Ship agents, freight forwarders
- ¶9 Ship repair and maintenance workers

¶10 Employment data should distinguish:

- ¶11 Number of persons employed

- ¶12 Full-time equivalents (FTEs)
- ¶13 Hours worked
- ¶14 Compensation of employees

¶15 **Residence-basis measurement and seafarer reconciliation.** Employment should be measured on a residence basis consistent with SNA 2025 Chapter 19, adjusting flag-state data from MLC 2006 sources to reflect the number of seafarers resident in the compiling country regardless of vessel flag.[36] The BIMCO/ICS *Seafarer Workforce Report* (2021 edition) provides national seafarer supply estimates by country of residence that may be used as a reference benchmark.[37] Compilers should document the reconciliation approach in metadata and reflect the adjustment in the employment row of the worked example (see the note attached to Table 3.7.2).

¶16 **Linkage to social accounts.** For integration of maritime transport employment data with social accounts, including labour income distribution, working conditions, occupational safety, and gender disaggregation, see **TG-3.5 Social Accounts**.

3.4.3 Supply Chain Linkages

¶1 Maritime transport has extensive backward and forward linkages:[38]

¶2 **Backward linkages (inputs):**

- ¶3 Shipbuilding and repair (ISIC 3011)
- ¶4 Fuel suppliers
- ¶5 Port services
- ¶6 Classification societies
- ¶7 Marine insurance

¶8 **Forward linkages (outputs):**

- ¶9 Wholesale and retail trade
- ¶10 Manufacturing (imported inputs)
- ¶11 Agriculture (commodity exports)
- ¶12 Tourism (cruise industry)

¶13 These linkages can be quantified using supply and use tables and input-output analysis (see **TG-3.3 Economic Activity Relevant to the Ocean**).[39]

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3.5 Environmental Interactions

¶1 Table 3.5.1 summarises the main environmental interactions of maritime transport and their corresponding SEEA account entries.

¶2 *Table 3.5.1: Maritime transport environmental interactions and SEEA flow types*

Interaction	SEEA Flow Type	Section	Related Circular
Ballast water discharge	Biological pressure (ecosystem condition)	3.5.1	**TG-2.1 Biophysical Indicators**
Hull biofouling	Residual flow (biological)	3.5.2	**TG-3.4 Flows from Economy to Environment**
Anchoring damage	Ecosystem condition change	3.5.3	**TG-6.1 Coral Reef**, **TG-6.3 Seagrass**
Oil and chemical spills	Residual flow (water)	3.5.4	**TG-3.4 Flows from Economy to Environment**

3.5.1 Ballast Water

¶1 Ships take on ballast water for stability, potentially transporting organisms across biogeographic boundaries.[40] Ballast water discharge is treated as a biological pressure indicator rather than a SEEA residual air or water flow. Compilers should record ballast water indicators alongside ecosystem condition variables and link them to invasive species monitoring programmes.

¶2 **Accounting elements:**

- ¶3 Volume of ballast water discharged (by port, by vessel origin)
- ¶4 Species detection monitoring
- ¶5 Compliance with Ballast Water Management Convention
- ¶6 Expenditure on ballast water treatment systems (recorded as environmental protection expenditure)

¶7 **Cross-reference:** See **TG-2.1 Biophysical Indicators**.

3.5.2 Hull Biofouling

¶1 Hull biofouling is a pathway for invasive species introduction.[41]

¶2 **Accounting elements:**

- ¶3 Antifouling system application and maintenance
- ¶4 Hull cleaning activities and waste disposal
- ¶5 Biofouling inspections at ports
- ¶6 Linkage to invasive species monitoring

3.5.3 Anchoring Impacts

¶1 Anchoring causes physical damage to seabed habitats, particularly seagrass meadows and coral reefs.[42]

¶2 **Accounting elements:**

- ¶3 Anchorage locations and frequency of use
- ¶4 Duration of anchor events
- ¶5 Overlap with sensitive habitat areas
- ¶6 Mooring buoy installation as mitigation

¶7 **Cross-reference:** See **TG-6.1 Coral Reef** and **TG-6.3 Seagrass**.

3.5.4 Oil and Chemical Spills

¶1 Despite improved safety, shipping remains a source of marine pollution from accidental and operational discharges.[43]

¶2 **Accounting elements:**

- ¶3 Spill volume and substance type
- ¶4 Location and environmental sensitivity
- ¶5 Response costs
- ¶6 Natural resource damage assessments
- ¶7 Linkage to SEEA pollution flow accounts (**TG-3.4 Flows from Economy to Environment**)

¶8 Operational discharges (bilge water, cargo residues) remain a persistent source of chronic pollution that should be captured in flow accounts alongside acute events.

3.6 Compilation Procedure: Maritime Transport Supply-Use Table

¶1 Compiling maritime transport accounts follows a systematic procedure for extracting maritime transport sub-matrices from national supply and use tables, adapted from SNA 2025 Chapter 15

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and the ocean economy thematic account compilation approach in **TG-3.3 Economic Activity Relevant to the Ocean** Section 3.4.[44]

Step-by-step compilation

¶1 **Step 1: Identify maritime transport industries by ISIC code.** Using Table 3.1.1, identify all ISIC classes constituting maritime transport: Division 50, Class 5222, Class 5224 (port portion), and related industries. For each class, determine whether it is wholly maritime-related (ocean ratio = 1.0) or partially maritime-related (ocean ratio < 1.0).

¶2 **Step 2: Extract maritime transport sub-matrices from national SUTs.** From the balanced national supply and use tables, extract columns corresponding to maritime transport industries to create a maritime transport supply table and use table.

¶3 *Excluding non-resident enterprise output.* For countries that are major port hubs or transshipment centres, maritime transport columns may include services provided by non-resident enterprises. The residence principle requires excluding non-resident maritime output before deriving GVA. Practical data sources include balance of payments supplementary data on transportation services and port authority records of vessel nationality and operator residence. Cross-reference BPM6 paragraphs 10.73–10.88 on transportation services.[45]

¶4 **Step 3: Determine the maritime share for mixed industries.** For partially maritime-related industries, estimate the share of output attributable to maritime activity. For Class 5224 (Cargo Handling), the 0.70 ratio used in Section 3.7 is illustrative, and compilers must derive their own country-specific ratio from primary data. At least one of the following methods must be documented in metadata: (a) *Revenue-based split*: share of cargo handling revenue attributable to seaport establishments from structural business surveys or port authority financial accounts. (b) *Physical-unit split*: seaport cargo handling tonnes as a share of total cargo handling tonnes from port authority and customs statistics. Where neither method is feasible, apply a sensitivity analysis around the assumed ratio and report the range of resulting GVA estimates in metadata.

¶5 **Step 4: Calculate Maritime Transport Direct GVA.** For each maritime industry, multiply the industry's gross value added from the Use Table by its maritime ratio:

¶6

$$\text{Maritime Transport Direct GVA} = \sum_{i} (\text{GVA}_i \times \text{Maritime ratio}_i)$$

¶7 **Step 5: Compile employment accounts.** Using labour input rows from the Use Table, calculate maritime transport employment by applying the same maritime ratios to employment data by industry.

¶8 **Step 6: Derive trade flow indicators.** From the Exports column in the Use Table, sum across maritime transport service products to calculate maritime transport service exports. From customs data, compile merchandise trade volumes and values passing through ports.

¶9 **Step 7: Integrate emissions accounts.** Using the emissions calculation methods in Section 3.3, compile air emissions by maritime transport industries from national air emissions accounts, ensuring consistency with GVA and activity data in the maritime transport SUTs.

Data sources

¶1 Key data sources for maritime transport account compilation:[46]

- ¶2 National supply and use tables (primary source for GVA and output)
- ¶3 Port authority statistical reports (cargo volumes, vessel calls, employment)
- ¶4 Maritime administration records (vessel registries, seafarer certification)

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- ¶5 Structural business surveys (port and shipping company financial data)
- ¶6 Customs declarations (trade values and volumes)
- ¶7 AIS tracking data (vessel activity, voyage data)
- ¶8 Fuel sales records (maritime fuel consumption for emissions)
- ¶9 Balance of payments transport services supplementary data (for resident/non-resident enterprise attribution)

3.7 Worked Example: Synthetic Port/Shipping Account

¶1 This section presents a worked example for a synthetic medium-income coastal state ("Country B") with a total GDP of approximately USD 80 billion, total employment of 15 million persons, and two major ports handling combined cargo volumes of 45 million tonnes per year. The example illustrates the mixed-industry apportionment for ISIC 5224. It applies an illustrative maritime ratio of 0.70.

¶2 **Table 3.7.1: Country B Maritime Transport Account — Production Account**

Component	ISIC 501 (Sea Transport)	ISIC 5222 (Port Services)	ISIC 5224 (Cargo Handling, 0.70 maritime ratio)	Total Maritime
Output (P.1)	1,850	680	245	2,775
Intermediate consumption (P.2)	1,200	380	140	1,720
GVA (B.1g)	650	300	105	1,055
Depreciation (P.51c)	120	85	18	223
NVA (B.1n)	530	215	87	832

¶3 All monetary values in millions of USD at current prices. The ISIC 5224 column reports the maritime-attributable share after applying the 0.70 maritime ratio (total ISIC 5224 output of 350 x 0.70 = 245). The depreciation entry for ISIC 501 (USD 120 million) reflects vessel capital consumption derived through the perpetual inventory method described in Section 3.2.4.

¶4 **Table 3.7.2: Country B Maritime Transport Employment**

Indicator	Sea Transport	Port Services	Cargo Handling (0.70)	Total Maritime
Persons employed	22,000	18,000	5,600	45,600
FTE employment	21,500	17,000	5,400	43,900
Average compensation (USD/year)	18,500	16,200	14,800	17,138
Labour productivity (USD GVA per person)	29,545	16,667	18,750	23,136

¶5 Sea transport employment is measured on a residence basis as set out in Section 3.4.2. For Country B, seafarer employment from MLC flag-state data has been adjusted to a residence basis using the BIMCO/ICS *Seafarer Workforce Report* (2021) national supply estimates.

¶6 **Table 3.7.3: Country B Maritime Transport Emissions**

¶7 *Panel A: Greenhouse gases (tonnes CO2e, AR6 GWP100)*

Emission	Sea Transport	Port Services	Cargo Handling (0.70)	Total
CO2 from fuel combustion	1,250,000	85,000	22,000	1,357,000
CH4 (fossil, GWP 29.8)	191	16	4	211

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Emission	Sea Transport	Port Services	Cargo Handling (0.70)	Total
N2O (GWP 273)	227	19	5	251
Total GHG (CO2e)	1,250,418	85,035	22,009	1,357,462
Emission intensity (kg CO2e per USD 1,000 GVA)	1,924	283	210	1,287

¶8 *Note (biogenic CH4):* The CH4 row applies the AR6 GWP100 of 29.8 for fossil-sourced methane. As biofuel blends and bio-LNG become material under IMO's 2023 GHG Strategy fuel-mix scenarios, biogenic CH4 should be reported separately at GWP100 = 27.0 (AR6 non-fossil value). Compilers should document the fuel-type split and apply the corresponding GWP factor for each CH4 emission stream once biofuel uptake is material.

¶9 *Panel B: Air pollutants (tonnes; illustrative, derived from the same fuel-consumption activity data using EMEP/EEA emission factors)*

Pollutant	Sea Transport	Port Services	Cargo Handling (0.70)	Total
SOx	4,200	95	25	4,320
NOx	25,500	1,400	360	27,260
PM2.5	1,150	75	20	1,245
Black carbon (BC)	165	9	2	176

¶10 The figures in Panel B are derived from the same fuel-consumption activity data used for Panel A, applying air pollutant emission factors from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (2019), Chapter 1.A.3.d. Emission factors applied at the IMO 2020 global 0.50% sulphur cap (non-ECA). Compilers applying this method to pre-2020 data or ECA-regulated routes should substitute factors consistent with the applicable sulphur limit. For linkage to health impact assessment, see **TG-2.7 Pollution and Other Flows**.

¶11 **Table 3.7.4: Country B Port Infrastructure Capital Stock (PIM approach)**

Asset Type	Gross Capital Stock	Accumulated Depreciation	Net Capital Stock	Annual Depreciation
Quay walls and berths	1,200	480	720	20
Container handling equipment	350	210	140	23
Port buildings and facilities	280	140	140	8
Breakwaters and navigation aids	450	180	270	9
Total port infrastructure	2,280	1,010	1,270	60

¶12 All monetary values in millions of USD at current replacement cost. The net capital stock of USD 1,270 million represents approximately 4.2 times the annual GVA from port services (USD 300 million). Vessel capital stock for ISIC 501 (not shown: see Section 3.2.4) is compiled separately under SNA asset class AN1131. The compilation applies vessel-type-specific PIM parameters. The USD 60 million annual depreciation on port infrastructure is lower than port-services depreciation in Table 3.7.1 (USD 85 million) because ISIC 5222 depreciation also covers fixed assets outside this table; compilers should reconcile the two and document the USD 25 million difference by asset type.

¶13 The maritime transport sector contributes 1.3 per cent of Country B's GDP (USD 1,055 million / USD 80 billion) whilst employing 0.30 per cent of the workforce (45,600 / 15 million). The GHG emission intensity of 1,287 kg CO2e per USD 1,000 of GVA provides a baseline for tracking decarbonisation progress under IMO targets.

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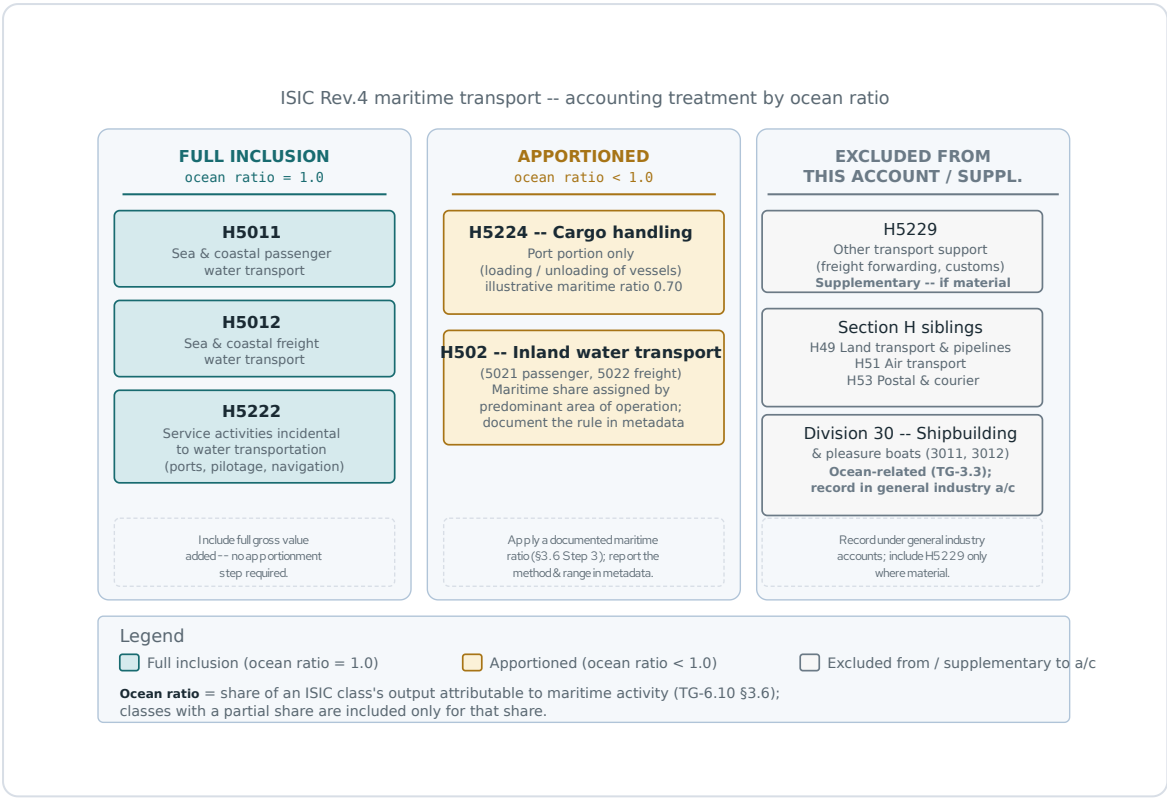


Figure 6.10.1 Maritime-transport ISIC classes placed by ocean-ratio treatment: wholly maritime, partly apportioned, or excluded to general industry accounts. H502 predominant-area rule and 0.70 cargo-handling ratio are illustrative; document country ratios in metadata.

Source: TG-6.10 §3.1.1, §3.6 (ocean-ratio apportionment) and §3.7 (worked 0.70 cargo-handling example); ISIC Rev.4 Section H, Division 50, and Classes 5222/5224/5229. Shipbuilding scope per TG-3.3 (ISIC 3011, ocean-related/direct).

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4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

¶3 **Contributing frameworks and sources:**

¶4 This Circular draws upon:

- ¶5 *SEEA Central Framework* (UN et al., 2012)
- ¶6 ISIC Revision 4 (UN, 2008)
- ¶7 *SNA 2025* (UN et al., 2025)
- ¶8 MARPOL Convention (IMO)
- ¶9 Ballast Water Management Convention (IMO)
- ¶10 Fourth IMO GHG Study (IMO, 2020)
- ¶11 UNCTAD *Review of Maritime Transport*
- ¶12 IPCC Guidelines for National Greenhouse Gas Inventories
- ¶13 IPCC AR6 WGI Chapter 7 Supplementary Material (GWP100 values)
- ¶14 BIMCO/ICS *Seafarer Workforce Report* (2021)
- ¶15 EMEP/EEA *Air Pollutant Emission Inventory Guidebook* (2019)
- ¶16 OECD *Measuring Capital: OECD Manual* (2009)

5. References

1. ¶1 UNCTAD. (2023). *Review of Maritime Transport 2023*. United Nations Conference on Trade and Development. Geneva: United Nations. Estimates maritime transport at over 80% of global merchandise trade by volume. unctad.org/publication/review-maritime-transport-2023 (https://unctad.org/publication/review-maritime-transport-2023)
2. ¶2 ISIC Rev.4, Division 50 "Water transport" and Class 5222 "Service activities incidental to water transportation."
3. ¶3 SEEA Central Framework (2012), Chapter 3, Section 3.6 on emission accounts (air emissions covered under sub-section 3.6 of Chapter 3 physical flow accounts; verify exact sub-paragraph range against the SEEA CF PDF).
4. ¶4 SNA 2025, Chapter 6 on production accounts and value added measurement.
5. ¶5 SEEA Central Framework, Chapter 4 on produced assets including infrastructure.
6. ¶6 IMO guidelines on biofouling and ballast water management; UNCLOS Part XII on marine environment protection.
7. ¶7 ISIC Rev.4, International Standard Industrial Classification of All Economic Activities, United Nations, 2008.
8. ¶8 ISIC Rev.4, Division 50 scope note: "This division includes the transport of passengers or freight over water, whether scheduled or not. Also included are the operation of towing or pushing boats, excursion, cruise or sightseeing boats, ferries, water taxis etc."
9. ¶9 ISIC Rev.4, Part Three, Section H (Transportation and Storage), Division 50 (Water Transport), pages 194–196.
0. ¶10 IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 2 (Energy), Chapter 3 (Mobile Combustion), Section 3.4.3 on water-borne navigation (inland navigation emission factors); see also the NGGIP background paper on water-borne navigation emissions. National Greenhouse Gas Inventories Programme, IGES.
1. ¶11 ISIC Rev.4, Class 5222 scope note: "activities related to water transport of passengers, animals or freight: operation of terminal facilities such as harbours and piers, operation of waterway locks etc., navigation, pilotage and berthing activities, lighterage, salvage activities, lighthouse activities."
2. ¶12 IMO vessel type classifications align with SOLAS and MARPOL conventions.
3. ¶13 IMO. (2020). *Fourth IMO GHG Study*. International Maritime Organization. Provides emission factors by vessel type, size category, and operating mode.
4. ¶14 CIF (Cost, Insurance, Freight) and FOB (Free on Board) are standard international trade valuation bases per BPM6.
5. ¶15 AIS (Automatic Identification System) coverage is most complete for commercial vessels over 300 GT operating on major shipping lanes; coverage is materially lower for vessels in remote ocean areas (parts of the Pacific, Indian Ocean and Arctic), for smaller vessel classes, and where terrestrial AIS predominates over satellite AIS. UNCTAD (2023) *Review of Maritime Transport* and IMO GISIS provide vessel registry data for cross-checking AIS completeness. See also: Comer, B., Olmer, N., Mao, X., Roy, B. and Rutherford, D. (2017). *Black carbon emissions and fuel use in global ship-borne trade*. International Council on Clean Transportation.
6. ¶16 PIANC (World Association for Waterborne Transport Infrastructure) guidelines on port facility classification.
7. ¶17 SEEA Central Framework, Chapter 5 on land and ecosystems accounting.
8. ¶18 ISIC Rev.4, Class 4290 includes "dredging of waterways" as part of civil engineering activities. For the capital/maintenance distinction in coastal works generally, see TG-6.11 Section 3.2.4.
9. ¶19 SEEA Central Framework (2012), paragraph 3.267 on dredging material flows within physical flow accounts. Contaminated (polluted) dredging spoil is recorded as a residual flow within waste accounts; unpolluted spoil is excluded from the waste-flow boundary. Verify paragraph reference against the SEEA CF PDF before final publication.
0. ¶20 SEEA EA, Chapter 4 on ecosystem extent accounts and land cover change.
1. ¶21 SNA 2025 treatment of gross fixed capital formation in infrastructure.
2. ¶22 OECD (2009). *Measuring Capital: OECD Manual*, 2nd edition. Chapter 6 provides detailed guidance on applying the perpetual inventory method to infrastructure assets.
3. ¶23 SNA 2025, asset classification AN1131 (Transport equipment) covers vessels as produced assets in national balance sheets. Vessel registries and the Lloyd's Register / IHS Markit (LSEG/Clarksons) maritime fleet databases provide standard data sources for vessel acquisition costs and characteristics used in PIM-based vessel capital stock estimation. See OECD (2009), Chapter 6 for PIM application.
4. ¶24 SEEA CF (2012), Chapter 3 (Physical Flow Accounts). Air emissions accounts record the generation of gaseous and particulate substances released to the atmosphere by establishments and households as a result of production, consumption and accumulation processes. The specific paragraph supporting this definition is in Chapter 3, Section 3.6 on air emissions accounts; the paragraph number (previously cited as 3.91) has not been confirmed against the SEEA CF 2012 print edition and has been replaced with this section-level citation to ensure robustness.
5. ¶25 IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Chapter 7 (The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity), Supplementary Material Table 7.SM.7 (GWP100 values, including climate-carbon-feedback effects for fossil CH4). Cambridge University Press. See also UNFCCC Decision 18/CMA.1 on the common reporting framework for national GHG inventories.
6. ¶26 IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 2, Chapter 3 on mobile combustion.
7. ¶27 Fourth IMO GHG Study (2020) and IPCC 2006 Guidelines provide complementary emission factor sources for maritime transport.
8. ¶28 SEEA CF, paragraph 2.110 on the residence principle, aligned with SNA. See also SNA 2025, Chapter 4 on globalisation and institutional units.

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9. ¶29 IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 2 (Energy), Chapter 3 (Mobile Combustion), Section 3.4 on international bunkers (treated as a memo item excluded from national totals). For broader reconciliation between SEEA-attributed shipping emissions and IPCC memo-item bunker fuel quantities, see **TG-2.8 Climate Indicators**.
0. ¶30 WHO. (2021). *Air Quality Guidelines*. World Health Organization. European Environment Agency guidance on shipping emissions. See also EMEP/EEA (2019), *Air Pollutant Emission Inventory Guidebook*, Chapter 1.A.3.d on shipping.
1. ¶31 IMO MARPOL Annex VI establishes global sulphur limits and designates Emission Control Areas (ECAs). The 2020 sulphur cap reduced the global limit from 3.50% to 0.50% m/m.
2. ¶32 NOAA. (2023). *Ocean Noise Strategy Roadmap*. National Oceanic and Atmospheric Administration. Identifies shipping as dominant source of low-frequency noise.
3. ¶33 JOMOPANS (Joint Monitoring Programme for Ambient Noise in the North Sea) project methodology for mapping shipping noise in European waters. IMO MEPC.1/Circ.833 provides voluntary guidelines.
4. ¶34 SNA 2025, Chapter 6 on the production account and derivation of value added.
5. ¶35 ILO. (2006). *Maritime Labour Convention (MLC 2006)*. International Labour Organization. Definitions for seafarer employment.
6. ¶36 ILO Maritime Labour Convention, 2006 (MLC 2006), Title I, Regulation 1.4; SNA 2025, Chapter 19 on labour accounts and residence.
7. ¶37 BIMCO and International Chamber of Shipping (ICS). (2021). *Seafarer Workforce Report: 2021 edition*. BIMCO/ICS. ICS Publications (https://www.ics-shipping.org/publications/). Provides national seafarer supply estimates by country of residence; used as a reference benchmark when reconciling MLC flag-state data to a residence basis.
8. ¶38 Leontief input-output framework for measuring inter-industry linkages.
9. ¶39 Supply and use tables methodology per SNA 2025 Chapter 15.
0. ¶40 IMO. (2017). *Ballast Water Management Convention (BWM Convention)*. International Maritime Organization. Entered into force 2017.
1. ¶41 IMO. (2011). *Biofouling Guidelines (MEPC.207(62))*. International Maritime Organization. Voluntary measures for hull biofouling management.
2. ¶42 UNEP/MAP guidelines on anchoring impacts in Mediterranean Marine Protected Areas.
3. ¶43 ITOPF statistics on oil spill trends and response operations.
4. ¶44 SNA 2025, Chapter 15, paras 15.9, 15.130–15.139 on supply and use table compilation. See also TG-3.3 Section 3.4 on ocean economy SUT compilation.
5. ¶45 BPM6 (Balance of Payments and International Investment Position Manual, 6th edition), paragraphs 10.73–10.88 on transportation services in the balance of payments (chapter number and paragraph range to be verified against the BPM6 PDF — IMF editions vary between Chapter 10 and Chapter 12 for the services treatment). Provides the framework for identifying maritime services provided by non-resident enterprises (foreign shipping lines at domestic ports).
6. ¶46 Data source guidance aligns with **TG-4.2 Survey Methods**, **TG-4.3 Administrative Data**, and **TG-4.6 Data Harmonisation**.

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Coastal Infrastructure Accounting

Provides technical guidance for accounting for coastal infrastructure assets within the ocean accounting framework.

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

This Circular provides technical guidance for accounting for coastal infrastructure assets within the ocean accounting framework. It establishes methods for recording and valuing physical structures that protect, modify, or interact with coastal and marine environments, including both traditional engineered ("grey") infrastructure and nature-based ("green" or "blue") solutions. Grey infrastructure refers to conventional engineered structures such as seawalls, breakwaters, and port facilities. Green infrastructure refers to terrestrial nature-based solutions such as dune restoration and riparian planting. Blue infrastructure refers to marine and coastal nature-based solutions such as mangrove forests, coral reefs, and living shorelines. Some literature uses "blue-green" interchangeably. This Circular distinguishes the two where the distinction matters for accounting treatment.

Upon completing this guidance, practitioners will be able to:

- Classify coastal infrastructure assets by function and characteristics, applying the framework from TG-3.1 Asset Accounts
- Apply perpetual inventory methods and depreciation to produced coastal assets, following TG-3.1 Asset Accounts Section 3.3
- Account for nature-based solutions as ecosystem enhancement investments, linking to TG-2.9 Disaster Risk
- Integrate hybrid infrastructure systems combining engineered and natural components
- Link infrastructure accounting to climate adaptation investment tracking in TG-2.8 Climate Indicators
- Compile coastal infrastructure asset accounts from construction records, asset registers, and spatial data sources

The SNA classifies many coastal infrastructure assets as "other structures" (AN1122) under produced non-financial assets, including "the construction of sea walls, dykes, flood barriers etc. intended to improve the quality and quantity of land adjacent to them." The accounting treatment must recognise the distinction between produced assets created through human activity and natural capital assets that provide similar services. A concrete seawall represents produced capital subject to depreciation, whilst a mangrove forest providing equivalent coastal protection constitutes an ecosystem asset valued through the net present value of expected ecosystem service flows. Hybrid infrastructure combining both elements requires careful attribution of values to each component.

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1. Outcome

¶1 This Circular provides technical guidance for accounting for coastal infrastructure assets within the ocean accounting framework. It establishes methods for recording and valuing physical structures that protect, modify, or interact with coastal and marine environments, including both traditional engineered ("grey") infrastructure and nature-based ("green" or "blue") solutions. Grey infrastructure refers to conventional engineered structures such as seawalls, breakwaters, and port facilities. Green infrastructure refers to terrestrial nature-based solutions such as dune restoration and riparian planting. Blue infrastructure refers to marine and coastal nature-based solutions such as mangrove forests, coral reefs, and living shorelines. Some literature uses "blue-green" interchangeably. This Circular distinguishes the two where the distinction matters for accounting treatment.

¶2 Upon completing this guidance, practitioners will be able to:

- ¶3 Classify coastal infrastructure assets by function and characteristics, applying the framework from **TG-3.1 Asset Accounts** [1]
- ¶4 Apply perpetual inventory methods and depreciation to produced coastal assets, following **TG-3.1 Asset Accounts** Section 3.3 [2]
- ¶5 Account for nature-based solutions as ecosystem enhancement investments, linking to **TG-2.9 Disaster Risk**
- ¶6 Integrate hybrid infrastructure systems combining engineered and natural components
- ¶7 Link infrastructure accounting to climate adaptation investment tracking in **TG-2.8 Climate Indicators**
- ¶8 Compile coastal infrastructure asset accounts from construction records, asset registers, and spatial data sources

¶9 The SNA classifies many coastal infrastructure assets as "other structures" (AN1122) under produced non-financial assets, including "the construction of sea walls, dykes, flood barriers etc. intended to improve the quality and quantity of land adjacent to them." [3] The accounting treatment must recognise the distinction between produced assets created through human activity and natural capital assets that provide similar services. A concrete seawall represents produced capital subject to depreciation, whilst a mangrove forest providing equivalent coastal protection constitutes an ecosystem asset valued through the net present value of expected ecosystem service flows. [4] Hybrid infrastructure combining both elements requires careful attribution of values to each component.

1.1 Decision Use Cases

¶1 Coastal infrastructure accounts support three categories of policy decisions:

¶2 **Coastal resilience investment allocation**: Asset accounts provide the analytical framework for comparing engineered and nature-based protection options — engineered structures appear as gross fixed capital formation with annual depreciation, whilst nature-based solutions appear as environmental protection expenditure with ecosystem asset enhancement. The accounts enable annualised equivalent cost comparisons accounting for different service lives and maintenance requirements.

¶3 **Climate adaptation planning and monitoring**: Coastal infrastructure accounts quantify adaptation investment flows (seawall raising, drainage improvement, mangrove restoration) and track the resulting changes in asset stocks. Where adaptation retrofits extend the useful life of existing infrastructure, the accounts distinguish between consumption of fixed capital under original design assumptions and revised depreciation schedules. This feeds directly into **TG-2.8 Climate Indicators**, enabling countries to track SDG target 13.1 and report adaptation finance to UNFCCC

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processes. The 2025 SNA now treats climate change as "a major risk affecting current and future wellbeing."[5]

¶4 **Infrastructure maintenance and budget prioritisation**: Asset condition data from infrastructure accounts inform trade-offs between competing maintenance claims — breakwater repair, channel dredging, mangrove buffer rehabilitation. The accounts ensure transparent classification between intermediate consumption (routine maintenance) and gross fixed capital formation (life-extending rehabilitation).

1.2 Upward Connections

¶1 **TG-1.1 National Ocean Budgets**: Asset accounts demonstrate the scale of public capital formation in coastal infrastructure, informing capital budget allocations and depletion-adjusted income measures.

¶2 **TG-2.9 Disaster Risk**: Infrastructure extent and condition compiled here feed directly into exposure and vulnerability assessments. The combined presentation of produced and ecosystem protective assets enables calculation of total protective capacity and identification of protection gaps.

¶3 **TG-3.1 Asset Accounts**: This Circular applies the TG-3.1 framework to coastal infrastructure, populating physical and monetary asset accounts for AN1122 structures. The worked examples in Section 3.7 illustrate the full compilation chain.

¶4 ⓘ **Framework Position**

¶5 This Circular owns the **produced-asset accounts for coastal infrastructure** within the territorial sea and on land: classification, valuation, depreciation, service life, and the capital formation and adaptation investment those assets generate.

¶6 It cross-refers for the produced asset framework (**TG-3.1**), spatial delineation (**TG-4.1**), asset registers and consent records (**TG-4.3**) and valuation principles (**TG-1.9**).

¶7 Three boundaries are load-bearing. The **coastal protection service flow** from an ecosystem asset is recorded by the ecosystem circular (**TG-6.1**, **TG-6.2**, **TG-6.3**), not here; this Circular records the produced-asset cost stream and the avoided-expenditure interface. The **ecosystem side of a placed structure** follows the M4.1 rule owned by **TG-6.9** Section 3.5.2. And where an intervention qualifies as a nature-based solution, its ledger, additionality, permanence and lifecycle cost are **TG-6.15**, which also supplies the method for comparing engineered and nature-based options against this Circular's cost stream.

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2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-4.1 Remote Sensing and Geospatial Data** — spatial delineation of coastal infrastructure footprint and shoreline change.
- ¶3 **TG-4.3 Administrative Data Sources** — asset registers, consent records and public works accounts are the primary source for the asset valuation in Section 3.2.
- ¶4 **TG-0.1 General Introduction to Ocean Accounts** — foundational concepts including spatial boundaries and integration with national accounts.[6]
- ¶5 **TG-3.1 Asset Accounts** — asset classification, balance sheet construction, and the produced/non-produced asset distinction.[7]

¶6 **Scope note on offshore structures**: This Circular focuses on coastal infrastructure within the territorial sea and on land. For infrastructure associated with offshore energy operations beyond the territorial sea, see TG-6.9 Offshore Energy and TG-6.10 Maritime Transport. Where port approach channels or breakwaters extend into the exclusive economic zone, apply the same institutional unit (resident port authority) and asset classification (AN1122) used for the landward components, noting the geographic extent in spatial metadata.[8]

¶7 **Related circulars:**

- ¶8 **TG-6.2 Mangrove and Coastal Wetland Accounting** — mangrove extent, condition, and service accounting relevant to Section 3.3.2. Practitioners are strongly encouraged to consult TG-6.2 as a co-requisite.
- ¶9 **TG-2.4 Environmental (including Ecosystem) Goods and Services** Section 3.10 — valuation methods; **TG-3.1 Asset Accounts** Section 3.3 — discount rate selection and the NPV approach used in Section 3.2.
- ¶10 **TG-2.9 Disaster Risk** — coastal hazard exposure, vulnerability, and infrastructure protection capacity.
- ¶11 **TG-2.8 Climate Indicators** — climate-related indicators for adaptation investment tracking in Section 3.5.
- ¶12 **TG-6.9 Offshore Energy** — infrastructure associated with offshore energy operations beyond the territorial sea.
- ¶13 **TG-6.10 Maritime Transport and Ports** — maritime transport infrastructure including offshore port elements.

2.1 Data Requirements

¶1 **Physical infrastructure data:**

- ¶2 Asset registers for ports, harbours, and marine terminals
- ¶3 Coastal protection structure inventories (seawalls, breakwaters, groynes, revetments)
- ¶4 Reclaimed land area and construction records
- ¶5 Dredging and channel maintenance records [9]

¶6 **Ecosystem asset data:**

- ¶7 Mangrove extent and condition assessments (see **TG-6.2 Mangrove and Coastal Wetland Accounting**)
- ¶8 Coral reef coverage and health indicators
- ¶9 Seagrass meadow extent
- ¶10 Salt marsh and coastal wetland boundaries [10]

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¶11 Remote sensing platforms provide essential data for consistent time-series monitoring of ecosystem extent. Landsat (30 m resolution, records from 1972) and Sentinel-2 (10 m resolution, from 2015) offer freely available multispectral imagery suitable for detecting changes in mangrove, seagrass, and salt marsh coverage. The Global Mangrove Watch initiative demonstrates how satellite-derived extent data can be integrated into accounting frameworks. [11]

¶12 **Financial data:**

- ¶13 Capital expenditure on coastal construction
- ¶14 Maintenance and rehabilitation costs
- ¶15 Insurance valuations and damage assessments
- ¶16 Market transactions for coastal land and facilities [12]

2.2 Classification Frameworks

¶1 This guidance aligns with the SEEA Central Framework (AN1122 Other structures), Central Product Classification (CPC) for construction services, Classification of the Functions of Government (COFOG) for coastal protection expenditure, and IUCN Global Ecosystem Typology for coastal ecosystem types. [13]

¶2 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

3.1 Coastal Infrastructure Types

3.1.1 Port and Harbour Infrastructure

¶1 Ports and harbours represent major produced assets within the coastal zone. The 2025 SNA classifies harbour facilities under "other structures" (AN1122), including:

> *"harbour bottoms and harbour channels, breakwaters, quays, piers, jetties, docks, wharves and similar structures"* [14]

¶2 Key infrastructure categories include:

¶3 **Structural facilities:** quay walls and wharves; piers and jetties; breakwaters and wave barriers; dry docks and slipways; cargo handling facilities. [15]

¶4 **Navigation infrastructure:** dredged channels and basins; navigation aids (lighthouses, buoys, beacons); vessel traffic management systems.

¶5 **Supporting facilities:** storage and warehousing; road and rail connections; utilities and services. [16]

¶6 Port infrastructure valuation should apply the perpetual inventory method (PIM) using acquisition costs, service lives, and appropriate depreciation profiles. The SEEA Central Framework notes that "consumption of fixed capital (commonly known as depreciation) should be deducted from income and recognized as a cost of production." [17]

¶7 To illustrate the PIM approach: a concrete quay wall constructed in 2010 at USD 50 million with a 60-year service life and 3.3 per cent geometric depreciation would, by 2025, have a net value of roughly USD 30 million in constant 2010 prices after approximately 40 per cent accumulated depreciation. [18]

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3.1.2 Coastal Protection Structures

¶1 Coastal protection infrastructure comprises engineered structures designed to defend shorelines from erosion, flooding, and storm damage.

¶2 **Seawalls and Revetments**

¶3 Seawalls are vertical or near-vertical structures providing a hard barrier between land and sea. Revetments are sloped structures armoring the shoreline using rock, concrete blocks, or similar materials. [19] Both are classified as produced assets under AN1122, recorded at construction cost less accumulated depreciation. Typical service lives range from 25 to 75 years depending on materials, design, and environmental exposure. Major rehabilitation that extends useful life should be recorded as gross fixed capital formation. [20]

¶4 **Breakwaters and Groynes**

¶5 Breakwaters are offshore or nearshore structures that reduce wave energy reaching protected areas. Groynes extend perpendicular to the shoreline to trap sediment and control longshore drift. [21] CPC 53262 covers dredging services and other water-associated construction relevant to breakwater construction and maintenance. [22]

¶6 **Flood Barriers and Tidal Gates**

¶7 Movable flood barriers and tidal gates manage water levels in estuaries and tidal zones. These assets combine structural elements with mechanical and electrical systems, requiring separate depreciation schedules for each component category. [23] Notable systems include the Thames Barrier

(operational since 1984), the Maeslantkering (part of the Netherlands Delta Works), and Venice's MOSE barrier (completed 2020, 78 mobile gates). These examples illustrate capital values in the billions of dollars, design lives of 50–100 years, and ongoing maintenance that must be classified between intermediate consumption and capital formation.[24]

3.1.3 Reclaimed Land

¶1 Land reclamation creates new terrestrial area through the deposition of fill material and conversion of seabed or intertidal zones to dry land. The SEEA Central Framework recognises that land area may increase "owing to reclamation of land through the construction of dykes and other barriers."[25] Reclaimed land represents a produced asset distinct from the underlying natural seabed.

¶2 Accounting treatment records:

- ¶3 Initial construction costs as gross fixed capital formation
- ¶4 The resulting land area as an addition to produced assets
- ¶5 Ongoing maintenance costs (pumping, drainage, structural repairs)
- ¶6 Ecosystem service losses from converted marine or intertidal areas[26]

¶7 **SNA classification of reclamation works and reclaimed land**: The engineered works (dykes, fill structures, drainage, containment walls) are recorded as gross fixed capital formation in AN1122. Once reclamation is complete and the land functions as a productive asset, the land area itself is reclassified to AN.211 (Land underlying buildings and structures) or AN.212 (Land under cultivation) as a non-produced asset, whilst the engineered works retain their AN1122 classification. The two components — engineered structures (produced) and land area (non-produced) — must be recorded separately to avoid double counting. Cross-reference SNA 2025 paragraph 11.85 and **TG-3.1 Asset Accounts**.[27]

¶8 When coastal ecosystems are converted to reclaimed land, the framework captures both sides: the new produced land asset is recorded as gross fixed capital formation, whilst the ecosystem asset loss is recorded as ecosystem degradation and conversion in extent and condition accounts. The SEEA EA provides that "the value of losses in ecosystem services that result from ecosystem degradation should be recorded as an ecosystem degradation cost,"[28] enabling a structured comparison between the produced asset gain and the ecosystem capital loss.

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3.2 Asset Valuation

3.2.1 Capital Stock Measurement

¶1 Coastal infrastructure assets should be valued following SNA principles for produced non-financial assets using the perpetual inventory method (PIM). For PIM principles and price index selection, see **TG-3.1 Asset Accounts**.

¶2 The PIM requires:

1. ¶3 **Historical investment series** — gross fixed capital formation in coastal infrastructure over the expected asset life
2. ¶4 **Price indices** — construction cost indices to express investments in current prices
3. ¶5 **Service life assumptions** — expected useful life by asset type
4. ¶6 **Depreciation functions** — geometric, linear, or other profiles reflecting loss of productive capacity[29]

¶7 The 2025 SNA specifies that "consumption of fixed capital in the SNA is calculated on the basis of the estimated opportunity costs of using the assets at the time they are used, as distinct from the prices at which the assets were acquired."[30]

3.2.2 Depreciation and Service Lives

¶1 Consumption of fixed capital for coastal infrastructure should reflect physical wearing out, normal obsolescence, and expected terminal costs.

¶2 *Table 3.2.2: Indicative service lives and depreciation profiles for coastal infrastructure*

Asset Type	Typical Service Life	Depreciation Profile	Typical Maintenance (% of replacement cost per year)
Quay walls (concrete)	50–75 years	Geometric	1–2%
Steel sheet piling	30–50 years	Geometric	2–3%
Breakwaters (rock)	50–100 years	Linear	0.5–1%
Seawalls (concrete)	40–60 years	Geometric	1–2%
Groynes (timber)	15–25 years	Linear	3–5%
Navigation dredging	1–5 years	Full write-off	N/A (recurring)
Reclamation structures	50–75 years	Geometric	1–2%
Beach nourishment	1–5 years	Straight-line (full write-off over cycle)	N/A (recurring placement)
Living shoreline — engineered component	10–20 years	Geometric	2–4%
Living shoreline — ecosystem component	N/A (ecosystem asset)	N/A — record under ecosystem accounts	N/A

¶3 [31]

¶4 The maintenance cost column assists compilers in distinguishing routine maintenance expenditure (intermediate consumption) from major rehabilitation (capital formation). Where annual maintenance expenditure exceeds the indicative percentages by a material margin, the excess may indicate capital improvements that should be classified as gross fixed capital formation.

¶5 Service life estimates should be adjusted based on local environmental conditions including wave climate, storm frequency, sediment dynamics, and water quality factors. [32]

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3.2.3 Asset Classification for Coastal Protection

¶1 *Table 3.2.1: Coastal protection asset classification*

Infrastructure Type	SNA Asset Class	SEEA Asset Class	Depreciation	Co-benefits
Seawall	Produced (AN.1122)	N/A	Yes (40–60 yr)	Minimal
Breakwater	Produced (AN.1122)	N/A	Yes (50 yr)	Artificial reef
Beach nourishment	Produced (inventory)	N/A	Yes (annual)	Recreation
Mangrove forest	N/A	Ecosystem asset	No	Carbon, fisheries, biodiversity
Coral reef	N/A	Ecosystem asset	No	Fisheries, tourism, biodiversity
Living shoreline	Hybrid	Hybrid	Mixed	Moderate

¶2 Produced assets are valued at construction cost less accumulated depreciation. Ecosystem assets are valued through the net present value of expected ecosystem service flows. Hybrid assets require attribution between their produced and ecosystem components. [33]

3.2.4 Maintenance and Rehabilitation

¶1 Routine maintenance that sustains current productive capacity should be recorded as intermediate consumption, not capital formation. Major rehabilitation extending asset life or materially improving capacity constitutes gross fixed capital formation. [34]

¶2 Dredging presents particular accounting challenges. Maintenance dredging to restore design depths is typically treated as intermediate consumption. Capital dredging creating new or expanded facilities represents gross fixed capital formation. [35] The SEEA Central Framework includes "dredgings" within the physical flow accounts for material resources. [36]

3.3 Nature-Based Solutions

3.3.1 Living Shorelines

¶1 Living shorelines use natural materials and ecosystem features to provide coastal protection while maintaining ecological function. [37] Components may include planted vegetation (salt marsh grasses, mangroves, dune vegetation), oyster reef structures, submerged aquatic vegetation, natural or placed rock features, and biodegradable erosion control materials. [38]

¶2 Accounting treatment depends on primary purpose and ownership:

¶3 **Ecosystem restoration expenditure** — where the primary objective is habitat restoration, costs should be recorded as environmental protection expenditure under CEPA classification and tracked through ecosystem extent and condition accounts. [39]

¶4 **Coastal protection investment** — where the primary objective is shore protection with ecological co-benefits, engineered components may be capitalised as produced assets whilst ecosystem elements are tracked through ecosystem accounts. [40]

3.3.2 Where the ecosystem protection service is recorded

¶1 Mangroves, salt marshes, coastal wetlands, seagrass meadows and coral reefs all provide coastal protection through wave attenuation, sediment stabilisation and storm surge reduction. Five circulars in this publication touch that service, so the recording point has to be stated rather than left to the compiler. Protection is a final ecosystem service distinct from fisheries habitat and recreation, so recording it once does not suppress the other services the same asset supplies. [41]

¶2 ⓘ **Recording rule — coastal protection service**

¶3 The **ecosystem circular records the protection service flow** from the ecosystem asset, once, in the ecosystem service supply and use table: **TG-6.1** Section 3.3 for coral reefs, **TG-6.2** Section 3.4 for mangroves and coastal wetlands, **TG-6.3** Section 3.3 for seagrass.

¶4 **This Circular records the produced-asset side** — the capital cost, depreciation profile and service life of engineered and hybrid protection works — and cross-refers to the ecosystem circular for the service. It does not independently estimate protection service values for areas an ecosystem circular already covers.

¶5 **TG-6.15** Section 3.8 supplies the method for comparing the two, drawing the produced-asset cost stream from here and the risk-adjusted ecosystem stream from the ecosystem circulars.

¶6 The valuation methods themselves — avoided damage cost, replacement cost, benefit transfer, and the expected damage function procedure they rest on — are set out in **TG-6.2** Section 3.6 and **TG-3.2 Flows from Environment to Economy** Section 3.5, and are not restated here. [42], [43], [44]

¶7 What this Circular adds is the **interface**: where a protection service recorded in an ecosystem circular is the reason an engineered work was deferred, reduced in scope or avoided altogether, that avoided capital expenditure is recorded in the infrastructure investment account with a note identifying the ecosystem asset and the circular carrying its service value. The avoided expenditure and the ecosystem service value are two views of one benefit and must not be summed.

3.3.3 Condition variables that carry protection capacity

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¶1 The condition variables governing protection capacity are recorded in the ecosystem condition account under the relevant ecosystem circular, but infrastructure planners are their main user, so the dependency is stated here.

¶2 Coral reef protection capacity depends on three measurable condition indicators: reef crest depth relative to sea level determines the degree of wave breaking, structural complexity (rugosity) affects energy dissipation, and reef width determines the distance over which wave energy is absorbed. These should be tracked alongside biological condition metrics such as live coral cover, since declines in biological condition translate into reduced structural complexity and diminished protection capacity. The Allen Coral Atlas and the GCRMN Status of Coral Reefs reports provide standardised approaches at national and regional scales.[45] For mangroves and saltmarsh the equivalent variables are canopy width, stem density and surface elevation relative to sea level; for seagrass, meadow width and shoot density.

¶3 A compiler planning protection infrastructure should read these variables as a forward signal: an ecosystem asset on a declining condition trajectory will deliver less protection over the life of the works being appraised, which is a change in the counterfactual and not a change in the discount rate. Changes in condition affecting protection capacity are recorded as ecosystem degradation or enhancement in the ecosystem asset account, and restoration investment as environmental protection expenditure, in both cases under the ecosystem circular.[46]

3.4 Blue-Grey Integration

3.4.1 Hybrid Infrastructure Systems

¶1 Hybrid infrastructure combines engineered structures with natural ecosystem elements to achieve coastal protection objectives.[47] Examples include breakwaters designed to support coral growth, seawalls with integrated mangrove planting, groyne fields with saltmarsh restoration, and artificial reefs for wave attenuation and habitat.

¶2 Accounting for hybrid systems requires clear attribution between:

1. ¶3 **Produced asset components** (engineered structures) — valued at construction cost less depreciation
2. ¶4 **Ecosystem asset components** (natural or restored ecosystems) — valued through NPV of expected ecosystem service flows
3. ¶5 **Land area changes** resulting from infrastructure or restoration[48]

¶6 Components that are clearly engineered should be recorded as produced assets, and components that are clearly natural should be recorded as ecosystem assets.

¶7 Where a placed structure has developed confirmed ecological function — an artificial reef that derives wave attenuation jointly from the placed substrate and biological growth is the standard case — the two sides are separated by ecosystem type rather than by apportionment. **TG-6.9 Offshore Energy Thematic Methods** Section 3.5.2 owns this rule for the publication and it applies inside the territorial sea exactly as it does beyond it: the structure remains a produced asset at construction cost less depreciation, and the ecological function it acquires is recorded as a separate **IUCN GET M4.1 Submerged artificial structures** ecosystem extent entry, sized at structure footprint plus a defined ecological halo, reversible if the ecological function is not confirmed. The capital-expenditure proportion is used only where the *produced* asset itself must be split between coastal-protection and other purposes; it is not a method for dividing value between the produced and ecosystem sides.[49]

3.4.2 Ecosystem Enhancement Investment

¶1 Where infrastructure investments improve ecosystem condition, the SEEA EA provides for recording ecosystem enhancement:

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> *"Ecosystem enhancement is the increase in the value of an ecosystem asset over an accounting period that is associated with an improvement in the condition of the asset during that accounting period."*[50]

¶2 Enhancement activities in coastal zones include rehabilitation of degraded mangroves and wetlands, reef restoration and transplantation, seagrass meadow replanting, sediment management improving habitat quality, and water quality improvements benefiting coastal ecosystems.[51]

¶3 Restoration, rehabilitation, and reclamation activities have different implications:

- ¶4 **Restoration** aims to re-establish pre-existing structure and function including biotic integrity
- ¶5 **Rehabilitation** aims to reinstate ecosystem functionality with a focus on supplying ecosystem services
- ¶6 **Reclamation** aims to return degraded land to a useful state[52]

¶7 The value of ecosystem enhancement should be measured through changes in the NPV of expected ecosystem service flows, not simply as expenditure incurred. There should be "no prior expectations regarding the results of such a comparison" between enhancement value and expenditure levels.[53]

3.5 Climate Adaptation

3.5.1 Sea Level Rise Resilience

¶1 Climate change affects the required performance and expected service life of coastal infrastructure. The SEEA EA recognises that "changes at the edges of the realms and associated transition areas, particularly between the marine and terrestrial realms, are likely to occur, for example, through coastal erosion, sediment deposition and aggradation and sea level rise."[54]

¶2 Infrastructure accounting should address:

¶3 **Design standard adjustments** — new infrastructure designed for higher sea levels or increased storm intensity should be fully capitalised as gross fixed capital formation.[55]

¶4 **Asset life reappraisal** — existing infrastructure may face shortened useful lives if design standards are exceeded by changed conditions. Downward reappraisal of remaining service potential should be recorded in the other changes in volume account.[56]

¶5 **Adaptation retrofits** — modifications maintaining function under changed conditions should be recorded as gross fixed capital formation where they extend useful life or maintain capacity.[57]

¶6 **Stranded asset recognition** — infrastructure that becomes functionally obsolete due to sea level rise or permanent inundation may require accelerated depreciation or full write-off. Where sea level rise projections indicate specific infrastructure will be rendered obsolete before the end of its originally estimated service life, compilers should revise the depreciation schedule to write off the remaining value over the shortened horizon. Where infrastructure is abandoned due to managed retreat, the residual book value should be written off through the other changes in volume account.[58]

3.5.2 Adaptation Investment Tracking

¶1 Coastal climate adaptation investment spans multiple asset categories:

¶2 **Grey infrastructure:** raised seawall heights; strengthened flood defences; upgraded drainage systems; relocated facilities.[59]

¶3 **Nature-based solutions (green and blue):**

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¶4 *Terrestrial (green):* dune restoration and stabilisation; coastal riparian planting; inland wetland creation contributing to coastal flood attenuation. [60]

¶5 *Marine and coastal (blue):* mangrove restoration and expansion; coastal wetland creation; beach nourishment; seagrass and oyster reef establishment. [61]

¶6 **Hybrid solutions:** integrated defence systems combining structural and natural elements; managed realignment creating new intertidal habitat; building with nature approaches. [62]

¶7 The Framework for the Development of Environment Statistics (FDES) identifies relevant indicators including "sea level" and "flood/storm surge, sea level rise, coastal storm risk" for tracking climate-related changes affecting coastal infrastructure. [63]

¶8 Investment tracking should link to [64]:

- ¶9 Government expenditure accounts (COFOG – coastal protection expenditure) [65]
- ¶10 Environmental protection expenditure accounts (CEPA/CREMA classifications) [66]
- ¶11 Infrastructure asset accounts showing capital stock and changes
- ¶12 Ecosystem accounts showing condition and extent changes from nature-based interventions [67]

3.6 Compilation Procedure

Step 1: Identify and classify infrastructure assets

¶1 Assemble an inventory of coastal infrastructure assets within the accounting area using the sources in Table 3.6.1.

Source	Description
Port authority asset registers	Detailed inventories of quays, breakwaters, dredged channels, cargo handling equipment, and warehouses, typically maintained for operational management and financial reporting.
Coastal zone management databases	Spatial datasets maintained by environmental agencies documenting seawalls, groynes, revetments, and tidal barriers, often linked to permit records and inspection programmes.
Public works departments	Construction and maintenance records for coastal roads, drainage systems, and shore protection works funded through government capital budgets.
Spatial data repositories	National geographic databases and cadastral systems documenting reclaimed land, port boundaries, and infrastructure footprints.

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¶2 **Privately owned coastal infrastructure**: Infrastructure owned by private enterprises and households (resort seawalls, private marina structures, industrial facility protection) should be included where material, consistent with SNA's balance sheet coverage of all institutional sectors. In many tourism-dependent and SIDS contexts, privately owned coastal protection constitutes a substantial share of total coastal resilience infrastructure. Data sources include construction permit records, property insurance databases, sector surveys, and cadastral records. Where private infrastructure cannot be directly measured, estimation using construction permit volumes combined with sector-specific asset intensity ratios provides a practical approach, with all assumptions documented in metadata. [68]

¶3 For each identified asset, record:

1. ¶4 **Physical characteristics**: type, dimensions, materials, location
2. ¶5 **Ownership and institutional unit**: government, port authority, private, or mixed
3. ¶6 **Construction date and original cost**: for PIM application
4. ¶7 **Current condition**: inspection reports, condition ratings
5. ¶8 **Functional status**: operational, partially operational, decommissioned, or planned

¶9 Map each asset to AN1122 Other structures and relevant sub-categories consistent with the national chart of accounts.

Step 2: Assemble financial data

¶1 Collect historical and current financial data for each asset or asset category:

¶2 **Historical investment series** (for PIM):

- ¶3 Annual GFCF in coastal infrastructure over the maximum service life (typically 100 years for long-lived breakwaters)
- ¶4 Source from government finance statistics, port authority financial statements, and construction industry surveys
- ¶5 Express in current prices using construction cost indices

¶6 **Current-period expenditure**:

- ¶7 Capital formation: new construction and major rehabilitation
- ¶8 Maintenance: routine repair, classified as intermediate consumption
- ¶9 Disposals and retirements with any scrap value

¶10 **Valuation data**: insurance valuations, market transactions, replacement cost estimates from engineering studies.

¶11 Where financial data for individual assets are unavailable, apply average cost factors by asset type and size category calibrated to available benchmark observations.

Step 3: Apply perpetual inventory method

¶1 Apply the PIM framework from Section 3.2.1, using the indicative service lives from Table 3.2.2, geometric depreciation for structural assets, and construction cost indices for price revaluation.

¶2 Key account identity:

- ¶3 Closing stock = Opening stock + GFCF - Depreciation - Retirements ± Other volume changes

¶4 Record catastrophic losses from storms and reappraisals of service life in the other-changes-in-volume sub-account.

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Step 4: Record ecosystem asset changes

¶1 Where hybrid or blue-grey infrastructure systems involve ecosystem components, compile parallel ecosystem extent and condition accounts:

¶2 **Extent changes** (from mangrove restoration, coral transplantation, living shoreline establishment):

- ¶3 Opening extent (hectares) at start of accounting period
- ¶4 Managed expansion: area established or restored through deliberate investment
- ¶5 Natural expansion: area of natural colonisation or accretion
- ¶6 Closing extent (hectares) at end of period

¶7 **Condition changes**:

- ¶8 Select condition variables relevant to coastal protection function: mangrove canopy density, coral structural complexity, seagrass shoot density (see **TG-3.1 Asset Accounts**, Section 3.5.2 for guidance)
- ¶9 Record opening and closing values for each variable
- ¶10 Where monetary asset accounts exist, record ecosystem enhancement as the change in NPV of expected future ecosystem service flows

¶11 **Expenditure attribution**:

- ¶12 Environmental protection expenditure: costs of restoration, rehabilitation, and ongoing management
- ¶13 Ecosystem enhancement: value change in ecosystem assets due to improved condition
- ¶14 Cross-reference produced asset investment (engineered components) and ecosystem investment to avoid double counting

Step 5: Integrate with balance sheets

¶1 **Balance sheet position**:

- ¶2 Coastal infrastructure (produced) appears under AN1122 Other structures
- ¶3 Coastal ecosystem assets appear under SEEA EA ecosystem asset classification

¶4 **Accumulation accounts**:

- ¶5 Capital account: GFCF in coastal infrastructure and environmental protection expenditure
- ¶6 Other changes in volume: catastrophic losses, reappraisals, ecosystem conversions
- ¶7 Revaluation account: holding gains/losses due to price changes

¶8 **Cross-account consistency**:

- ¶9 Depreciation in capital account equals consumption of fixed capital in production account
- ¶10 GFCF recorded in capital formation agrees with construction output in supply-use tables
- ¶11 Ecosystem enhancement expenditure appears in environmental protection accounts (CEPA)

Step 6: Quality assurance and documentation

¶1 **Internal consistency**:

- ¶2 Asset account identity: Closing stock = Opening stock + Additions − Reductions ± Revaluations
- ¶3 Cross-check depreciation rates against observed asset lifetimes
- ¶4 Compare maintenance expenditure percentages (Table 3.2.2) against actual port authority accounts

¶5 **External benchmarking**:

- ¶6 Compare total infrastructure capital stock to international port statistics and infrastructure benchmarks
- ¶7 Validate ecosystem asset values against comparable restoration cost or avoided damage studies
- ¶8 Cross-reference climate adaptation investment totals with government climate finance reporting to UNFCCC

¶9 **Documentation**:

- ¶10 Record all classification decisions, service life assumptions, and depreciation profiles
- ¶11 Document data sources and estimation methods for each asset category
- ¶12 Prepare metadata describing coverage, quality, and limitations

3.7 Worked Example

Scenario description

¶1 The accounting area is Coastal City, population 250,000, with a container port, 12 km of urban seawall, and a 150-hectare mangrove restoration project. The accounting period is calendar year 2025. Key infrastructure includes:

1. ¶2 **Port infrastructure**: Quay walls and cargo handling equipment (original construction 2005–2015)

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2. ¶3 **Seawall**: Concrete barrier protecting low-lying urban areas (constructed 1980–1990, with major rehabilitation in 2010)
3. ¶4 **Mangrove restoration**: 150 hectares established 2018–2022, now providing measurable coastal protection

Asset inventory and classification

¶1 *Table 3.7.1: Coastal City infrastructure asset inventory*

Asset Type	Classification	Original Investment	Service Life	Depreciation Profile
Port quay walls	AN1122 Other structures	USD 85 million (2005–2015)	60 years	Geometric (3% p.a.)
Port cargo handling equipment	AN1123 Machinery & equipment	USD 40 million (2010–2020)	20 years	Geometric (10% p.a.)
Urban seawall	AN1122 Other structures	USD 60 million (1980–1990), USD 15 million rehab (2010)	50 years	Geometric (4% p.a.)
Mangrove forest	Ecosystem asset (MFT1.2)	Restoration cost USD 2.5 million (2018–2022)	N/A (natural asset)	No depreciation

Physical asset account (quay walls)

¶1 To demonstrate the PIM approach, this worked example calculates the 2025 asset account for port quay walls constructed progressively from 2005–2015. All current-price columns are stated in 2025 prices unless otherwise noted.

¶2 **Step 1: Revalue historical investment to 2025 prices**

¶3 Assume construction cost inflation of 3% per annum. Investment in constant 2025 prices:

Vintage Year	Original Cost (USD million)	Construction Cost Index (2025=100)	Revalued Cost (USD million, 2025 prices)
2005	8.5	100 × 1.03^20 = 181	8.5 × 1.81 = 15.4
2010	25.5	100 × 1.03^15 = 156	25.5 × 1.56 = 39.8
2015	51.0	100 × 1.03^10 = 134	51.0 × 1.34 = 68.3
Total	**85.0**		**123.5**

¶4 **Step 2: Calculate accumulated depreciation by vintage**

¶5 Geometric depreciation at 3% per annum. Accumulated depreciation = 1 - (1 - 0.03)^age:

Vintage	Age in 2025 (years)	Accumulated Depreciation (%)	Net Value (USD million, 2025 prices)
2005	20	46%	15.4 × 0.54 = 8.3
2010	15	37%	39.8 × 0.63 = 25.1
2015	10	26%	68.3 × 0.74 = 50.5
Total opening stock (1 Jan 2025)			**83.9**

¶6 **Step 3: Record current-period changes**

¶7 During 2025:

- ¶8 GFCF: No new quay construction (USD 0)
- ¶9 Depreciation: 3% of opening stock = USD 2.5 million

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- ¶10 Catastrophic losses: Cyclone damage requiring USD 1.2 million write-off (recorded as other changes in volume)
- ¶11 Revaluation: 3% construction cost inflation = USD 2.5 million holding gain

¶12 **Physical asset account for port quay walls (USD million, current prices)**

Entry	Value
Opening stock (1 Jan 2025)	83.9
Transactions	
Gross fixed capital formation	0.0
Consumption of fixed capital (depreciation)	-2.5
Other changes in volume	
Catastrophic losses (cyclone damage)	-1.2
Revaluation	
Holding gains (construction cost inflation)	2.5
Closing stock (31 Dec 2025), current prices	**82.7**

¶13 **Reconciliation between current-price and constant-price closing stock**: The USD 82.7 million current-price closing stock includes the USD 2.5 million holding gain from construction cost inflation. Removing the revaluation effect yields 83.9 - 2.5 - 1.2 = USD 80.2 million, which is the figure presented in the constant-price integrated Table 3.7.2 below.

¶14 **Interpretation**: The net capital stock of quay walls declined by USD 1.2 million during 2025 on a current-price basis despite a holding gain of USD 2.5 million, because depreciation and cyclone damage exceeded the revaluation. In constant 2025 prices, the real decline was USD 3.7 million, the combined effect of capital consumption and storm damage.

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Ecosystem asset account (mangrove restoration)

¶1 The 150-hectare mangrove restoration provides coastal protection, carbon sequestration, and fisheries nursery services.

¶2 **Extent account (hectares)**

Entry	Value
Opening extent (1 Jan 2025)	145
Managed expansion (new planting)	5
Natural expansion (seedling colonization)	2
Natural reduction (edge erosion)	1
Closing extent (31 Dec 2025)	151

¶3 **Condition assessment**

Variable	Opening (Jan 2025)	Closing (Dec 2025)	Reference Value	Interpretation
Canopy density (%)	62	68	85	Improving, but below reference
Prop root height (cm)	45	52	70	Maturing structure
Sediment accretion (mm/yr)	8	9	10	Approaching reference

¶4 The condition improvements reflect the maturing of the restored forest. By 2025, the restoration ranges from 3 to 7 years old (established 2018–2022), with the oldest sections approaching functional equivalence with natural mangroves.

¶5 **Methodological note on condition index construction**: The condition index used in this worked example is an unweighted arithmetic mean of three normalised condition ratios (canopy density, prop root height, sediment accretion). In national compilation, condition weighting schemes should reflect the relative contribution of each variable to the specific service being valued. Where coastal protection is the primary service, structural complexity variables (canopy density and prop root architecture) should be assigned higher weights than biogeochemical variables (sediment accretion). Compilers should document the weighting scheme and reference a published condition scoring framework. See **TG-2.1 Aggregate Biophysical Indicators of Environmental State** for condition variable selection guidance.[69]

¶6 **Monetary valuation**

¶7 Ecosystem service valuation (annual flow):

- ¶8 Coastal protection: Replacement cost of equivalent seawall = USD 8,000 per hectare per year
- ¶9 Carbon sequestration: 10 tonnes CO2 per hectare per year × USD 50 per tonne = USD 500 per hectare per year
- ¶10 Fisheries nursery: Productivity contribution = USD 400 per hectare per year
- ¶11 **Total annual service flow**: USD 8,900 per hectare per year

¶12 Adjusted for current condition:

- ¶13 Condition index = (68/85 + 52/70 + 9/10) / 3 = (0.80 + 0.74 + 0.90) / 3 = **0.81** (81% of reference condition)
- ¶14 Adjusted service flow = USD 8,900 × 0.81 = USD 7,209 per hectare per year

¶15 **Discount rate selection and sensitivity**: A social discount rate of 4% per annum is applied, consistent with indicative rates used in multilateral development bank cost-benefit analyses. National compilers should select a rate consistent with national fiscal guidelines or central bank long-run real rates. See **TG-1.9 Valuation** for selection criteria.[70]

¶16 Asset value (NPV at 4% discount rate, perpetual horizon):

- ¶17 Asset value per hectare = Annual service flow / discount rate = USD 7,209 / 0.04 = **USD 180,225 per hectare**
- ¶18 Total asset value (151 ha) = **USD 27.2 million**

¶19 *Note on the perpetuity assumption*: The perpetuity formula treats the adjusted annual service flow as continuing indefinitely. For recently restored ecosystems subject to sea level rise, cyclone mortality, and management uncertainty, a finite horizon may be more appropriate. For comparison, a 50-year finite-horizon NPV at 4% yields approximately USD 154,800/ha — materially below the USD 180,225/ha perpetuity figure. Compilers should select horizon assumptions appropriate to the maturity and risk profile of the restored ecosystem and present sensitivity ranges. See TG-1.9 for guidance.[71]

¶20 *Sensitivity table — per-hectare mangrove asset value at alternative discount rates (perpetual horizon, USD per hectare)*:

Discount Rate	Asset Value per Hectare (USD)	Total Asset Value, 151 ha (USD million)
2%	360,450	54.4
4% (central)	180,225	27.2
6%	120,150	18.1

¶21 The sensitivity table illustrates that a 1-percentage-point change in the discount rate alters the asset value by approximately 25–50%. This magnitude makes explicit discount rate justification and sensitivity testing important to any compilation that reports mangrove asset values.

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¶22 **Monetary ecosystem asset account (USD million)**

Entry	Value
Opening value (1 Jan 2025, 145 ha)	23.4
Ecosystem enhancement (condition improvement)	2.7
Ecosystem conversions (net extent increase, 6 ha)	1.1
Revaluation (service price changes)	0
Closing value (31 Dec 2025, 151 ha)	27.2

¶23 **Interpretation**: The mangrove asset value increased by USD 3.8 million during 2025, driven by both extent expansion (6 hectares net, contributing USD 1.1 million) and condition improvement (canopy density increased from 62% to 68%, contributing USD 2.7 million).

Integrated infrastructure and ecosystem account

¶1 *Table 3.7.2: Coastal City total coastal protection asset value (USD million, constant 2025 prices)*

Asset Category	Opening Stock	GFCF / Enhancement	Depreciation / Degradation	Other Changes (incl. ecosystem conversions) [72]	Closing Stock
Port quay walls (produced)	83.9	0	-2.5	-1.2 (cyclone)	80.2
Urban seawall (produced)	45.6	3.2 (raising)	-1.8	0	47.0
Mangrove forest (ecosystem)	23.4	2.7 (enhancement)	0	1.1 (ecosystem conversions — net extent increase)	27.2
Total	**152.9**	**5.9**	**-4.3**	**-0.1**	**154.4**

¶2 Note: Values shown at constant 2025 prices (revaluation effects removed for clarity). The port quay walls closing stock of USD 80.2 million corresponds to the USD 82.7 million current-price closing stock shown above, with the USD 2.5 million holding gain removed.

¶3 **Policy implications**:

¶4 This integrated account reveals three findings:

1. ¶5
   Capital maintenance gap: Produced infrastructure depreciation (USD 4.3 million) exceeded new investment (USD 3.2 million), indicating net capital consumption. The cyclone damage compounded this gap.
2. ¶6
   Ecosystem asset performance: The mangrove restoration generated USD 3.8 million in asset value increase. At an establishment cost of USD 2.5 million over 2018–2022 (amortised to USD 500,000 per year), the ecosystem enhancement exceeds annual expenditure.
3. ¶7
   Portfolio diversification: The combined portfolio of grey and blue infrastructure maintained nearly constant total value despite the cyclone impact. The mangrove asset was unaffected by the storm that damaged the quay. Hybrid protection systems spread risk across asset types that do not share the same failure mode.

Budget implications

¶1 *Infrastructure maintenance and adaptation budget request (2026)*

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Item	Amount (USD million)	Justification from Asset Accounts
Port quay rehabilitation	2.5	Accelerated depreciation and cyclone damage require intervention to prevent further deterioration
Seawall climate adaptation (raising)	4.0	Continue 2025 programme; projected sea level rise of 0.5m by 2050 requires raising 12km seawall by 1.5m
Mangrove expansion and maintenance	0.6	Extend restoration to additional 50 ha; condition monitoring and maintenance for existing 151 ha
Total request	**7.1**	

¶2 The asset accounts provide the evidence base. Produced infrastructure is depreciating faster than it is being replaced, cyclone damage demonstrates exposure to climate hazards, and mangrove investment has delivered measurable returns.

4. Summary

¶1 Coastal infrastructure accounting integrates produced asset measurement with ecosystem accounting approaches to cover the full range of assets that protect and modify coastal zones.

¶2 Key principles:

1. ¶3
   Classification – distinguish produced assets (ports, seawalls, reclaimed land) from ecosystem assets (mangroves, coral reefs, wetlands) whilst recognising functional equivalence in service provision, as summarised in Table 3.2.1
2. ¶4
   Valuation – apply perpetual inventory methods to produced assets and net present value of ecosystem services to natural assets, following **TG-1.9 Valuation**
3. ¶5
   Integration – account for hybrid systems through clear attribution of produced and ecosystem components, avoiding double counting whilst capturing full asset values
4. ¶6
   Adaptation – track climate adaptation investments across grey, green, and hybrid infrastructure with linkages to **TG-2.8 Climate Indicators**
5. ¶7
   Cross-references – maintain consistency with related circulars, particularly **TG-6.2 Mangrove and Coastal Wetland Accounting** and **TG-2.9 Disaster Risk**

Cross-Reference Summary

Related Circular	Relevance to TG-6.11
TG-0.1 General Introduction	Prerequisite – foundational concepts
TG-3.1 Asset Accounts	Prerequisite – asset classification and balance sheets
TG-6.2 Mangrove and Coastal Wetland Accounting	Detailed mangrove extent, condition, and service accounting
TG-2.4 Environmental (including Ecosystem) Goods and Services Section 3.10	Valuation methods for ecosystem services and assets
TG-2.9 Disaster Risk	Coastal hazard exposure assessment, vulnerability, and infrastructure protection capacity
TG-2.8 Climate Indicators	Climate-related indicators for adaptation tracking

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Related Circular	Relevance to TG-6.11
TG-1.1 National Ocean Budgets	Budget integration and fiscal planning applications
TG-6.9 Offshore Energy	EEZ-located offshore infrastructure beyond the territorial sea
TG-6.10 Maritime Transport and Ports	Port infrastructure classification and dredging

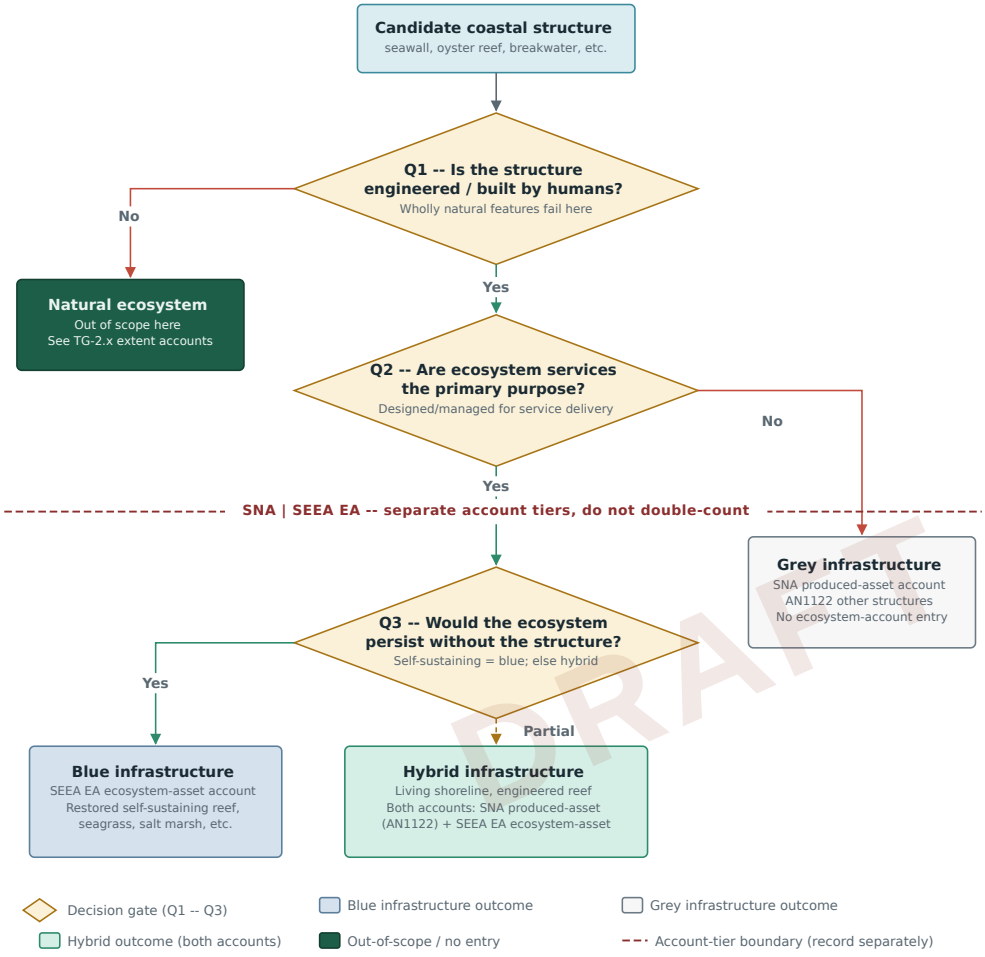


Figure 6.11.1 Three-gate decision tree classifying coastal or offshore structures as natural, grey, blue, or hybrid across SNA and SEEA EA account tiers. Edge colour: green Yes, coral No, ochre-dashed Partial. Dashed double-rule = account-tier boundary (no double-count).

Source: TG-6.11, Section 3.4 (blue-grey integration) and Table 3.2.1 (coastal protection asset classification); SEEA EA (2021), Chapter 5 (ecosystem assets and extent accounts) and Chapter 10 (monetary asset accounts); SNA 2025, Chapter 11, para. 11.85 (AN1122 other structures).

5. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

6. References

1. ¶1 SEEA Central Framework (2012), Chapter 5, Environmental Assets.
2. ¶2 2025 SNA, Chapter 11, The Capital Account, paragraphs 11.85–11.89 on other structures and land improvements.
3. ¶3 2025 SNA, paragraph 11.85: "Other structures (AN1122) include structures other than buildings, including the cost of the streets, sewer, etc... the construction of sea walls, dykes, flood barriers etc. intended to improve the quality and quantity of land adjacent to them."
4. ¶4 SEEA EA (2021), Chapter 10, Monetary Asset Accounts, on NPV approach for ecosystem asset valuation.
5. ¶5 2025 SNA, Chapter 35, paragraph 35.3: "Climate change can be considered as one of the major risks affecting current and future wellbeing."
6. ¶6 This Circular assumes familiarity with ocean accounting boundaries including territorial seas and exclusive economic zones as defined in the United Nations Convention on the Law of the Sea (UNCLOS), Part V.
7. ¶7 SEEA Central Framework (2012), Chapter 5, provides the core asset accounting framework extended in this guidance.
8. ¶8 UNCLOS Article 56 defines the rights, jurisdiction, and duties of coastal States in the EEZ, including sovereign rights for economic exploitation and exploration of natural resources and jurisdiction over artificial islands, installations, and structures. See United Nations (1982), UNCLOS, Article 56. For infrastructure associated with offshore energy operations, see TG-6.9 Offshore Energy; for maritime transport infrastructure in the EEZ, see TG-6.10 Maritime Transport and Ports, Section 3.2.
9. ¶9 CPC Ver.2.1, Class 53262 "dredging services, rock and silt removal and other water-associated construction services."
0. ¶10 SEEA EEA Technical Recommendations (2022) provides guidance on ecosystem extent measurement.
1. ¶11 Bunting, P. et al. (2018). The Global Mangrove Watch—A New 2010 Global Baseline of Mangrove Extent. *Remote Sensing*, 10(10), 1669. Sentinel-2 and Landsat data are available through the Copernicus Open Access Hub and USGS EarthExplorer respectively.
2. ¶12 Financial data requirements align with government finance statistics and business accounting standards.
3. ¶13 Classification frameworks: SEEA Central Framework (2012), paragraph 5.46 (AN1122); CPC Ver.2.1, Division 53 (Construction services); COFOG groups 04.5 (water transport) and 05.6 (protection of biodiversity and landscape) — see footnote 67 for COFOG classification guidance; Keith, D.A. et al. (2022), A function-based typology for Earth's ecosystems, *Nature*, 610, 513–518 (IUCN Global Ecosystem Typology).
4. ¶14 2025 SNA, paragraph 11.85. Other structures (AN1122) include "harbour bottoms and harbour channels, breakwaters, quays, piers, jetties, docks, wharves and similar structures."
5. ¶15 ISIC Rev.4, Division 52 (Warehousing and support activities for transportation).
6. ¶16 Port infrastructure classification aligns with UNCTAD port statistics frameworks.
7. ¶17 SEEA Central Framework (2012), paragraph 4.199.
8. ¶18 OECD (2009). *Measuring Capital: OECD Manual*, 2nd edition, Chapter 6, provides detailed guidance on applying the PIM to infrastructure assets.
9. ¶19 Coastal engineering classification following CIRIA (2007). *The Rock Manual: The Use of Rock in Hydraulic Engineering*, 2nd edition.
0. ¶20 2025 SNA, paragraph 11.87 on major improvements constituting gross fixed capital formation.
1. ¶21 Breakwater and groyne classifications follow coastal engineering standards.
2. ¶22 CPC Ver.2.1, Class 53262.
3. ¶23 Complex assets with multiple components should be depreciated by component where values are material.
4. ¶24 Environment Agency (2018). *Thames Estuary 2100 Plan*; Deltacommissie (2008). *Working Together with Water: A Living Land Builds for its Future*; Consorzio Venezia Nuova (2020). *MOSE: Experimental Electromechanical Module*.
5. ¶25 SEEA Central Framework (2012), paragraph 5.265.
6. ¶26 SEEA EA (2021), Chapter 4, Ecosystem Extent Accounting, for recording conversions.
7. ¶27 SNA 2025, paragraph 11.85 on AN1122 "other structures" (covering sea walls, dykes, flood barriers, and engineered land-improvement works); SNA non-produced asset classifications AN.211 (Land underlying buildings and structures) and AN.212 (Land under cultivation). The two-component recording approach — produced engineered works as GFCF in AN1122 and the resulting land area as a non-produced asset in AN.211/AN.212 once the land begins to function as a productive asset — preserves the SNA produced/non-produced boundary while recognising both the human-made structures and the resulting usable land area. See also TG-3.1 Asset Accounts for general land accounting principles.
8. ¶28 SEEA EA (2021), paragraph 10.23, on ecosystem degradation costs.
9. ¶29 OECD Manual on Measuring Capital (2009) provides detailed PIM guidance.
0. ¶30 2025 SNA, Chapter 7, paragraphs 7.60–7.65, on consumption of fixed capital at opportunity cost. See also SEEA Valuation (2023), paragraph 3.3.
1. ¶31 Service life estimates based on engineering literature and asset management practices. Maintenance cost percentages are indicative and should be calibrated to local conditions. Actual lives depend on design, materials, and environmental conditions. Beach nourishment is typically written off over the renourishment cycle (1–5 years) since placed sand is progressively lost to longshore transport and storm dispersal. Living shoreline engineered components (placed rock, oyster-reef substrate, sills) follow a shorter service life than fully-engineered breakwaters because of

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their interaction with biological growth and intentional partial submergence; the associated ecosystem components are recorded under ecosystem accounts rather than as produced assets.

2. ¶32 Asset condition assessment should follow standard infrastructure management protocols.
3. ¶33 Table 3.2.1 draws on SEEA Central Framework (2012) Chapter 5 for produced asset classification and SEEA EA (2021) Chapter 10 for ecosystem asset valuation approaches.
4. ¶34 2025 SNA distinguishes intermediate consumption (current expenditure maintaining capacity) from capital formation (investment extending capacity).
5. ¶35 PIANC guidelines distinguish maintenance from capital dredging.
6. ¶36 SEEA Central Framework (2012), paragraph 3.267.
7. ¶37 NOAA (2015). *Living Shorelines: From Barriers to Opportunities*.
8. ¶38 Living shoreline components classification follows NOAA and coastal management guidance.
9. ¶39 CEPA 2000, Class 6 (Protection of biodiversity and landscapes).
0. ¶40 Hybrid classification requires judgment on primary purpose and asset characteristics.
1. ¶41 Reef protection services are distinct from fisheries and recreation services, avoiding double counting.
2. ¶42 World Bank (2016). *Managing Coasts with Natural Solutions: Guidelines for Measuring and Valuing the Coastal Protection Services of Mangroves and Coral Reefs*.
3. ¶43 SEEA Valuation (2023) recommends avoided damage cost method using expected damage functions where data permit.
4. ¶44 Menendez, P. et al. (2020). The Global Flood Protection Benefits of Mangroves. *Scientific Reports*, 10, 4404.
5. ¶45 Ferrario, F. et al. (2014). The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. *Nature Communications*, 5, 3794. The Allen Coral Atlas provides globally consistent reef mapping at ~5 m resolution.
6. ¶46 SEEA EA (2021), Chapter 10, on ecosystem enhancement and degradation accounting.
7. ¶47 "Building with Nature" and "Engineering with Nature" approaches integrate ecological and engineering objectives. See Waterman, R.E. (2010). *Integrated Coastal Policy via Building with Nature*, The Hague.
8. ¶48 Attribution between produced and ecosystem asset components requires clear documentation.
9. ¶49 This classification approach follows the general SNA principle that assets should be classified according to their primary economic function. Where multiple functions are inseparable, proportional allocation based on capital expenditure provides a practical basis.
0. ¶50 SEEA EA (2021), paragraph 10.15.
1. ¶51 Enhancement activities following SEEA EA classification in paragraph 10.18.
2. ¶52 SEEA EA (2021), paragraph 10.18 distinguishes restoration, rehabilitation, and reclamation.
3. ¶53 SEEA EA (2021), paragraph 10.19.
4. ¶54 SEEA EA (2021), paragraph 4.21.
5. ¶55 Climate-adapted design costs should be fully capitalized as part of asset value.
6. ¶56 SEEA Central Framework (2012), Chapter 5, other changes in volume account entries.
7. ¶57 Adaptation retrofits extending useful life constitute gross fixed capital formation.
8. ¶58 2025 SNA, Chapter 12, on other changes in the volume of assets, provides the general framework for recording unforeseen asset value changes including catastrophic losses. Application to climate-related stranded coastal assets is an area where international guidance is expected to develop further.
9. ¶59 Grey infrastructure adaptation following coastal engineering guidance.
0. ¶60 Terrestrial (green) nature-based solutions for adaptation, consistent with the Section 1 distinction between green (terrestrial NbS) and blue (marine/coastal NbS) infrastructure.
1. ¶61 Marine and coastal (blue) nature-based solutions for adaptation. Mangroves, coastal wetlands, beach nourishment, seagrass, and oyster reef interventions are classified as blue infrastructure under the Section 1 definitions and accounted for through ecosystem extent, condition, and (where applicable) monetary ecosystem asset accounts following SEEA EA.
2. ¶62 Hybrid adaptation approaches combining structural and natural elements.
3. ¶63 FDES (2013), Component 1, Environmental Conditions and Quality.
4. ¶64 G20 Data Gaps Initiative, Third Phase (2022–2025), Recommendation 4 on climate change indicators. TNFD (2023). *Recommendations of the Taskforce on Nature-related Financial Disclosures*, particularly Recommended Disclosure Strategy C on risk management for nature-related dependencies and impacts.
5. ¶65 COFOG Group 05.6 (Protection of biodiversity and landscape) is the standard classification for coastal protection expenditure where the primary purpose is environmental protection (for example, nature reserve buffer works, dune stabilisation, residential seawall protection of community assets), as set out in the COFOG scope note: "Outlays on protection of nature and landscape (species, habitats, erosion protection, coastal protection, dune stabilization…)". Coastal protection structures that primarily serve transport infrastructure functions (port breakwaters, navigation channel protection) should instead be classified under COFOG Division 04 (Economic affairs), Group 04.5 (Transport), water-transport class. Where a structure serves both functions (for example, a breakwater protecting both a port and a residential coastline), classify by primary purpose and document the secondary function in compilation metadata. Compilers should verify the precise COFOG class codes against the COFOG edition in use (UN 2000 COFOG manual or its IMF GFSM 2014 adaptation), since class-level numbering and any current revisions may differ. See also CEPA/CREMA classifications for environmental protection expenditure (footnote 68).
6. ¶66 CEPA/CREMA classifications for environmental protection and resource management expenditure.

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7. ¶67 Integration across expenditure, asset, and ecosystem accounts enables coherent adaptation tracking.
8. ¶68 SNA institutional sector balance sheet coverage includes non-financial assets owned by all institutional sectors (general government, non-financial corporations, financial corporations, households, and NPISH). Coastal protection structures owned by private enterprises and households fall within this scope and should be recorded where material. See also Section 2.1 (Data Requirements) on financial data sources.
9. ¶69 SEEA EA (2021), Chapter 5, paragraphs 5.20–5.32, on ecosystem condition measurement, transparent weighting, and reference-value selection. Weighting schemes used in condition index construction should be transparent, justifiable in terms of the service being valued, and documented in compilation metadata.
0. ¶70 SEEA EA (2021), Chapter 10 (paragraphs in the range 10.30–10.42 cover discount rate selection for monetary ecosystem asset valuation, including the distinction between private market-based and social discount rates and the recommendation to present asset values under alternative discount rate assumptions). World Bank (2016) and indicative rates used in multilateral development bank cost-benefit analyses for natural-capital and infrastructure investments. See TG-1.9 Valuation for national rate selection criteria.
1. ¶71 SEEA EA (2021), Chapter 10, paragraphs in the range 10.35–10.42 on NPV calculation for ecosystem assets, including finite-horizon NPV where there is material uncertainty about asset persistence. The 50-year illustrative figure is provided for comparison; appropriate horizons vary with restoration age, climate risk, and management arrangements.
2. ¶72 For produced assets, “Other Changes” covers catastrophic losses and reclassifications, consistent with the SEEA Central Framework other-changes-in-volume account. For ecosystem assets, this column records “ecosystem conversions” — a distinct SEEA EA concept. Both types of entry are shown here for presentational compactness; compilers should record them in the appropriate sub-account in detailed compilations.

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Marine Litter and Plastics Accounting

Provides guidance on establishing stock-flow accounts for marine litter and plastics within the Ocean Accounts framework.

Version 0.8.1 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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ABOUT THIS CIRCULAR

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OUTCOME

This Circular provides guidance on establishing stock-flow accounts for marine litter and plastics within the Ocean Accounts framework. Upon completing this Circular, readers will understand how to:

- categorise marine litter by material type and source
- compile flow accounts tracking litter from land-based and maritime sources to the marine environment
- develop stock accounts for accumulated litter in coastal zones, surface waters, the water column, and the seafloor
- allocate flows to economic sectors and geographic sources
- align marine litter accounts with SDG Target 14.1 indicators on marine pollution
- derive circular economy indicators linking litter accounts to plastics reduction targets under emerging international frameworks
- compile material flow accounts for synthetic materials from production through disposal to marine leakage
- score the availability and reliability of the national plastics data the accounts depend on, and prioritise the gaps worth closing first
- establish the institutional mandate, stakeholder arrangements and reporting cycle that turn a one-off estimate into a repeatable account

The accounts compiled using this guidance support derivation of indicators for environmental pressure assessment in TG-2.7 Pollution Flows, contribute to assessment of residual flows from economy to environment in TG-3.4 Flows from Economy to Environment, inform circular economy indicators in TG-2.11 Resource Efficiency, and support reporting to the multilateral environmental agreements described in TG-2.10 MEA Indicators. Marine litter accounting also complements maritime transport activity accounts in TG-6.10 Maritime Transport where vessel-sourced litter is concerned.

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Framework Position

This Circular owns the stock and flow accounts for marine litter and plastics: the material and source categories, the land-based and maritime input flows, the accumulation stocks by marine compartment, and the source attribution that connects them to economic units. It specialises TG-3.4 Flows from Economy to Environment, which owns the residual-flow framework and the solid waste account this Circular's flows enter, and cross-refers for survey and administrative data methods (TG-4.2, TG-4.3, TG-4.4) and readiness (TG-0.8). Indicator derivation is not this Circular's: SDG 14.1.1 and the circular-economy indicators are built in TG-2.7, TG-2.10 and TG-2.11; Section 3.7 states only what the accounts must carry for them. Nutrient pollution — the other half of SDG 14.1.1 — is TG-6.13 and TG-3.4.

1. Outcome

¶1 This Circular provides guidance on establishing stock-flow accounts for marine litter and plastics within the Ocean Accounts framework. Upon completing this Circular, readers will understand how to:

- ¶2 categorise marine litter by material type and source
- ¶3 compile flow accounts tracking litter from land-based and maritime sources to the marine environment
- ¶4 develop stock accounts for accumulated litter in coastal zones, surface waters, the water column, and the seafloor
- ¶5 attribute litter flows to economic sectors and geographic sources
- ¶6 align marine litter accounts with SDG Target 14.1 indicators on marine pollution
- ¶7 derive circular economy indicators linking litter accounts to plastics reduction targets under emerging international frameworks
- ¶8 compile material flow accounts for synthetic materials from production through disposal to marine leakage
- ¶9 score the availability and reliability of the national plastics data the accounts depend on, and prioritise the gaps worth closing first
- ¶10 establish the institutional mandate, stakeholder arrangements and reporting cycle that turn a one-off estimate into a repeatable account

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> ¶12 ⓘ **Framework Position**
> ¶13 This Circular owns the **stock and flow accounts for marine litter and plastics**: the material and source categories, the land-based and maritime input flows, the accumulation stocks by marine compartment, and the source attribution that connects them to economic units.
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2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-0.1 General Introduction** — foundational Ocean Accounts components and SIDS-specific considerations relevant to marine litter accounting in small island contexts.
- ¶3 **TG-3.4 Flows from Economy to Environment** — residual flow accounting, solid waste accounts, and attribution of emissions and waste to economic sectors, which underpins the marine litter flow accounting approach in Section 3.3.

3. Guidance Material

¶1 Marine litter is defined as any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment. It constitutes one of the most visible forms of marine pollution[1]. Plastics are the dominant material category, accounting for approximately 80 percent of all marine debris by count[2].

¶2 SDG Target 14.1 (preventing and reducing marine pollution) provides the primary policy anchor for this Circular[3]. SDG indicator 14.1.1 specifically includes "floating plastic debris density" as a component of the index of coastal eutrophication and plastic debris density[4]. An INC process to develop a legally binding instrument on plastic pollution (UNEA Resolution 5/14, March 2022) is ongoing. Compilers should consult the UNEP INC website for current treaty status and emerging reporting obligations[5], [6].

¶3 **Scope — microplastics.** Microplastics (plastic particles less than 5mm in diameter, whether primary or secondary) are out of scope of this Circular. Detailed accounting for microplastic flows, stocks, and fragmentation is deferred pending further methodological development. This Circular addresses macroplastics (>25mm) and mesoplastics (5-25mm) only. Inline references to microplastics in the pathway descriptions are retained for completeness but are flagged as out-of-scope inputs that compilers should not attempt to quantify under this guidance. Countries developing experimental microplastic accounts should document methods separately and treat results as supplementary information.

¶4 The SEEA CF physical supply and use table structure for solid waste records waste generation by economic sector and tracks flows to collection, treatment, and disposal destinations[7], [8]. For marine litter accounting, this framework is extended to capture waste that escapes management systems and enters the marine environment, as well as litter generated directly by maritime activities. General solid waste accounting structure follows **TG-3.4 Flows from Economy to Environment**.

¶5 **Operational companion.** This Circular specifies what a marine litter and plastics account contains and how its entries relate to one another. The GOAP *Plastics Data Collection and Reporting Handbook* specifies how a country finds, scores and generates the underlying data, and is the operational companion to this Circular[9]. Where this Circular calls for a quantity, the Handbook names the instrument that produces it — the Plastics Data Checklist, the Global Plastics Data Tracker, the survey and sampling protocols, and the classification code sets. The two documents share a deliberate scope boundary: neither provides quantified guidance for microplastics or for certified biodegradable materials, and neither covers extraction and processing upstream of primary polymer manufacture.

¶6 The Handbook also establishes the maturity sequence inside which this Circular's compilation phases sit. Improving individual data points yields a **plastics data inventory** — a coherent collection of data points measuring flows across the value chain. An inventory becomes a **plastics account** only when its data categories are reproduced periodically under a documented, standing methodology[10]. The distinction has practical force: a single well-researched estimate of marine leakage is an inventory entry, not an account, and the accounting entries in Sections 3.3 to 3.6 assume the repeatability that Section 4 sets out to secure.

¶7 The starting point for most countries is sparse. A 2025 review of government-reported plastics data for every UN Member State found that 10 percent of countries report no plastics data at all and 60 percent report no data on waste generation[11]. Compilers should expect the first cycle to be a data-development exercise as much as an accounting one, and should read Section 4 before attempting the flow and stock tables.

3.1 Decision Use Cases and Upward Connections

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Plastics treaty reporting and compliance monitoring

¶1 Marine litter accounts link plastics material flow accounts (tracking production and use) to waste management accounts (tracking collection and disposal) to residual flow accounts (tracking marine leakage). This linkage eliminates redundant data collection across reporting obligations and keeps national waste statistics and international environmental monitoring consistent with one another.

Circular economy metrics for plastics

¶1 Marine litter accounts quantify the proportion of plastic waste that escapes collection and treatment systems, providing the "leakage rate" indicator central to circular economy assessment. SEEA CF paras 3.268-3.278 establish the applicable residual flow framework[12]. These indicators feed directly into **TG-2.11 Resource Efficiency**.

Beach and ocean cleanup investment justification

¶1 Where the case for cleanup rests on protecting tourism revenue, the revenue figure should be taken from the marine and coastal tourism segment compiled in **TG-6.14**, so that the benefit claimed and the sector account agree.

¶2 Stock accounts by environmental compartment (beach, floating, benthic) provide baseline estimates of litter volumes requiring removal. Flow accounts by source category enable prioritisation of interventions targeting high-contribution pathways. Time-series accounts tracking stock changes before and after cleanup programmes provide the quantitative basis for return-on-investment assessment. This use case links to environmental protection expenditure accounts addressed in **TG-3.7 Governance Accounts**.

Upward connections to indicator frameworks

- ¶1 **SDG 14.1.1 (Marine pollution)** — directly supplies floating plastic debris density component[13]
- ¶2 **Pollution pressure indicators (TG-2.7)** — provides physical flow data for litter generation intensity, mismanaged waste rates, and marine leakage indicators
- ¶3 **Circular economy indicators (TG-2.11)** — enables calculation of recycling rates, waste utilisation rates, and decoupling factors
- ¶4 **MEA reporting (TG-2.10)** — supports Kunming-Montreal Global Biodiversity Framework Target 2 and UNFCCC reporting

¶5 The combined presentations approach in **TG-3.8 Combined Presentations** provides methods for integrating marine litter account data with economic and ecosystem condition accounts.

3.2 Marine Litter Framework: Categories, Sources, and Pathways

Aligning contested definitions

¶1 The terms on which marine litter accounts depend — mismanaged waste, leakage, litter, dumping — carry materially different definitions across the frameworks a compiler will draw on. UNEP's 2024 assessment of plastics terminology records at least two competing definitions each for *mismanaged waste*, *leakage* and *sanitary landfill*, advocated respectively by the UNEP/IUCN Hotspotting methodology, the OECD, GIZ's Waste Flow Diagram and UN-Habitat's Waste Wise Cities Tool[14]. The divergences are not cosmetic.

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Term	Narrower reading	Broader reading	Accounting consequence
Mismanaged waste	Uncollected waste plus improperly disposed waste (UNEP/IUCN Hotspotting; PLASTEAX)	Any waste not captured by state-of-the-art collection or treatment, including unsanitary landfills and dumpsites (OECD)	The broader reading moves waste in unsanitary landfills from inside the economy to the mismanaged pool, raising both the mismanaged rate and the base to which leakage factors apply
Leakage	Plastic released to rivers, lakes and oceans (PLASTEAX)	Plastic entering any environmental compartment, including soils and air (UNEP/IUCN; OECD)	The broader reading is not the residual flow to marine waters; using it without adjustment inflates the marine leakage estimate
Litter / littering	Incorrect disposal of small one-off items, which street cleaning may or may not recover (UNEP/IUCN)	Waste arising from littering and fly-tipping, treated as distinct from mismanaged waste because it is not correlated with collection infrastructure (OECD)	Under the broader reading litter must be estimated separately rather than derived from collection coverage
Dumping	Deliberate uncontrolled disposal of large quantities in a particular area, from the formal or informal sector (UNEP/IUCN)	Overlaps with *fly-tipping*, the deliberate disposal of large items or quantities at no specific location	Double-counting risk wherever the two are estimated from separate surveys

¶2 Accounts are not comparable across countries unless the definition applied to each entry is stated. Compilers should record, for every row of the flow and stock accounts, which definition has been applied and which source it comes from, and should not mix readings within a single time series. Where a country's own legal definitions differ from all of the above, the national definition governs the account and the divergence is documented in the metadata.

¶3 The three waste measurement points must also be kept distinct, because they are measured at different places in the chain and are not interchangeable [15]:

- ¶4 **Waste generated** — the total plastic discarded within the system boundary during the period, regardless of subsequent fate.
- ¶5 **Waste collected** — measured at the point of collection, before sorting or processing; includes contamination and material that will later be rejected.
- ¶6 **Waste treated** — measured after sorting and cleaning, on entry to recycling, energy recovery or other treatment.
- ¶7 **Recovered tonnes** — the material that completes the recycling process and leaves the facility as saleable recyclate.

¶8 Collection and treatment figures should each be split between formal and informal management (Sections 3.3 and 3.5).

Material categories

¶1 **Plastics** — the dominant component, requiring disaggregation by:

- ¶2 Polymer type (polyethylene, polypropylene, polystyrene, PET, PVC, other polymers)
- ¶3 Product category (packaging, single-use items, fishing gear, consumer goods, industrial materials)
- ¶4 Size class (macroplastics >25mm, mesoplastics 5-25mm, microplastics <5mm)

¶5 Bioplastics and materials marketed as biodegradable warrant careful treatment. Many do not degrade under marine conditions and should be accounted equivalently to conventional plastics.

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For materials with certified marine biodegradability (per ISO 18830:2016 and ISO 19679:2016 or equivalent), compilers may apply a degradation rate in the stock account's outflow rows rather than treating the material as persistent. ISO 18830 and ISO 19679 certify aerobic biodegradation potential under controlled laboratory conditions and do not directly yield field rate constants. Compilers wishing to apply a degradation outflow should derive a first-order rate constant from field studies, document the temperature, UV, and turbulence assumptions applicable to the accounting area, and record the mass outflow in a dedicated "Certified biodegradation" row separate from the general "Degradation" row. Where certified degradation rates are unavailable, conservative practice treats all plastics as persistent.

¶6 **Other materials** — including glass and ceramics, metal, rubber, textiles, paper and cardboard, processed wood, and other manufactured materials.

¶7 The GESAMP Guidelines for the monitoring and assessment of plastic litter in the ocean provide a harmonised categorisation framework[16]. The European Waste Catalogue (EWC-Stat) offers additional detail for waste source identification[17].

Classification systems and codes

¶1 Accounts assembled from production, trade and waste statistics inherit those statistics' classifications. The code sets below are the ones a compiler will actually query, and using them consistently is what makes the material flow account in Section 3.6 reconcilable against official statistics[18].

System	Domain	Plastics codes
ISIC	Production, consumption	20.16 plastics in primary forms; 22.20 plastic products; 38.32 recovery of sorted materials
CPC	Production, consumption, trade	Group 347 primary forms; 363 semi-manufactures; 364 packaging; 369 other plastic products
PRODCOM (EU)	Production	Divisions 20 and 22, at eight digits
NAICS (North America)	Production	325211 resin manufacturing; 326 plastics and rubber products; 326199 other plastic products
HS	Trade	3901–3914 primary forms; 3915 waste and scrap; 3916–3926 products
SITC	Trade	Division 57 primary forms; 58 non-primary forms; 893 articles of plastic
Basel Convention	Waste, transboundary movement	Y48 (Annex II); A3210 (Annex VIII, hazardous); B3011 (Annex IX, clean recyclable)
European List of Waste (EWC/LoW)	Waste	15 01 02 packaging; 02 01 04 agriculture and horticulture; 07 02 13 plastics manufacturing; 12 01 05 shavings and turnings; 16 01 19 end-of-life vehicles; 17 02 03 construction and demolition; 19 12 04 mechanical treatment of waste; 20 01 39 separately collected municipal fractions
EWC-Stat	Waste statistics	07.4 plastic waste; 07.4.1 plastic packaging waste; 07.4.2 other plastic wastes
Plastic-KEYs (UNITAR)	Finished products	59 keys in eight groups: P1 packaging, P2 transport, P3 building and construction, P4 electrical and electronic equipment, P5 consumer and institutional products, P6 industrial machinery, P7 textiles, P8 other

¶2 The systems carrying a legal mandate — HS for trade, ISIC and NAICS for production, and the Basel Convention for waste — are the most consistently populated and should anchor the account; the others supply detail[18]. One break in comparability is worth flagging: the Basel Convention's plastic waste entries took effect on 1 January 2021, so transboundary plastic waste series do not run continuously across that date.

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¶3 Where polymer disaggregation is attempted, the practical reporting set is PET, HDPE, PVC, LDPE and LLDPE, PP, and PS and EPS[19].

Source categories

¶1 **Land-based sources** — estimated to contribute approximately 80 percent of marine litter globally (Jambeck et al. 2015), including municipal solid waste, industrial and manufacturing residues, construction and demolition waste, agricultural plastics, sewage-related debris, coastal tourism and recreation waste, and riverine transport from inland areas.

¶2 **Sea-based sources** — including: fishing activities (abandoned, lost, or discarded fishing gear — ALDFG); shipping (cargo loss, operational waste); offshore energy operations; aquaculture (equipment, floats, feed bags); recreational boating; and maritime structures and port operations.

¶3 **Release routes within the waste system** — uncollected, dumped and burned waste are distinct release routes rather than a single residual, and the distinction carries into the account[20]:

- ¶4 **Uncollected waste** — all solid plastic waste that escapes waste management systems, formal and informal alike.
- ¶5 **Open dumping** — waste deliberately discarded at unauthorised, uncontrolled or unmanaged locations without containment or treatment.
- ¶6 **Open burning** — waste deliberately set on fire by households, businesses or industry to reduce volume.
- ¶7 **Fly-tipping** — deliberate disposal of large items or quantities at no particular location.
- ¶8 **Littering** — incorrect disposal of small, one-off items unlikely to be recovered by managed collection.

¶9 Open burning matters to the account for a reason easily missed: it removes mass from the pool available for marine leakage while creating an emissions flow recorded elsewhere. Burned plastic should be recorded as an explicit outflow from the mismanaged waste pool rather than left implicitly available to leak, with the corresponding emissions cross-referenced to greenhouse gas inventory reporting (Section 3.3).

¶10 The relative contribution of different sources varies by location. SIDS may have higher proportionate contributions from sea-based sources. See SIDS-specific considerations in **TG-0.1 General Introduction**[21].

Pathways to the marine environment

Pathway	Description
Direct coastal input	Waste deposited, blown, or washed directly from coastal zones into the sea.
Riverine transport	Waste carried by rivers from upstream sources; rivers are major conduits for land-based marine litter[22].
Stormwater and urban runoff	Waste transported through drainage systems during precipitation events.
Wastewater discharge	Microplastics and other debris not removed during wastewater treatment.
Atmospheric transport	Lightweight items and microplastics transported by wind.
Open dumping and fly-tipping	Waste deposited at uncontrolled sites or discarded at no particular location, from which wind, runoff and watercourses mobilise it[20].
Open burning	Waste burned to reduce volume; a competing fate that removes mass from the leakage pool and creates an emissions flow instead[20].
Direct disposal at sea	Deliberate dumping (regulated under the London Convention and Protocol)[23].
Accidental loss at sea	Cargo loss, equipment failure, vessel incidents.

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¶1 The SEEA CF notes that controlled landfills are within the economy, whilst uncontrolled disposal to the environment represents a residual flow[24]. For marine litter accounting, waste reaching marine waters represents a flow to the environment recorded in residual flow accounts.

¶2 Figure 6.12.1 summarises marine litter stock-flow relationships (see also TG-3.4 Section 3.2).

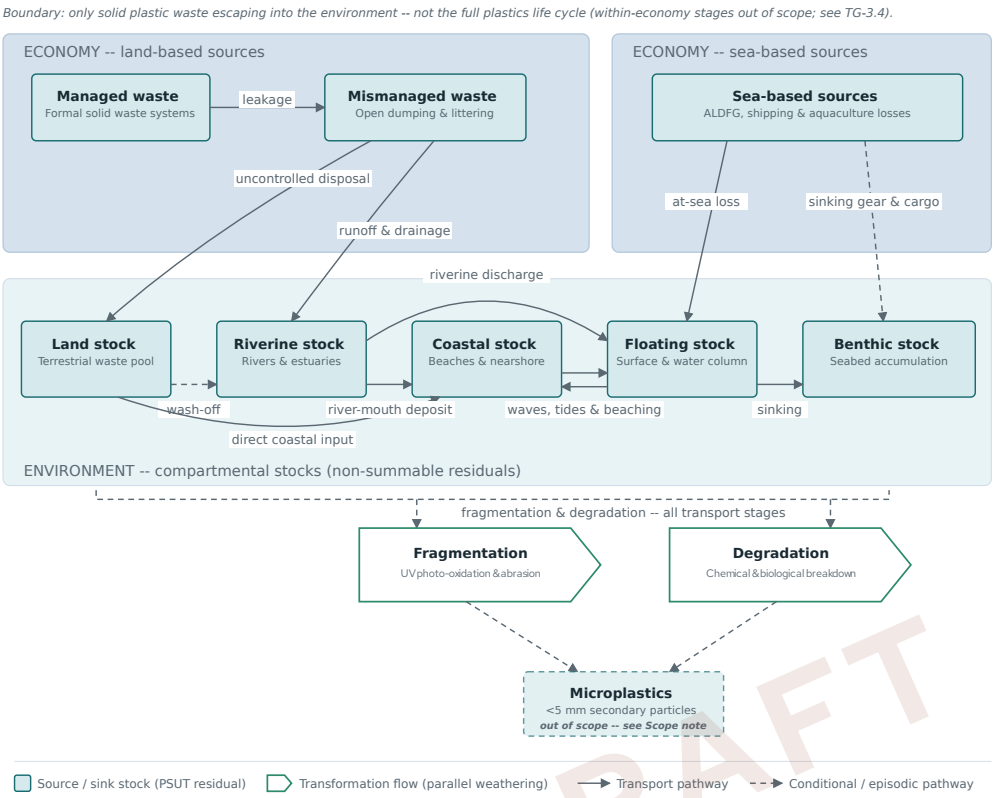


Figure 6.12.1 Marine solid-plastic residual flows from managed and mismanaged sources through coastal, floating, and benthic stocks toward microplastics. Dashed edges = conditional/episodic paths; double arrow = coastal ↔ floating exchange; microplastics terminal muted (out of scope). Stocks non-summable.

Scope: Escape residuals only; economy-side waste SUT out of scope -- TG-3.4.

Source: TG-6.12 (marine solid plastic waste accounting framework); SEEA CF 2012, Chapter 3 (residual flows and waste treatment); UNEP/GESAMP 2021 (Sources, Fate and Effects of Microplastics in the Marine Environment, Pt. 2), paras. 2.1--2.4.

3.3 Flow Accounting: Litter Inputs to the Marine Environment

¶1 Flow accounts record the quantity of litter entering the marine environment during an accounting period, measured in mass units (tonnes) or, for monitoring purposes, item counts.

Land-based source flows

¶1 Land-based litter flows require estimation of:

- ¶2 **Mismanaged waste** – waste not formally collected or improperly disposed after collection
- ¶3 **Leakage rates** – the proportion of mismanaged waste that reaches marine waters (dependent on proximity to coast, hydrological connectivity, and waste characteristics)

¶4 The methodology developed by Jambeck et al. (2015) estimates plastic waste input from land to ocean based on coastal population, waste generation rates, waste management infrastructure, and modelled leakage[25]:

```
Plastic marine debris = Coastal population ×
                        Waste generation rate ×
                        Plastic content of waste ×
                        Inadequately managed waste share ×
                        Leakage factor to ocean
```

¶5 Lau et al. (2020) extended this framework for scenario analysis of waste management interventions and material substitution [26]. Borrelle et al. (2020) projected plastic waste growth trajectories [27].

¶6 For ocean accounting purposes, this estimation approach should be disaggregated by economic sector where possible, geographically referenced to identify priority coastal areas, and time-series consistent to track trends.

¶7 **Default composition data where national studies are absent.** Every term in a Jambeck-type estimator after coastal population depends on the plastic fraction of municipal solid waste, which many countries have never measured. Two fallbacks precede borrowing a neighbouring country's figure. Countries reporting to the UNFCCC often already hold waste composition data compiled for national atmospheric emissions inventories, prepared in order to calculate landfill emissions; this is the preferred fallback because it is nationally specific and already quality-assured [28]. Failing that, the IPCC's regional default plastic shares of municipal solid waste provide a documented tier-1 assumption [29]:

Region	Plastic share of MSW (%)	Region	Plastic share of MSW (%)
Central Asia	8.4	Eastern Europe	4.6
Eastern Asia	6.5	Northern Europe	4.9
South-Eastern Asia	10.2	Southern Europe	11.8
Southern Asia	7.0	Western Europe	20.5
Western Asia	17.2	Central America	10.3
Northern Africa	13.8	South America	13.7
Eastern Africa	8.0	Northern America	15.8
Middle Africa	7.1	Australia and New Zealand	8.3
Southern Africa	26.5	Western Africa	6.4

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¶8 A regional default is an interim device, not a result. It should be tagged as such in the account's metadata and replaced by a national waste composition study — systematic sampling and manual sorting of waste streams, typically 100–200 kg per sampling event, repeated to capture seasonal variation — as soon as one exists [30]. Because composition studies are point-in-time and resource-intensive, they are usually run quarterly or annually rather than continuously, so the account should state which study year each composition assumption comes from.

¶9 **Open burning.** Where open burning is material, the IPCC provides a standardised estimator that can be adapted to yield the plastic mass burned rather than only the resulting emissions [31]:

¶10

$$SW = P \times P_{frac} \times SW_c \times B_{frac} \times 365 \times 10^{-6}$$

¶11 Here SW is the total solid waste openly burned (Gg per year), P the population, P_{frac} the fraction of the population burning waste, SW_c per capita waste generation (kg per person per day), and B_{frac} the fraction of waste burned relative to total waste treated. Multiplying through by

the plastic fraction of the waste stream gives the plastic mass burned. Some of this waste originates from uncollected sources and some from collected sources, so compilers must take care not to deduct it twice.

¶12 **Collection coverage and the informal sector.** Mismanaged waste is normally derived as generation minus formal collection, which systematically overstates it wherever an informal collection sector operates. Three collection systems should be measured separately[32]:

- ¶13 **Formal** — government-approved or contracted services operating through established infrastructure with regular schedules and official protocols.
- ¶14 **Informal** — waste pickers, itinerant buyers and small-scale entrepreneurs recovering saleable plastic outside municipal systems.
- ¶15 **Community-based** — environmental groups, community organisations and volunteer networks conducting periodic collection drives and clean-ups that supplement formal services where coverage is incomplete.

¶16 Informal recovery is not marginal. An estimated 15 million people work as informal waste collectors in developing countries, around one percent of the urban population[33]. Omitting their recovery from the collected column transfers that mass to the mismanaged pool and then, through the leakage factor, into the marine leakage estimate. Collection coverage — the share of population or area with access to collection services — should be recorded alongside tonnages, because the two constrain one another.

¶17 The SEEA CF physical supply and use table for solid waste provides the structural framework[34]:

Flow Category	Physical Unit	Recording
Waste generation by industry	Tonnes	Supply table, by ISIC class
Waste generation by households	Tonnes	Supply table, household sector
Waste collected	Tonnes	Use table, waste management industry
Waste to controlled disposal	Tonnes	Use table, controlled landfill/incineration
Waste to environment	Tonnes	Use table, environment (residual flow)

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¶18 For marine-specific accounting, "waste to environment" is disaggregated to distinguish:

- ¶19 Waste to marine and coastal waters
- ¶20 Waste to inland waters (with subsequent marine pathway)
- ¶21 Waste to land (coastal littering, beach deposits)

Maritime source flows

¶1 **Fishing gear losses** — ALDFG estimation uses fishing and aquaculture activity data from TG-6.7 and TG-6.8. Abandoned, lost, or discarded fishing gear is estimated at 5.7 percent of fishing nets, 8.6 percent of traps, and 29 percent of fishing lines lost globally each year[35]. These global average rates may not reflect conditions in artisanal fisheries. Compilers should apply gear-specific and fishery-specific loss rates where available from national or regional fisheries management organisations[36]. Accounting requires data on fishing fleet composition, gear types, estimated loss rates, and conversion to mass units.

¶2 **Vessel operational waste** — MARPOL Annex V regulates discharge of garbage from ships[37]. Accounting draws on port reception facility records, MARPOL incident reporting, and vessel surveys.

¶3 **Offshore operations** — Waste from offshore energy platforms, aquaculture installations, and maritime structures. Cross-reference to **TG-6.9 Offshore Energy** for offshore accounting context.

¶4 **Cargo losses** — Container losses and other cargo overboard incidents, reported under maritime incident databases.

Riverine inputs

¶1 Rivers transport substantial quantities of litter from inland areas to the marine environment, with a small number of rivers contributing a disproportionate share of global riverine plastic input [38]. Accounting requires:

- ¶2 Monitoring of litter concentrations in river outflows
- ¶3 Estimation of total transport based on flow volumes
- ¶4 Attribution to upstream catchment sources where possible

¶5 For national ocean accounts, riverine inputs represent the cumulative effect of upstream waste management and should be linked to inland waste generation and management accounts. Hydrological data used for water flow accounting may serve as a basis for estimating litter transport volumes where direct litter monitoring data are limited.

3.4 Stock Accounting: Marine Litter Accumulation

¶1 Stock accounts record the quantity of litter accumulated in the marine environment at the opening and closing of an accounting period. The following template provides a compilation framework.

¶2 *Table 3.4.1: Marine litter physical stock-flow account (tonnes)*

Entry	Floating	Beach	Seabed	Water Column	Total
Opening stock	850	1,240	3,100	420	5,610
Inflows					
Land-based input (rivers)	180	–	–	–	180
Land-based input (direct coastal)	–	95	–	–	95
Sea-based input (shipping, fishing)	45	–	12	–	57
Import via ocean transport (transboundary)	0	0	0	0	0
Transfer from other compartment	25	110	65	15	215
Total inflows	250	205	77	15	547
Outflows					
Collection/removal	–	140	–	–	140
Degradation	12	8	5	3	28
Transfer to other compartment	135	65	–	15	215
Export (currents)	25	–	–	–	25
Total outflows	172	213	5	18	408
Closing stock	928	1,232	3,172	417	5,749

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¶3 The "primary entry" notation indicates the compartment where each source type is first recorded. Subsequent redistribution is captured through transfer rows. Inter-compartment transfers balance: total outflows as transfers (215 tonnes) equal total inflows from transfers (215 tonnes), maintaining mass conservation. Column arithmetic: for each compartment, opening stock + total inflows - total outflows = closing stock. The "import via ocean transport" row records transboundary litter flows arriving via ocean currents. Receiving-coastline countries (e.g., Pacific island states in North Pacific Gyre currents) should populate this row to distinguish externally-sourced accumulation from domestic inputs (see Section 3.5).

¶4 **Note on terminal sinks:** The seabed compartment is treated as a terminal sink, with no resuspension or redistribution from seabed to other compartments recorded. Where monitoring data indicate significant resuspension (e.g., in high-energy shallow-water environments), compilers should add a transfer outflow row for the seabed compartment and a corresponding inflow row for the water column.

Monitoring methods by compartment

¶1 The accounting compartments correspond to distinct sampling problems, and the appropriate protocol differs for each. The mapping below follows the IUCN Global Ecosystem Typology so that litter monitoring aligns with the spatial units used for ecosystem accounting [39].

Compartment	IUCN GET unit	Sampling and monitoring methods	Principal protocols
Beach and coastal	MT1 shorelines; MT2 supralittoral coastal; MT3 anthropogenic shorelines	Transect or quadrat surveys; sieving for buried macrolitter in the top 5-10 cm; sediment cores; aerial and remote sensing	OSPAR beach litter guideline; NOAA marine debris monitoring protocols and field datasheets; UNEP/IOC (2009); European Commission (2023); AMDI monitoring protocols
Floating and water column	M2 pelagic ocean waters	Net tows; visual observation and photographic survey from vessels; water sampling; submersible pumps to known depth; remote sensing	GESAMP (2019); UNEP (2021) global manual on measuring SDG 14.1.1
Seafloor	M3 deep sea floors; M1 marine shelf	Trawling; towed video and ROV transects; sediment cores; acoustic methods (sonar, side imaging) to locate accumulation points; diver survey above 30 m	GESAMP (2019); EMODnet; European Commission (2023); JAMSTEC Deep-sea Debris Database
Estuarine and transitional	FM1 semi-confined transitional waters	Shoreline transects and quadrats; surface water sampling; sediment cores; remote sensing	UNEP (2020) rivers and lakes guidelines; GESAMP (2019); OSPAR
Artificial marine structures	M4 anthropogenic or artificial marine	Underwater survey for debris and entanglement; aerial and remote sensing	No compartment-specific protocol existed as of 2025; marine protocols are adapted, and the adaptation documented

¶2 Sampling in pelagic waters requires specialist and costly platforms. The recommended practice is to acquire these observations opportunistically — during biodiversity surveys, oceanographic research cruises, fisheries assessments, or offshore engineering and exploration missions — rather than commissioning dedicated survey effort that a national programme is unlikely to sustain [39]. Compilers should record the survey platform alongside each estimate, because opportunistic sampling carries spatial biases that a dedicated design would avoid.

¶3 **Remote sensing.** Satellite imagery, drone survey, thermal imaging, multispectral analysis, LiDAR volume estimation and fixed monitoring cameras each address a different part of the detection problem, and openly available imagery libraries make several of them inexpensive [40]. Two constraints govern their use in accounts. Detection must be converted to quantity through a validated model, and results must be ground-truthed at selected locations before they enter the account; without that step remote sensing yields extent, not mass. Resolution, cloud cover and seasonality all interrupt time series, so acquisition conditions should be documented for each period. Thermal imagery additionally detects the heat signatures of active open burning, linking this method to the burning estimator in Section 3.3.

Beach and coastal stocks

¶1 Beach litter is the most accessible stock for monitoring, with established survey methodologies [41]. Stock accounts record mass or item counts per unit area (beach length, surface area), aggregated to total coastal stock and disaggregated by material category.

¶2 Beach stock accounts recognise that beaches are dynamic interfaces:

- ¶3 New litter deposits during each tidal cycle and storm event
- ¶4 Removal occurs through clean-up activities, burial, and resuspension
- ¶5 Opening and closing stocks relate through: Closing stock = Opening stock + Deposits - Removals - Degradation

¶6 Clean-up activities should be recorded as economic flows (environmental protection expenditure under CEPA 3) and their effect on beach stocks quantified [42]. This links to environmental expenditure accounts in **TG-3.7 Governance Accounts**.

Floating litter stocks

¶1 Surface and near-surface floating litter is measured through visual surveys, net tows, or remote sensing. SDG indicator 14.1.1 specifies floating plastic debris density as a monitoring parameter [43]. Stock accounts for floating litter face specific challenges:

- ¶2 Dynamic distribution influenced by currents, winds, and convergence zones
- ¶3 Variable vertical distribution (surface to depth)
- ¶4 Difficulty in scaling point observations to total stock estimates

¶5 Global accumulation zones (ocean gyres) represent areas of elevated floating debris concentration. Stock accounts may record density estimates (items or mass per km²) for defined ocean areas, total estimated stock based on density and area, and uncertainty ranges. Litter density may also serve as an ecosystem condition indicator. The relationship between accumulation and ecosystem condition is addressed in **TG-2.1 Biophysical Indicators**.

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Water column stocks

¶1 Litter suspended in the water column is less well characterised than surface or benthic stocks. Accounting approaches are necessarily more experimental and may rely on depth-stratified sampling data, modelled vertical distribution based on particle characteristics, or extrapolation from limited survey data.

Seafloor stocks

¶1 Benthic litter accumulates on the seabed, particularly in areas of high sedimentation, submarine canyons, and deep-sea plains. Monitoring uses trawl surveys, remotely operated vehicle (ROV) transects, and baited camera systems. Stock accounts should record density by seabed type and depth zone, estimated total stock within national waters, and composition by material category. The SEEA EA addresses ecosystem condition, including pollutant presence as a condition variable [44].

3.5 Source Attribution and Material Flow Accounts

¶1 Effective marine litter policy requires attribution of litter to the economic units and locations responsible for its generation. The SEEA CF principle of recording residual flows by source industry applies [45].

Industry source attribution

¶1 Industry sources of marine litter, classified by ISIC:

Sector	ISIC	Marine litter nexus
Plastic resin/product manufacture	20, 22	Production waste, pellet losses
Food, beverage, tobacco	10-12	Packaging waste

Sector	ISIC	Marine litter nexus
Textiles and apparel	13-14	Microfibre release
Marine fishing	0311	Fishing gear losses, operational waste
Marine aquaculture	0321	Equipment losses, feed bags
Water transport	50	Vessel waste, cargo losses
Accommodation and food service	55-56	Disposable items, packaging
Waste management	38	Leakage from collection and disposal

¶2 Where direct industry-level data on marine litter contributions are unavailable, compilers may use waste composition data from beach litter surveys to attribute litter to source industries through product-to-industry concordances. For example, packaging items in beach surveys can be mapped to the manufacturing industry that produced them (ISIC 10-12 for food packaging) and to the retail or hospitality industry that distributed them (ISIC 47, 55-56). Detailed guidance on industry classification is in **TG-3.3 Economic Activity**.

Household source attribution

¶1 Households are major sources of marine litter through consumer product disposal, littering, inadequate waste storage, and microplastic releases (laundry, personal care products). Household marine litter is recorded in the household sector column of the physical supply table.

Informal sector attribution

¶1 The informal collection and recovery sector is a recovery pathway rather than a source, and misplacing it distorts both the collected column and the mismanaged residual. It is also the hardest segment to enumerate: operations are irregular, records are rarely kept, and engagement depends on trust that a statistical exercise cannot assume [46]. The practical attribution routes are cooperative-level reporting of recovered volumes by material type, market price data from itinerant buyers and aggregators, and recycler input records traced back to supply channel. Where the sector is enumerated, the corresponding employment and livelihood data should be captured in the same exercise (Section 3.7).

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Geographic allocation

¶1 **Coastal zone delineation** — Coastal zone definitions should align with administrative boundaries whilst recognising functional connectivity to marine waters [47]. See **TG-1.2 Marine Spatial Planning**.

¶2 **Catchment-based accounting** — River catchments as accounting units enable tracking of riverine litter pathways.

¶3 **Maritime zone accounting** — Recording of sea-based source litter by location (territorial sea, EEZ, high seas) supports jurisdictional analysis.

¶4 **Transboundary litter flows.** Litter originating in foreign jurisdictions and transported by ocean currents should be recorded separately in physical flow accounts using the "import via ocean transport" row in Table 3.4.1. Failure to do so will distort domestic source attribution. The three principal estimation approaches are: (a) ocean debris transport modelling (using circulation models to back-calculate probable source regions); (b) source-marker or polymer-signature analysis (comparing polymer types and additive profiles to known source regions); and (c) branded-product origin analysis from beach surveys. Each approach carries substantial uncertainty, so transboundary import estimates should always be reported with a sensitivity range and a method tag. Attribution of transboundary litter to source countries requires international coordination through regional seas conventions (e.g., SPREP for the Pacific) [48]. For SDG 14.1.1 reporting, domestic source attribution takes precedence, and transboundary flows should be reported as supplementary information.

¶5 The SEEA CF supports sub-national disaggregation where data permit [49]. Priority geographic units include coastal municipalities, river catchments with marine outlets, port areas and shipping lanes, and marine protected areas.

3.6 Material Flow Account for Synthetic Marine Litter: Worked Example

¶1 This section presents a worked example tracking plastics from production through consumption, waste generation, collection and treatment, to marine leakage.

¶2 The procedure is a material flow analysis: a systematic quantification of the flows and stocks of a material within a defined system boundary over a defined period, closed by mass balance [50]. Stated formally it has five stages — system definition (geographical and temporal boundaries, processes and actors), data collection, flow quantification, balance calculation, and visualisation and interpretation. The balance stage is what converts a collection of unrelated statistics into an account: an unexplained residual is either a real stock change or a data error, and the analysis must say which.

¶3 National precedents exist and are worth consulting before designing a first compilation. Sri Lanka's national plastic waste inventory (2024) and Statistics Norway's plastic account are the closest analogues to the procedure below, both built as national-scale material flow analyses; the Netherlands, Germany (healthcare sector), Australia, New Zealand, and a four-country South-East Asian study through the ERIA Regional Knowledge Centre on Marine Plastic Debris provide further worked national and sectoral examples [51].

Compilation procedure overview

1. ¶1 **Identify synthetic material production and imports** — from industrial production statistics and trade data
2. ¶2 **Estimate synthetic material consumption** — using supply-use balancing (domestic production + imports - exports)
3. ¶3 **Record waste generation by sector** — from waste surveys and composition studies
4. ¶4 **Estimate waste collection and treatment** — from municipal and industrial waste management records
5. ¶5 **Model mismanaged waste** — as the difference between waste generated and waste formally collected
6. ¶6 **Estimate marine leakage** — applying leakage factors to mismanaged waste based on proximity to marine environment

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Step 1: Synthetic material production and imports

¶1 From industrial production statistics (ISIC 20.16 and 22.20) and customs trade data (HS 3901-3914 for primary forms, 3916-3926 for products, and 3915 for waste and scrap; HS chapters 54 and 55 additionally cover the man-made filaments and staple fibres relevant to synthetic textiles):

Flow	Quantity (tonnes)	Source
Domestic production of plastic resins	125,000	Industrial census
Imports of plastic products	68,000	Trade statistics
Exports of plastic products	42,000	Trade statistics
Net supply to domestic economy	**151,000**	Calculated

Step 2: Synthetic material consumption by sector

Consuming Sector	ISIC	Quantity (tonnes)	Share (%)
Food & beverage manufacturing	10-11	35,000	23.2
Retail trade (packaging)	47	28,000	18.5

Consuming Sector	ISIC	Quantity (tonnes)	Share (%)
Accommodation & food service	55-56	18,000	11.9
Fishing	0311	12,000	7.9
Construction	41-43	15,000	9.9
Households (direct consumption)	HH	38,000	25.2
Other industries	Various	5,000	3.3
Total consumption		**151,000**	**100.0**

Step 3: Waste generation

Waste Source	ISIC/Sector	Waste Generated (tonnes)	Plastic Content (%)	Plastic Waste (tonnes)
Food manufacturing	10-11	45,000	60	27,000
Retail & hospitality	47, 55-56	38,000	55	20,900
Fishing	0311	15,000	75	11,250
Construction	41-43	22,000	40	8,800
Households	HH	95,000	35	33,250
Other industries	Various	12,000	30	3,600
Total waste generated		**227,000**	–	**104,800**

¶1 **Material balance closure.** The 46,200-tonne difference between consumption (151,000 tonnes) and waste generation (104,800 tonnes) represents the net addition to the stock of plastic products in use (durable goods with remaining service life), together with minor losses from degradation during the use phase. The SEEA CF material balance principle requires that all material inputs be accounted for in outputs, stock changes, or dissipative losses. This in-use stock change should be recorded in a separate physical balance sheet:

```
Opening stock of plastic products in use
  + Consumption
  - Waste generation
  - Use-phase dissipative losses
  = Closing stock of plastic products in use
```

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¶2 The collected-for-recycling rate is calculated against waste generated, not total consumption: 18,500 / 104,800 = 17.7%. It is a collection rate, not a recycling rate (see the measurement-point note in Step 4). Compilers should clearly state the denominator when reporting recycling rates to ensure comparability with international reporting.

Step 4: Waste collection and treatment

Treatment Pathway	Quantity (tonnes)	Share (%)
Collected for recycling	18,500	17.7
Collected for incineration	12,300	11.7
Collected for controlled landfill	48,200	46.0
Total formally collected	**79,000**	**75.4**
Mismanaged waste	25,800	24.6
Total waste generated	**104,800**	**100.0**

¶1 **Measurement point of the treatment figures.** The rows above are collection figures, measured at the point of collection and before sorting, and they therefore include contamination and

material that will be rejected downstream. The 18,500 tonnes collected for recycling is not the tonnage recycled. The recycling rate international reporting expects is built on **recovered tonnes**: material that completes the recycling process and leaves the facility as saleable recyclate [15]. Compilers holding both figures should report the recovered-tonnes rate as the headline and the collected-for-recycling rate as a supplementary measure of collection performance, stating the measurement point for each; the gap between them is itself a useful indicator of sorting loss. Where only collection data exist, the rate must be labelled a collection rate and not a recycling rate. Facility-level reject and residual waste tonnages, where reported, close the difference.

Step 5: Mismanaged waste estimation

Geographic Zone	Mismanaged Waste (tonnes)	Share (%)
Coastal zone (<50km from coast)	14,800	57.4
Inland zone (>50km from coast)	11,000	42.6
Total mismanaged	**25,800**	**100.0**

Step 6: Marine leakage estimation

¶1 Apply Jambeck et al. (2015) leakage factors as defined in Section 3.3. The values below are illustrative central estimates. Compilers should calibrate factors to national monitoring data or published country-level estimates where available.

Source Category	Mismanaged Waste (tonnes)	Leakage Factor (central)	Sensitivity Range (low—high)	Marine Leakage (tonnes)	Source basis
Coastal zone land-based	14,800	0.25	0.15 – 0.40	3,700	Jambeck et al. (2015), range from inadequately managed waste estimates [25]
Inland (via riverine transport)	11,000	0.08	0.02 – 0.15	880	Lebreton et al. (2017) riverine emission rates [22] ; Lau et al. (2020) sensitivity [26]
Fishing gear losses (direct)	1,200	1.00	0.80 – 1.00	1,200	Richardson et al. (2019) [35] ; gear losses assumed to enter marine environment directly
Maritime operational waste	450	0.60	0.10 – 0.60	270	Assumption pending peer review; see note below
Total marine litter input				**6,050**	

¶2 **Note on the maritime operational waste factor.** MARPOL Annex V requires all ships to deliver garbage to port reception facilities (PRFs) before discharge, with compliance monitored through Garbage Record Books and Port State Control (PSC) inspections. The 0.60 central value is an upper-bound assumption that does not reflect MARPOL Annex V compliance rates and should be replaced with a country-specific estimate based on PRF utilisation data (IMO GISIS database) and PSC inspection statistics. Where empirical national data are unavailable, compilers should report a sensitivity range rather than a single point estimate and flag the assumption as requiring expert peer review.

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¶3 Compilers should (1) cite the source for each leakage factor used, (2) report a low–high sensitivity range alongside the central estimate, (3) calibrate factors to national monitoring data where these exist, and (4) document any departures from published source-methodology values.

Interpretation

- ¶1 **Collection gap**: 24.6% of plastic waste is mismanaged, representing the primary intervention target
- ¶2 **Coastal concentration**: 57% of mismanaged waste is in coastal zones where leakage probability is highest (25% vs 8% for inland)
- ¶3 **Sector priorities**: Fishing, retail/hospitality, and households together account for 62% of total plastic waste generation
- ¶4 **Marine leakage rate**: land-based marine litter input (3,700 + 880 = 4,580 tonnes) / 104,800 = 4.4% of plastic waste generated ultimately enters marine environment. Fishing gear losses and maritime operational waste (1,470 tonnes) are not in the waste-generation denominator and are reported separately; total marine litter input is 6,050 tonnes

¶5 Policy implications:

- ¶6 Expanding waste collection coverage in coastal zones from 75% to 85% (assuming the coastal zone shares the national collection rate of about 75%) would reduce coastal mismanaged waste by an estimated 5,920 tonnes and marine leakage from this source by an estimated 1,480 tonnes annually
- ¶7 Extended producer responsibility for packaging (ISIC 10-11, 47) could address approximately 48,000 tonnes of plastic waste at source
- ¶8 Fishing gear deposit-return schemes could recover a portion of the 1,200 tonnes of gear losses

¶9 Quality assurance for this worked example is addressed in **TG-0.7 Quality Assurance**.

3.7 What the Accounts Supply to Indicator Reporting

¶1 **SDG 14.1.1 is derived in TG-2.7 Pollution and Other Flows to Environment Section 3.5, and its MEA reporting route in TG-2.10** [52], [53]. Neither the indicator definition, the sub-indicator structure nor the composite construction is restated here. This Section states only what the litter accounts must supply so that the indicator can be built from them without a parallel data collection.

What the account has to carry

¶1 **Floating plastic debris density** — the sub-indicator this Circular feeds — is reported as items or mass per square kilometre of sea surface. The stock accounts at Section 3.4 must therefore carry the surveyed area alongside the count or mass, in the compartment the indicator expects (sea surface, not beach or seafloor), and at a temporal reference matching the reporting year. An account that records national totals without the denominator cannot supply the indicator.

¶2 **Index of coastal eutrophication (ICEP)** is the other sub-indicator and is outside this Circular; nutrient accounting is at **TG-3.4 Flows from Economy to Environment** and **TG-6.13** Section 3.2. The two sub-indicators are reported in parallel rather than combined, so the practical requirement on a compiler running both is that the spatial and temporal reference units match; where a country's litter surveys and nutrient monitoring use different coastal segmentations, reconciling them is the work that has to be scheduled.

Multi-target linkages

- ¶1 **SDG 12.4** (Environmentally sound management of wastes) — Marine litter flow accounts quantify waste escaping management systems.

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- ¶2 **SDG 12.5** (Reduce waste generation) — Time-series accounts track progress in material circularity as reflected in declining leakage rates.
- ¶3 **SDG 6.3** (Improve water quality) — Riverine litter transport estimates link land-based pollution to downstream marine impacts.

Social and just-transition indicators

¶1 Marine litter accounts describe a workforce as well as a material, and the plastics data system that produces them can carry social indicators at marginal additional cost. Employment across the value chain (production, collection, sorting, recycling, administration) with demographic breakdown; formal against informal participation rates; income levels compared with regional living wage standards; working hours and occupational injury and illness rates; and community awareness and participation in collection are all collectable through the same household and workforce surveys that generate waste composition and disposal-behaviour data [54]. These indicators support SDG 1, 3, 5, 8, 10, 11 and 12, and they are the evidence base for a just transition in waste management — a question that arises directly whenever an account identifies informal recovery as a material part of the collection system (Section 3.5).

¶2 The multi-indicator framework for deriving ocean policy indicators is addressed in **TG-2.7 Pollution Flows**.

Indicator derivation from accounts

Indicator	Calculation	Unit
Litter generation intensity	Litter generated / GDP	Tonnes per million USD
Per capita litter generation	Litter generated / Coastal population	kg per capita
Mismanaged waste rate	Mismanaged waste / Total waste generated	Percent
Marine leakage rate	Land-based litter to ocean / Total waste generated	Percent
Fishing gear loss rate	ALDFG mass / Active gear mass	Percent
Beach litter accumulation	Beach stock change / Coastline length	Items per km
Clean-up effectiveness	Removed litter / Beach stock	Percent

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¶1 Guidance on indicator derivation and interpretation is in **TG-2.7 Pollution Flows**.

4. Data Sources and Compilation

¶1 Compilation of marine litter and plastics accounts draws on multiple data sources. General guidance on data collection methods is in **TG-4.1 Remote Sensing and Geospatial Data**, **TG-4.2 Survey Methods for Ocean Economic Activity**, and **TG-4.4 Citizen Science and Community-Based Monitoring**. Administrative data sources are addressed in **TG-4.3 Administrative Data**.

¶2 Key data sources include:

¶3 **Waste management statistics** — National waste statistics and composition surveys, municipal solid waste data, recycling and recovery rates by material type, and industrial waste reporting.

¶4 **Environmental monitoring programmes** — Beach litter surveys (national programmes, OSPAR, HELCOM, regional seas conventions); marine litter monitoring; microplastics monitoring; citizen science and clean-up organisation data.

¶5 **Maritime and fisheries data** — Port reception facility records (MARPOL Annex V), fishing gear inventories and loss reporting, maritime incident databases, and vessel tracking data (AIS).

¶6 **Economic statistics** — Industry production data for plastic-intensive sectors, trade data for plastic products, and tourism statistics.

¶7 **Modelling and estimation** — Waste leakage models (Jambeck methodology and derivatives), river transport models, ocean circulation and debris transport models, and fragmentation and degradation models.

¶8 **International reporting** — UNEP marine litter databases, regional seas convention assessments, and Global Partnership on Marine Litter data.

Named platforms and repositories

¶1 The repositories below should be checked before any new collection is commissioned. Several hold country-level data that a national programme has itself reported and may not know is retrievable.

Source	Coverage
Global Plastics Data Tracker (GOAP / CSDR)	Availability of government-reported plastics data for every UN Member State, from production to environmental release; each data point scored 1–5 for reliability, downloadable as a per-country checklist [11]
GPML Digital Platform (UNEP)	Country dashboards of plastic flow data, policy tracking, and consolidated global datasets spanning the economy, waste and the environment
What a Waste 2.0 (World Bank)	Waste generation, composition, collection, treatment and disposal for 217 countries and 367 cities, with projections
UN Comtrade; UNCTADstat; Comext (Eurostat)	Trade in primary plastics, products and waste by HS and SITC code
PRODCOM (Eurostat); **UN Industrial Commodity Statistics Database**	Industrial production of primary forms and plastic products
Eurostat waste statistics; Basel Convention national reporting; UNFCCC national inventories	Waste generation and treatment; transboundary plastic waste movements; waste composition compiled for emissions inventories
OSPAR Beach Litter Database; HELCOM Marine Litter Database; EMODnet	Regional beach, seafloor and sea-surface litter, with harmonised protocols and endorsed datasets
NOAA Marine Debris Monitoring and Assessment Project; Japanese marine plastic monitoring	National shoreline monitoring protocols, field datasheets and time series
JAMSTEC Deep-sea Debris Database	Seafloor imagery from the Pacific, Indian and Atlantic Oceans since 1983
LITTERBASE (Alfred Wegener Institute)	Synthesised global litter distribution and litter-organism interaction data
AMDI Database (Tangaroa Blue); **Marine Debris Tracker**; **Litterati**; **International Coastal Cleanup**	Citizen science and clean-up data, item-level and geolocated; AMDI is the largest southern hemisphere marine debris dataset, running since 2004
The Ocean Cleanup research	Modelled and observed floating debris distribution

¶2 Methodological guidance to pair with these sources: GESAMP (2019) for ocean plastic litter monitoring; UNEP (2021) *Understanding the State of the Ocean* for SDG 14.1.1, 14.2.1 and 14.5.1 measurement; UNEP/IOC (2009) for beach, benthic and floating litter surveys; UNEP (2020) for rivers and lakes; UNEP/IUCN national guidance on plastic pollution hotspotting; the IUCN marine plastic footprint methodology for leakage at the waste stage; and the European Commission's 2023 guidance on monitoring marine litter in European seas [9]. The GPML Community of Practice on Harmonisation of Monitoring and Assessment of Plastic Pollution is the forum in which the interoperability of these methods is being worked out, and compilers with unresolved comparability problems should raise them there rather than resolving them privately.

Assessing what the country already has

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¶1 Score what exists before generating anything new. Two independent scales apply to every data point, and the pairing matters: data can be available but unreliable, and a reliable one-off study is not a usable account input[55].

¶2 *Availability:*

Rating	Meaning
Green	Comprehensive national coverage, collected periodically, publicly available
Amber	Limited spatial or temporal resolution, restricted to particular sectors, or difficult to access consistently
Red	No data, or data that cannot measure plastic-relevant flows

¶3 *Reliability:*

Rating	Meaning
High	Nationally representative, from empirical and scientifically sound methods
Medium	Partially representative; or balanced from corresponding inputs and outputs; or using composition estimates borrowed from other regions or countries
Low	Limited representativeness or methodological rigour; derived from proxies such as monetary equivalence

¶4 Applying these scales to the entries this Circular requires yields the honest statement of account quality on which the sensitivity ranges in Section 3.6 depend. A marine leakage estimate built on medium-reliability composition data and default leakage factors should be published with that provenance visible rather than as a point estimate.

Prioritising which gaps to close

¶1 Not every gap is worth closing, and the cheapest are rarely the most useful. Score each data category on four dimensions and prioritise the lowest total, so that low availability, low reliability, easy remedy and high impact all pull in the same direction[56]:

Dimension	Scores
Availability	Available 4; partially available 2; not available 0
Reliability	High 2; medium 1; low 0
Expected ease of filling the gap	Challenging 3; moderate 2; easy 1
Impact of filling the gap	Low 3; medium 2; high 1

¶2 Ease and impact are judgements rather than measurements and should be drawn from the stakeholders identified below, not assigned by the compiling agency alone. The same technique settles which plastics to cover first: wholly plastic products are easier to measure than composites, and high-volume or policy-salient streams repay measurement sooner. A completed prioritisation should be validated through expert review, stakeholder consultation, cross-reference to national policy objectives and international commitments, and a final check of available resources against ambition[56].

Data quality issues by category

¶1 Each category fails in characteristic ways, and the countermeasures are known[57]:

Category	Characteristic quality issues	Countermeasures
Production	Reporting lags; small producers missing	Cross-check national against international databases; compare with installed capacity; validate against trade flows

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Category	Characteristic quality issues	Countermeasures
Consumption	Apparent consumption misses stockpiling; informal market activity invisible	Cross-validate apparent consumption against market surveys and industry reports; check consistency against waste generation
Trade	Small shipments below reporting thresholds; plastic waste trade poorly recorded; partner countries reporting differently; low-value flows estimated rather than measured	Compare mirror statistics between trading partners; cross-validate national against international databases; check thresholds and exemptions
Waste	Informal sector activity not captured; mixed streams difficult to characterise; inconsistent measurement between jurisdictions	Compare against consumption data; cross-check between successive stages of the waste chain; validate against extended producer responsibility collection data

¶2 Verification of any individual figure follows four steps: check the definition in use; cross-validate against an independent source; account for double-counting wherever the method sums across sources; and confirm that assumptions and conversion factors are listed, evidence-based and referenced [57].

Reconciling inconsistent data

¶1 Divergent figures for the same quantity are the normal condition rather than an exception, and the account must resolve them visibly. Establish a hierarchy of data reliability with a designated primary source for each category and a protocol governing when a secondary source may override it. Triangulate across independent sources, and document rather than suppress the discrepancies. Where a figure is missing, bound it: establish upper and lower values, run a sensitivity analysis, and state the confidence level. Proxy measurement (economic indicators, plastic-to-product weight ratios, data from comparable economies), statistical modelling and step-down scaling from national to sub-national estimates are all legitimate provided the derivation is recorded. Standardised templates, conversion tools between classification systems, automated validation at the point of data entry, and expert review panels for persistently problematic figures are the institutional means of holding this together [58]. Every reconciliation decision belongs in the metadata with its rationale.

¶2 Units follow a single convention: tonnes or kilotonnes for absolute quantities, and kilograms per capita for cross-country comparison. Each data point carries at minimum its weight, reference year and source, and wherever possible its polymer type, the industry of consumption or disposal, and the assumptions and conversion factors used to derive it [59].

Institutional arrangements

¶1 The generic institutional readiness framework — the mandate questions, the lead-agency choice, the coordination architecture and the readiness self-assessment — is set out in **TG-0.8 Implementation Readiness Assessment** Sections 3.1 and 3.5, and in **TG-4.7 National Data Coordination Architectures**. It is not restated here. What follows is what is specific to a plastics account.

¶2 None of the above survives a change of government or a staff departure unless it is somebody's job. Securing the institutional foundation precedes stakeholder engagement, because an agency without a mandate cannot compel data provision, and coordination without a designated lead fragments [60]. Four questions settle the arrangement: which agencies already hold legal authority to collect plastics-related data; which is best placed to lead, typically the environment ministry, the national statistical office or the waste management authority; what each agency already collects that could be reused rather than duplicated (customs for trade, industry ministries for production, municipalities for waste); and what inter-agency data-sharing protocols exist, with what formats, timelines, quality assurance procedures and named contact points.

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¶3 Stakeholder mapping proceeds in three phases: desktop research across agencies, trade databases, business registries, waste service providers, NGOs and research institutions; initial consultations to validate the list and begin building relationships; and snowball identification in which each stakeholder names others, the stage that surfaces the informal sector and other actors absent from registries [61]. The resulting arrangement is best expressed as an action matrix stating, for each stakeholder, the lifecycle stage covered, the data to be provided, the reporting frequency, the path the data travels, and the support required. Indicative frequencies run monthly for customs and municipal collection records, quarterly for producers, recyclers and the coordinating agencies, and annually for survey-based consumption and research inputs.

¶4 The obstacles are predictable and should be planned for rather than discovered: institutional and sectoral data silos; overlapping or conflicting mandates; commercial confidentiality; political sensitivity around waste generation rates and illegal dumping; limited technical capacity; interoperability between systems; and the difficulty of sustaining engagement and funding beyond a pilot phase [61].

Embedding the account in legislation and practice

¶1 An account is repeatable when the obligation to produce it is written down. Legislative frameworks should establish which agency is responsible for what; set reporting thresholds, frequencies and deadlines; specify verification procedures and consequences for non-compliance; protect commercial sensitivity while allowing publication of aggregates; and align with international commitments, including the instrument under negotiation on plastic pollution [62]. Precedents include the EU Packaging and Packaging Waste Directive (94/62/EC, as amended) together with the 2019 Single-Use Plastics Directive, which mandate material-specific packaging waste reporting; South Korea's 2003 Act on the Promotion of Saving and Recycling of Resources, whose extended producer responsibility system produces one of the most detailed national plastics datasets; and the 2022 amendments to the Canadian Environmental Protection Act, which created a national plastics registry with threshold-based reporting by manufacturers, importers and users [62].

¶2 Three supporting practices keep a standing account functioning [63]. Continuing engagement, through multi-stakeholder advisory committees, industry working groups on sector-specific measurement problems, and user forums that keep the statistics useful — the Australian Packaging Covenant Organisation and the UK Plastics Pact are working models. Continuing capacity development, through training in collection and validation methods, documented standard operating procedures, knowledge transfer between senior and incoming staff, and research partnerships; Eurostat's European Statistical Training Programme offers modules on plastic waste characterisation and material flow accounting. And digitalisation: secure online reporting in place of paper submission, automated validation at the point of entry, application programming interfaces transferring data directly from company systems, integration with customs data and business registries to reduce reporting burden, and mobile tools for field waste characterisation. Germany's LUCID packaging register is an operating example of the reporting-platform pattern. Dedicated funding can be sought through environmental fees on plastic products, earmarked allocations from waste management budgets, or international financing for plastic pollution and circular economy work.

Compilation pathways and phased implementation

¶1 **Phase 1: Foundation** — Beach litter survey data are the most widely available starting point. Countries with established beach monitoring programmes (OSPAR, HELCOM, or national programmes) can compile initial stock accounts for coastal compartments and use survey composition data to estimate source attribution.

¶2 **Phase 2: Flow estimation** — Building on waste management statistics, compilers estimate land-based litter flows using the Jambeck methodology. Maritime source flows are estimated from fisheries and port data using the physical supply and use table framework (Section 3.3).

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¶3 **Phase 3: Full accounts** — Integration of floating and benthic stock data and refined geographic disaggregation produces complete stock-flow accounts. This phase requires investment in monitoring infrastructure and modelling capacity.

¶4 These three phases describe the widening coverage of the litter account specifically, and sit inside the general phased implementation pathway at **TG-0.8** Section 3.2 rather than replacing it. They are also orthogonal to the maturity ladder set out at the start of Section 3: a Phase 1 compilation repeated annually under a documented methodology is already an account, whereas a Phase 3 compilation produced once is an inventory entry. Countries should secure repeatability at whatever coverage they can sustain before extending coverage, because a broken time series cannot be repaired retrospectively.

¶5 Data gap assessment and prioritisation guidance is in **TG-4.6 Data Harmonisation**. Quality assurance considerations are addressed in **TG-0.7 Quality Assurance**.

5. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

6. References and Further Reading

¶1 This Circular should be read in conjunction with:

- ¶2 SEEA Central Framework, Chapter III: Physical flow accounts, particularly section 3.6.5 on solid waste accounts [64]
- ¶3 GESAMP (2019). Guidelines for the monitoring and assessment of plastic litter in the ocean
- ¶4 UNEP (2021). From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution
- ¶5 SDG Framework, Target 14.1 and Indicator 14.1.1 methodology
- ¶6 Regional seas convention marine litter monitoring protocols (OSPAR, HELCOM, Barcelona Convention, NOWPAP)
- ¶7 TNFD disclosure recommendations for waste and pollution metrics [65]
- ¶8 Lau, W.W.Y. et al. (2020). Evaluating scenarios toward zero plastic pollution. *Science*
- ¶9 Borrelle, S.B. et al. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. *Science*
- ¶10 SPREP (2018). Pacific Regional Action Plan: Marine Litter 2018-2025. Secretariat of the Pacific Regional Environment Programme.
- ¶11 ISO 18830:2016 and ISO 19679:2016, Marine biodegradability test methods for plastic materials.
- ¶12 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook — the operational companion to this Circular.
- ¶13 UNEP (2021). Understanding the State of the Ocean: A Global Manual on Measuring SDG 14.1.1, SDG 14.2.1 and SDG 14.5.1.
- ¶14 UNEP / IOC (2009). Guidelines on Survey and Monitoring of Marine Litter.
- ¶15 UNEP (2020). Monitoring Plastics in Rivers and Lakes: Guidelines for the Harmonisation of Methodologies.
- ¶16 UNEP / IUCN. National Guidance for Plastic Pollution Hotspotting and Shaping Action; and IUCN, The Marine Plastic Footprint.

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- ¶17 IPCC (2006). Guidelines for National Greenhouse Gas Inventories, Volume 5 Chapter 5: Incineration and Open Burning of Waste; and the 2019 Refinement, Volume 5 Chapter 2: Waste Generation, Composition and Management Data.
- ¶18 World Bank (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050.
- ¶19 European Commission (2023). Guidance on Monitoring of Marine Litter in European Seas, MSFD Technical Group on Marine Litter.

FOOTNOTES

1. ¶1 UNEP (2021). From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution. Nairobi: UNEP, p. 10.
2. ¶2 GESAMP (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean, paragraph 2.1.
3. ¶3 United Nations (2015). Transforming our world: the 2030 Agenda for Sustainable Development. A/RES/70/1, Target 14.1.
4. ¶4 UN Statistics Division. SDG Indicator 14.1.1: Index of coastal eutrophication and floating plastic debris density. Metadata document.
5. ¶5 UNEP (2022). Resolution adopted by the United Nations Environment Assembly on 2 March 2022: End plastic pollution: towards an international legally binding instrument. UNEP/EA.5/Res.14.
6. ¶6 UNEP Intergovernmental Negotiating Committee on Plastic Pollution. Live status page: https://www.unep.org/inc-plastic-pollution (https://www.unep.org/inc-plastic-pollution). Compilers should consult this page for the current state of negotiations and any adopted reporting obligations.
7. ¶7 SEEA CF, paragraph 3.84. This aligns with the concept of waste in EU Directive 2008/98/EC Article 3(1).
8. ¶8 SEEA CF, paragraphs 3.268–3.278 and Table 3.18.
9. ¶9 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook. Draft of 10 November 2025, prepared with funding from the UK Blue Planet Fund. The Handbook was in preparation at the time this Circular was issued; compilers should check for the published version, whose section numbering may differ from the draft cited here. Its Annex 2 is the consolidated catalogue of the data sources named in this Section, and its Annex 5 the catalogue of sampling methods by environmental realm.
0. ¶10 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Introduction (“Objectives”) and Step 6, section 6.1. The three-level sequence is data points, then a plastics data inventory, then plastics accounts, the last requiring periodic publication under a standardised methodology.
1. ¶11 UNSW Centre for Sustainable Development Reform (2025). Global Plastics Data Tracker, https://plastictracker.org (https://plastictracker.org). The Tracker records the availability of government-reported plastics data for every UN Member State and scores each data point from 1 to 5 for reliability, the higher scores going to data published annually with plastic-specific breakdowns. The 10 percent and 60 percent figures are the review’s own findings as reported in the Handbook’s Introduction. The Tracker was compiled through a rapid review and is not exhaustive, so it should be used alongside, not instead of, the repositories listed in Section 4.
2. ¶12 SEEA CF, paragraphs 3.268–3.278. Paragraph 3.268 describes solid waste accounts as “useful in organizing information on the generation of solid waste and the management of flows of solid waste to recycling facilities, to controlled landfills or directly to the environment.”
3. ¶13 UN Statistics Division. SDG Indicator 14.1.1 Metadata.
4. ¶14 UNEP (2024), assessment of plastics definitions, as tabulated in GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Annex 3 (Waste Management Terminology Comparison). Attributions in the table are to the UNEP/IUCN Hotspotting methodology and PLASTEAX, the OECD, GIZ’s Waste Flow Diagram, and UN-Habitat’s Waste Wise Cities Tool. The fly-tipping definition follows Boucher et al. (2020); the littering definition follows Velis et al. (2017).
5. ¶15 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 1 (“Waste Data”) and Annex 1 (Key Definitions). The distinction between waste generated, collected and treated turns on the measurement point in the chain; “recovered tonnes” is measured after sorting and processing, when the material has become recyclate saleable to an end market.
6. ¶16 GESAMP (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection.
7. ¶17 European Commission (2010). Guidance on the interpretation of the waste classification. Commission Notice 2010/C 252/03.
8. ¶18 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.11 (Crosscutting Classification Systems), Table 29; trade and waste code sets also at Tables 1 and 2. The observation that legally mandated systems are the most consistently populated is the Handbook’s.
9. ¶19 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.5.1. Codes for the same polymers appear in the resin identification systems used in collection and sorting.

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0. ¶20 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, sections 5.7.1 and 5.8.1. Uncollected waste is defined as all solid plastic waste escaping waste management systems, formal and informal.
1. ¶21 SPREP (2018). Cleaner Pacific 2025: Pacific Regional Waste and Pollution Management Strategy 2016-2025.
2. ¶22 Lebreton, L.C.M. et al. (2017). River plastic emissions to the world's oceans. Nature Communications, 8: 15611.
3. ¶23 International Maritime Organization. London Convention (1972) and London Protocol (1996) on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.
4. ¶24 SEEA CF, paragraphs 3.78-3.79.
5. ¶25 Jambeck, J.R. et al. (2015). Plastic waste inputs from land into the ocean. Science, 347(6223): 768-771. Inadequately managed waste leakage range 15-40%, central estimate 15%.
6. ¶26 Lau, W.W.Y. et al. (2020). Evaluating scenarios toward zero plastic pollution. Science, 369(6510): 1455-1461.
7. ¶27 Borrelle, S.B. et al. (2020). Predicted growth in plastic waste exceeds efforts to mitigate plastic pollution. Science, 369(6510): 1515-1518.
8. ¶28 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.10.6. Waste composition data compiled for National Atmospheric Emissions Inventory reporting, used to calculate landfill emissions, feeds the submissions countries make to the UNFCCC and is often the only nationally specific composition data available.
9. ¶29 IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 2: Waste Generation, Composition and Management Data. Regional default shares as tabulated in GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Table 28.
0. ¶30 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.10.5. Composition studies are point-in-time measurements; the Handbook notes that resource intensity typically limits them to quarterly or annual intervals rather than continuous monitoring, and that sample selection is the principal threat to representativeness.
1. ¶31 IPCC (2006). Guidelines for National Greenhouse Gas Inventories, Volume 5, Chapter 5: Incineration and Open Burning of Waste. Adaptation of the equation to yield plastic mass rather than emissions follows GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.10.6.
2. ¶32 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.5.1.
3. ¶33 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.9.1, citing Medina (2008) and related literature on informal waste collection in developing economies.
4. ¶34 SEEA CF, Table 3.18 and paragraphs 3.268-3.278.
5. ¶35 Richardson, K. et al. (2019). Estimates of fishing gear loss rates at a global scale. Fish and Fisheries, 20(6): 1218-1231.
6. ¶36 Richardson et al. (2019) remains the primary source for global ALDFG loss-rate estimates. No comprehensive post-2019 update providing regional or gear-specific rates is yet available in the peer-reviewed literature. Compilers requiring country- or fishery-specific rates should consult national and regional fisheries management organisation (RFMO) data and outputs from the FAO/IMO GloLitter Partnerships programme (https://glolitter.imo.org/ (https://glolitter.imo.org/)), which is developing improved gear-loss datasets by gear type and region. Hodgson (2022) is a legal analysis and does not contain gear-specific loss-rate data; Macfadyen et al. (2009) is a precursor study that informed Richardson et al. (2019) and should not be cited as an independent source of loss-rate values.
7. ¶37 International Maritime Organization. MARPOL Annex V: Regulations for the Prevention of Pollution by Garbage from Ships.
8. ¶38 Schmidt, C., Krauth, T., and Wagner, S. (2017). Export of plastic debris by rivers into the sea. Environmental Science and Technology, 51(21): 12246-12253.
9. ¶39 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Annex 5, Table 60, which organises sampling and monitoring methods by realm and biome following the IUCN Global Ecosystem Typology (https://global-ecosystems.org/ (https://global-ecosystems.org/)) in order to remain consistent with accounting frameworks. The recommendation to sample pelagic waters opportunistically, and the observation that no protocol specific to artificial marine structures existed as of 2025, are both the Handbook's.
0. ¶40 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.10.4. Platforms named for analysis include Google Earth Engine, ArcGIS and QGIS; ground-truthing at selected locations is specified as a validation step, not an optional extra.
1. ¶41 OSPAR Commission (2010). Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area.
2. ¶42 Classification of Environmental Protection Activities and Expenditure (CEPA), Class 3.2: Collection and transport.
3. ¶43 UN Statistics Division. SDG Indicator 14.1.1 Metadata.
4. ¶44 SEEA Ecosystem Accounting (2021), Chapter 5 on ecosystem condition; see Table 5.1 on condition variable classification and paragraphs 5.15-5.30 on ecosystem condition characteristics, including physical and chemical state (abiotic characteristics).
5. ¶45 SEEA CF, paragraphs 3.268-3.277 and Chapter VI on combined presentations.

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6. ¶46 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 4, Table 11, which records the engagement challenges for informal collectors as trust-building, irregular operations and safety concerns.
7. ¶47 SEEA Ecosystem Accounting (2021), Chapter 3 on spatial units, particularly paragraphs 3.38-3.45 on marine areas.
8. ¶48 SPREP (2018). Pacific Regional Action Plan: Marine Litter 2018-2025. Secretariat of the Pacific Regional Environment Programme. https://pacific-data.sprep.org/system/files/Pacific%20Regional%20Action%20Plan%20-%20Marine%20Litter.pdf (https://pacific-data.sprep.org/system/files/Pacific%20Regional%20Action%20Plan%20-%20Marine%20Litter.pdf). UNEP (2021), From Pollution to Solution: A global assessment of marine litter and plastic pollution, Nairobi.
9. ¶49 SEEA CF, paragraphs 2.121-2.123 on geographical boundaries; see also paragraph 5.493 on spatial and temporal detail for water resources.
0. ¶50 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.10.3.
1. ¶51 National and sectoral material flow analyses compiled in GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Table 15: Ministry of Environment, Sri Lanka (2024), National Plastic Waste Inventory for Sri Lanka; Statistics Norway (2023), Plastic Account for Norway; Lobelle et al. (2023) for the Netherlands; Ivanovic et al. (2022) for the German healthcare sector; Kawecki et al. (2018) for Europe; the ERIA Regional Knowledge Centre for Marine Plastic Debris for Thailand, the Philippines, Malaysia and Viet Nam; the Australian Department of Climate Change, Energy, the Environment and Water (Australian Plastics Flows and Fates national report); and Deshpande et al. (2020) for Norway. Compilers should verify the current status and methodology of each before relying on it.
2. ¶52 United Nations (2015). Transforming our world: the 2030 Agenda for Sustainable Development. A/RES/70/1.
3. ¶53 UN Environment Programme (2021). SDG 14.1.1 Indicator Methodology: Index of Coastal Eutrophication and Floating Plastic Debris Density.
4. ¶54 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 5.9.2, Table 27.
5. ¶55 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 2, Tables 3 and 4.
6. ¶56 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 3, Tables 6 and 7, and Key Action 3 (Gap Analysis Validation).
7. ¶57 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 2, Key Action 4 and Table 5.
8. ¶58 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Annex 4 (Strategies for handling inconsistent reporting), and section 5 (“Dealing with Inconsistent Data”).
9. ¶59 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 1, Key Action 3, and section 5 (“Minimum Data Requirements”).
0. ¶60 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 4, Key Actions 1 and 2.
1. ¶61 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, Step 4, Key Actions 3 and 4, Tables 10 to 12 and the summary of engagement challenges.
2. ¶62 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, section 6.2.1. The legislative instruments cited are the EU Packaging and Packaging Waste Directive 94/62/EC as amended and Directive (EU) 2019/904 on single-use plastics; the Republic of Korea’s Act on the Promotion of Saving and Recycling of Resources (2003); and the 2022 amendments to the Canadian Environmental Protection Act establishing the federal plastics registry.
3. ¶63 GOAP / UNSW Centre for Sustainable Development Reform and GRID-Arendal (forthcoming). Plastics Data Collection and Reporting Handbook, sections 6.2.2 to 6.2.4.
4. ¶64 United Nations et al. (2014). System of Environmental-Economic Accounting 2012 — Central Framework. New York: United Nations, paragraphs 3.268-3.278.
5. ¶65 TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures, Metrics for nature-related risks and opportunities.

DRAFT

Freshwater–Marine Interaction Accounting

Helps practitioners compile accounts at the freshwater–marine interface, including catchment–coast linkages, nutrient and sediment flow accounts.

Version 0.8.0 **Status** Draft **Stability** Emerging

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

DRAFT

OUTCOME

After completing this Circular, practitioners will be able to compile accounts at the freshwater–marine interface, including catchment–coast linkages, nutrient and sediment flow accounts, and estuarine ecosystem assets. These accounts bridge terrestrial water accounting frameworks with marine and coastal ocean accounts.

The methodology integrates the SEEA Water framework for inland water resource accounts with SEEA Ecosystem Accounting for transitional and coastal ecosystems. For foundational framework context, see TG-0.1. Prerequisites: TG-3.2 (freshwater abstraction flows), TG-3.4 (return flows and residual discharges), TG-6.2 (coastal wetland ecosystem accounts), and TG-3.11 (river basin and coastal zone spatial disaggregation).

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

Freshwater-Marine Interaction Accounting (2026) (GOAP Technical Guidance on Ocean Accounting, TG-6.13, v0.8.0). GOAP Secretariat. https://guidance.oceanaccounts.org/circulars/section-6/6-13-freshwater-marine/

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1. Outcome

¶1 After completing this Circular, practitioners will be able to compile accounts at the freshwater-marine interface, including catchment-coast linkages, nutrient and sediment flow accounts, and estuarine ecosystem assets. These accounts bridge terrestrial water accounting frameworks with marine and coastal ocean accounts[1].

¶2 The methodology integrates the SEEA Water framework for inland water resource accounts with SEEA Ecosystem Accounting for transitional and coastal ecosystems[2]. For foundational framework context, see **TG-0.1**. Prerequisites: **TG-3.2** (freshwater abstraction flows), **TG-3.4** (return flows and residual discharges), **TG-6.2** (coastal wetland ecosystem accounts), and **TG-3.11** (river basin and coastal zone spatial disaggregation).

2. Requirements

¶1 **Essential prerequisites:**

- ¶2
  TG-0.1 General Introduction to Ocean Accounts – foundational Ocean Accounts framework context.
- ¶3
  TG-3.2 Flows: Environment to Economy – methodology for recording flows of environmental resources (including freshwater) to economic units. Freshwater abstraction within catchments directly reduces downstream flows to estuarine and marine environments.
- ¶4
  TG-3.4 Flows: Economy to Environment – framework governing return flows and residual discharges. Nutrient loading, sediment mobilisation, and pollutant discharges recorded under TG-3.4 constitute the primary anthropogenic pressures transmitted through the freshwater-marine interface.

¶5 **Helpful background:**

- ¶6
  TG-6.2 Mangrove and Coastal Wetland Accounting – ecosystem accounting methodology for coastal wetland systems directly influenced by freshwater inputs.
- ¶7
  TG-3.11 Sub-National Ocean Accounts – spatial disaggregation to river basin and coastal zone scales, supporting reconciliation of hydrological and administrative spatial units used throughout this Circular.

¶8 **Framework Position**

¶9 This Circular addresses how freshwater-marine interactions transmit economic pressures from upstream catchments to downstream coastal and marine ecosystems, and how those interactions support ecosystem services flowing to the economy and society. In the Ocean Accounts Framework (TG-0.1 Figure 0.1.2):

Edge	Direction	Description
E1	FG1 → SG3	Residuals from economy to environment (nutrient/pollutant discharges to rivers)
E9	SG3 → FG1	Resource extraction and use from environment to economy (freshwater abstraction reducing downstream flows; estuarine fisheries and freshwater supply)
E11	FG3 ↔ SG3	Intermediate ecosystem services (sediment transport, nutrient cycling)

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¶10 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 The accounting edges and ecosystem types covered by this Circular are identified in the Framework Position callout box above. The sections below provide compilation guidance for each component[3], [4], [5].

3.1 Catchment-Coast Accounting Linkages

¶1 Catchment-coast accounting establishes the systematic connection between economic activities within river basins and their downstream effects on coastal and marine ecosystems. The underlying accounting principle is that material flows through hydrological pathways link upstream economic pressures to downstream environmental outcomes. These linkages are bidirectional: tidal and storm-driven marine influences also penetrate upstream, affecting freshwater quality, sediment dynamics, and ecosystem condition in lower catchments[6].

¶2 Figure 6.13.1 traces the cross-domain flow from upstream driver through catchment ecosystem and transmission pathway to the coastal receiving ecosystem. The catchment-to-coast crossing is recorded as an Ocean Accounts Framework inter-ecosystem service flow (E11; see TG-0.1) at the terrestrial/coastal account boundary.

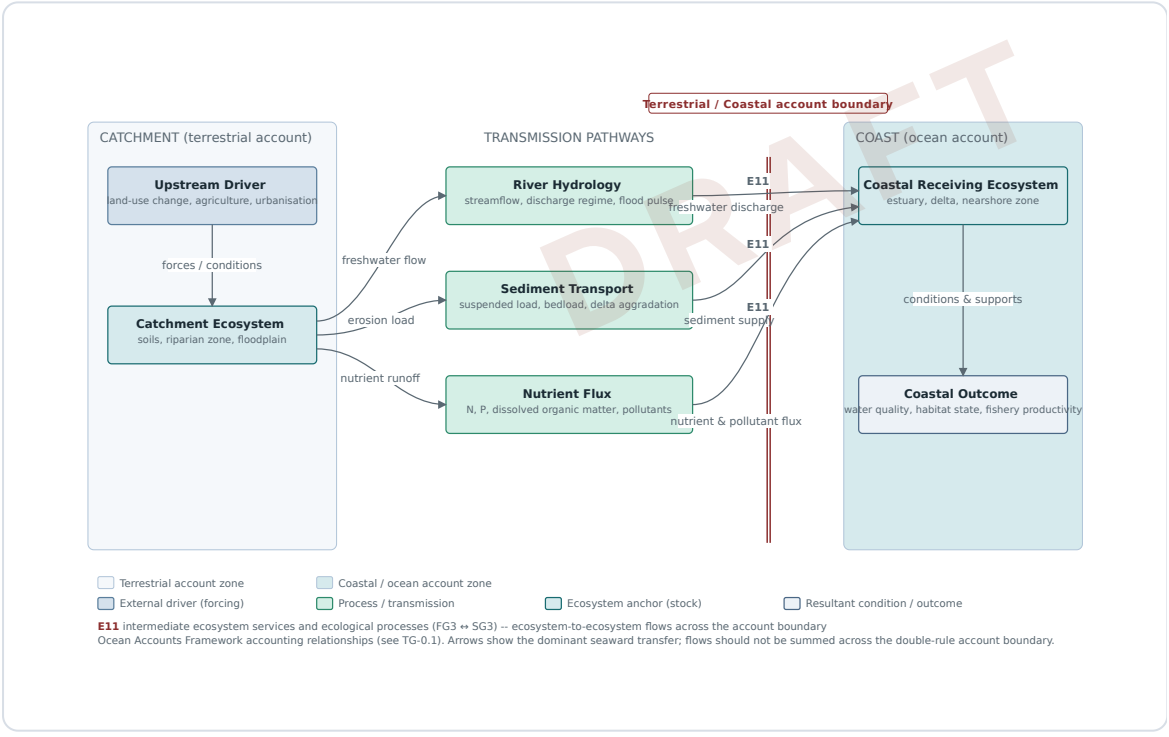


Figure 6.13.1 Catchment land-use drivers generate river, sediment, and nutrient pathways that cross into the coastal receiving ecosystem as E11 flows. Double-rule marks the terrestrial/coastal boundary; E11 flows must not be summed.
Source: TG-6.13, catchment-to-coast linkages; Ocean Accounts Framework accounting relationships (E11), TG-0.1.

River basin as accounting unit

¶1 The river basin (or catchment) is the natural spatial unit for freshwater-marine interaction accounting, with the river basin as upstream boundary and the coastal zone as downstream boundary[7]. Compilers should delineate river basins using hydrological boundaries (watersheds)

rather than administrative boundaries, though administrative disaggregation may be required for linking to economic statistics. See **TG-3.11 Sub-National Ocean Accounts** for reconciling hydrological and administrative spatial units. Where multiple river basins discharge into a single coastal zone, aggregate basin-level flows to derive total catchment inputs.

Linkage Type	Upstream Driver	Transmission Pathway	Coastal/Marine Outcome
Water quantity	Abstraction, dam regulation	Reduced river discharge	Altered salinity regime, reduced sediment supply
Nutrient loading	Agricultural fertiliser, wastewater	Dissolved N and P in river flow	Eutrophication, algal blooms, hypoxia
Sediment flux	Land clearing, mining, dam trapping	Suspended sediment in river flow	Coastal erosion/accretion, turbidity changes
Chemical pollution	Industrial discharge, urban runoff	Dissolved and particulate contaminants	Bioaccumulation, habitat degradation
Thermal effects	Power plant cooling, urban heat islands	Elevated water temperature	Altered species composition, coral stress
Biological connectivity	Habitat fragmentation, fish passage barriers	Migratory corridors	Disrupted diadromous fish populations

Temporal dynamics

¶1 Accounting periods should be aligned with hydrological years where possible, as episodic flood events can deliver the majority of annual sediment and nutrient loads within a few days [8]. Load estimates based on continuous monitoring will differ substantially from those based on periodic grab sampling, and the methodology used should be recorded in account metadata. Compilers should establish a reference period for baseline flows and document significant changes in catchment characteristics (dam construction, land use conversion, urbanisation) that alter the flow regime during the accounting period.

Accounting for regulated flows

¶1 Dam regulation creates a distinction between natural (unregulated) flow and actual (regulated) flow. Estimating the counterfactual natural flow quantifies hydrological alteration, though reliable estimation of unregulated baselines remains methodologically challenging [9].

Entry	Unit	Description
Natural (unregulated) annual discharge	m³/yr	Estimated flow without human intervention
Actual annual discharge to coast	m³/yr	Measured flow at river mouth/estuary
Hydrological alteration index	ratio	Actual/natural flow ratio (illustrative; see note below)
Seasonal flow modification	% change by season	Deviation from natural seasonal pattern
Inter-basin transfers in	m³/yr	Water imported from other basins
Inter-basin transfers out	m³/yr	Water exported to other basins

¶2 The hydrological alteration index is an illustrative summary measure whose application in a formal accounting context is still emerging. Where data permit, recording natural and actual discharge volumes separately is preferable to deriving a single ratio, as values close to 1.0 indicate near-natural regimes whilst values below 1.0 indicate flow reduction. This index informs the condition assessment of estuarine ecosystems (Section 3.3). The Indicators of Hydrologic Alteration (IHA) methodology provides standardised flow statistics for fuller flow-regime analysis [9].

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¶3 Estimating the natural (unregulated) baseline presents practical challenges. The following tiered approach is recommended:

- ¶4 **Tier 1 — Naturalised flow models.** A calibrated rainfall-runoff model run without the influence of dams, diversions, and inter-basin transfers provides the most defensible baseline. Compilers should document model version, calibration period, and assumptions.
- ¶5 **Tier 2 — Pre-regulation gauge records.** Where long-term gauge records predate major water infrastructure, the pre-regulation mean annual discharge provides an empirical baseline. The reference period should be documented explicitly.
- ¶6 **Tier 3 — Regional reference-catchment scaling.** Natural flow estimated by scaling discharge from a comparable, minimally regulated reference catchment in the same hydroclimatic region, adjusted for catchment area and mean annual precipitation.
- ¶7 **Tier 4 — Actual flow only.** Where none of the above approaches is feasible, record actual discharge only, note that the natural baseline could not be estimated, and set the Hydrological Alteration Index to "not estimated."

¶8 The tier applied should be recorded in account metadata, along with key assumptions and data sources.

3.2 Nutrient and Sediment Flow Accounts

¶1 Nutrient and sediment flows are recorded as physical flow accounts within the SEEA framework, tracking specific substances from economic sources through the environment to receiving coastal waters[10].

¶2 **Boundary with TG-6.8.** This account covers loads transmitted through the freshwater system. Aquaculture discharging **directly** to coastal or marine waters — marine cages and similar — is recorded at site level in **TG-6.8 Aquaculture Thematic Methods** Section 3.3.1 and is excluded from the catchment source terms below; land-based ponds and hatcheries discharging to a river or to sewer are catchment sources and belong here. Both accounts resolve to the same coastal receiving water, so applying the discharge-point test consistently is what prevents the same nitrogen being counted twice.

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Nutrient flow accounting

¶1 Nutrient loading to coastal waters, particularly nitrogen (N) and phosphorus (P), is the primary driver of coastal eutrophication[11]. The SEEA framework for recording residual flows (**TG-3.4 Flows: Economy to Environment**) provides the accounting structure for nutrient discharges.

¶2 Nutrient flow accounts should track loads (mass per unit time) rather than concentrations alone, as the ecological impact on receiving waters depends on total mass delivered:

Source Category	Nutrient Species	Measurement Approach	Accounting Entry
Agricultural diffuse sources	NO_3^-, NH_4^+, PO_4^{3-}	Export coefficient models, catchment monitoring	Residual flow: agriculture to environment
Municipal wastewater	Total N, Total P	Effluent monitoring, treatment plant records	Residual flow: households/government to environment
Industrial point sources	NH_4^+, PO_4^{3-}, organic N	Discharge permits, monitoring data	Residual flow: industry to environment
Atmospheric deposition	NO_x, NH_3	Deposition monitoring networks	Natural flow (where background) or residual flow (where anthropogenic)
Natural background	Dissolved N and P	Reference catchment data	Natural flow: within environment

¶3 The total nutrient load delivered to the coast is the sum of all source contributions minus in-stream retention (nutrient uptake and denitrification within rivers, wetlands, and floodplains), which should be recorded as a water purification regulating ecosystem service [12], consistent with the intermediate/final service classification framework in SEEA EA paras. 6.11-6.17 and **TG-2.4**. Compilers should distinguish gross nutrient discharge (total load entering waterways) from net nutrient delivery to coast (load at river mouth after in-stream processing): the difference quantifies the water purification service provided by freshwater ecosystems within the catchment.

Sediment flow accounting

¶1 Sediment flow accounts track the supply, transport, and delivery of particulate material through river systems to receiving coastal waters. Globally, dam construction has reduced sediment delivery to the coast by an estimated 25-30% [13]. The following sediment budget framework structures the physical flow account:

¶2 **Sediment delivery to coast ≈ Erosion supply - In-channel storage - Reservoir trapping - Floodplain deposition**

¶3 This expression is a simplified budget framework rather than a closed identity. Additional terms may be material in specific contexts, including: bedload transport (most routine monitoring captures suspended load only); bank erosion as a distinct sediment source; and aeolian deposition in arid catchments. Compilers should document which terms were measured, estimated, or assumed negligible, consistent with metadata requirements in SEEA CF Chapter 3.

Entry	Unit	Description
Gross erosion (hillslope + channel)	t/yr	Total sediment mobilised within catchment (suspended load; bedload separately where measurable)
Reservoir trapping	t/yr	Sediment retained behind dams
Floodplain deposition	t/yr	Sediment stored on floodplains
In-channel storage change	t/yr	Net change in channel bed/bank storage (includes bank erosion)
Sediment delivery to coast	t/yr	Measured or estimated load at river mouth
Sediment delivery ratio	%	Delivery/erosion ratio

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¶4 Reduced sediment supply from upstream dam construction or sand mining can lead to coastal wetland submergence and ecosystem loss [14], whilst excessive delivery from land clearing or mining can smother coral reefs and seagrass beds. These linkages connect the sediment flow account to the coastal ecosystem accounts compiled under **TG-6.2**.

Pollutant and contaminant tracking

¶1 Beyond nutrients and sediments, freshwater systems transport chemical contaminants to coastal waters. Compilers should identify priority contaminants for their national context and establish monitoring and accounting protocols for those substances [15].

Tier	Substances
Tier 1	Account for total nitrogen and total phosphorus loads (minimum requirement for all freshwater-marine interaction accounts).
Tier 2	Add suspended sediment load, biochemical oxygen demand (BOD), and priority metals (e.g., mercury, cadmium, lead).
Tier 3	Include emerging contaminants (microplastics, pharmaceuticals, per- and polyfluoroalkyl substances) where monitoring data exist.

¶2 The pollutant flow account should be structured consistently with **TG-3.4 Flows: Economy to Environment**. The following crosswalk maps each tier's substances to TG-3.4 source industry categories (by ISIC section):

Tier	Substance(s)	TG-3.4 Source Industry Row	Typical Units
1	Total nitrogen (TN), Total phosphorus (TP)	ISIC A (Agriculture); ISIC E (Water supply, sewerage); ISIC C (Manufacturing)	t N/yr; t P/yr
2	Suspended sediment (SS)	ISIC A (Agriculture); ISIC B (Mining and quarrying); ISIC F (Construction)	t/yr
2	Biochemical oxygen demand (BOD_5)	ISIC E (Sewerage); ISIC C (Food manufacturing)	t O_2/yr
2	Mercury (Hg), cadmium (Cd), lead (Pb)	ISIC B (Mining); ISIC C (Manufacturing); ISIC D (Electricity – coal combustion)	kg/yr
3	Microplastics	ISIC G (Wholesale/retail); ISIC E (Waste management)	t/yr (estimated)
3	PFAS	ISIC C (Manufacturing); ISIC N (Administrative services – fire-fighting foam)	kg/yr (estimated)

¶3 All flows should be reported in mass per year (t/yr or kg/yr as appropriate), consistent with TG-3.4 unit conventions.

3.3 Estuarine and Deltaic Ecosystem Asset Accounts

¶1 Estuaries, deltas, and coastal lagoons occupy the freshwater-marine interface, supporting fisheries nursery habitat, water filtration, and high biological productivity[16]. This section provides extent, condition, and ecosystem service accounts for these transitional systems.

Ecosystem type classification

¶1 Transitional water ecosystems span the boundary between freshwater and marine realms. Within the IUCN Global Ecosystem Typology (GET) reference classification used by SEEA EA, the relevant ecosystem functional groups include[17]:

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IUCN GET Code	Ecosystem Functional Group	Key Characteristics
MFT1.1	Coastal river deltas	Prograding depositional landforms at river mouths; mosaic of channels, floodplains, and wetlands
MFT1.2	Intertidal forests and shrublands	Mangroves and related tidal woody vegetation (covered in detail by TG-6.2)
MFT1.3	Coastal saltmarshes and reedbeds	Herbaceous intertidal wetlands (covered in detail by TG-6.2)
FM1.2	Permanently open riverine estuaries and bays	Tidally influenced river channels with persistent ocean connection
FM1.3	Intermittently closed and open lakes and lagoons	Coastal water bodies with periodic marine connection
F1.2	Permanent lowland rivers (lower reaches)	Tidal freshwater zones of large rivers

¶2 A single estuary may contain elements of several GET functional groups forming an integrated mosaic. Compilers may either (a) map and account for each component ecosystem type separately (greater analytical resolution) or (b) define composite estuarine or deltaic ecosystem assets documenting the internal composition (better captures functional integrity). Experience with both approaches is still limited.

Extent accounting for transitional ecosystems

¶1 Extent accounts follow the standard SEEA EA structure (see **TG-6.2** Section 3.1 for the general approach)[18]. Transitional water ecosystems present three specific measurement challenges:

¶2 **Dynamic boundaries.** The spatial extent of estuaries fluctuates with tidal cycles, river discharge, and seasonal variation. The accounting boundary should be defined using a consistent reference state (e.g., mean high water for the landward boundary, mouth cross-section for the seaward boundary) and documented in metadata. Changes in the estuary mouth configuration, such as barrier beach opening/closing in intermittently open systems, should be recorded as condition changes rather than extent changes unless they result in permanent loss or gain of the ecosystem type.

¶3 **Submerged extent.** Unlike terrestrial ecosystems where extent is measured as surface area, estuarine ecosystems include significant submerged components (subtidal channels, basins). Extent may be reported as either surface area or water volume, depending on the ecosystem type.

¶4 **Multi-dimensional classification.** Estuarine extent accounts should distinguish between intertidal and subtidal components, and between vegetated (mangrove, saltmarsh, seagrass) and unvegetated (mudflat, sand flat, open water) areas. This disaggregation enables linkage to the vegetation-specific accounts compiled under **TG-6.2 Mangrove and Coastal Wetland Accounting**.

¶5 The extent account template uses hectares (ha), consistent with SEEA EA Chapter 4. For FM1.2, FM1.3, and MFT1.1, water volume (m³) at a reference tidal state is reported as supplementary metadata where subtidal basin extent is a primary management concern:

Entry	Estuaries (FM1.2)	Lagoons (FM1.3)	Deltas (MFT1.1)	Tidal Rivers (F1.2)	Total
Opening extent (ha)					
Opening volume (m³) [FM1.2, FM1.3, MFT1.1 only]			–		
Additions to extent					
- Natural expansion					
- Managed restoration (see **TG-6.15**)					
Reductions in extent					
- Conversion (reclamation, infill)					
- Natural loss (erosion, submergence)					
Net change in extent					
Closing extent (ha)					
Closing volume (m³) [FM1.2, FM1.3, MFT1.1 only]			–		

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Condition assessment for transitional ecosystems

¶1 Estuarine condition depends on freshwater inputs, and condition assessment is therefore inseparable from catchment-coast flow accounting[19]. Variables are organised by ECT class following SEEA EA Table 5.1 and the generic frameworks in **TG-4.8** Section 3.1 and **TG-4.9** Section 3.1[20]. Interface-specific applications are listed below:

¶2 **Physical state (Class A1):**

- ¶3 Freshwater inflow volume and timing (deviation from reference hydrograph)
- ¶4 Salinity gradient (longitudinal and vertical stratification patterns)
- ¶5 Tidal prism (volume exchanged per tidal cycle, m³; specify reference tidal state, e.g., mean spring tide, in metadata)
- ¶6 Water residence time (flushing rate)
- ¶7 Sedimentation/erosion rates

¶8 **Chemical state (Class A2):**

- ¶9 Dissolved oxygen (spatial and temporal patterns, frequency of hypoxia)
- ¶10 Nutrient concentrations (N, P; linked to catchment loading accounts in Section 3.2)
- ¶11 Turbidity and light availability
- ¶12 pH and carbonate chemistry
- ¶13 Priority contaminant concentrations

¶14 **Compositional state (Class B1):**

- ¶15 Fish species richness and community composition
- ¶16 Benthic invertebrate diversity
- ¶17 Phytoplankton community structure (including harmful algal bloom species)
- ¶18 Presence of key/indicator species — e.g., diadromous fish (species migrating between freshwater and marine environments, such as salmon and eel) and filter-feeding bivalves

¶19 **Structural state (Class B2):**

- ¶20 Habitat heterogeneity (diversity of substrate types, depth classes)
- ¶21 Vegetation cover (emergent, submerged, riparian)
- ¶22 Biogenic reef structures (oyster reefs, mussel beds)

¶23 **Functional state (Class B3):**

- ¶24 Primary productivity (phytoplankton and benthic)
- ¶25 Nutrient cycling rates (denitrification, nutrient uptake)
- ¶26 Fish recruitment (juvenile abundance and growth)

¶27 **Landscape and seascape characteristics (Class C1):**

- ¶28 Connectivity to upstream catchment (barriers, flow modification)
- ¶29 Connectivity to marine environment (mouth openness, tidal exchange)
- ¶30 Surrounding land use (proportion of catchment under natural vegetation)
- ¶31 Fragmentation of estuarine habitats

¶32 Reference conditions should be established using historical baselines, minimally disturbed reference estuaries, or expert-defined targets (SEEA EA Section 5.3). For freshwater inflow-dependent variables, the reference should reflect the natural (pre-regulation) flow regime.

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ECT Class	Variable	Unit	Reference Level	Opening Value	Closing Value	Change
Physical state (A1)	Freshwater inflow ratio	% of natural	100%			
Physical state (A1)	Salinity gradient index	0-1 scale	Site-specific			
Chemical state (A2)	Dissolved oxygen (min)	mg/L	>6.0			
Chemical state (A2)	Total N concentration	mg/L	Pre-disturbance			
Compositional state (B1)	Fish species richness	count	Historical record			
Structural state (B2)	Biogenic reef area	ha	Historical extent			
Functional state (B3)	Net denitrification rate	t N/yr	Reference site			
Landscape (C1)	Mouth openness index	days open/yr	Natural regime			

Ecosystem services of transitional waters

¶1 Estuarine and deltaic ecosystems provide the following ecosystem services [21]:

¶2 **Water purification and nutrient regulation.** Estuaries attenuate nutrient loads through denitrification, sedimentation, and biological uptake. Physical quantity: mass of N or P removed between estuary head and mouth (t N or P/yr), derived from the difference between upstream delivery (Section 3.2) and downstream export, though attributing removal to specific processes remains methodologically challenging.

¶3 **Fisheries nursery and production.** Where TG-6.2 ecosystem types (MFT1.2 intertidal forests, MFT1.3 saltmarshes) are mapped within an estuary boundary, nursery service is recorded against the constituent ecosystem type rather than the composite estuary. Subtidal channel and basin nursery service is recorded against FM1.2 or FM1.3 (see **TG-6.2** Section 3.5 for double-counting guidance). Attribution approach must be documented in account metadata.

¶4 **Sediment regulation.** Estuaries trap, redistribute, and export sediment. See Section 3.2 and **TG-6.2** for the coastal wetland sediment accretion context.

¶5 **Flood attenuation.** Estuarine floodplains and wetlands attenuate riverine and coastal storm surge flooding, valued using avoided damage methods consistent with **TG-6.2** Section 3.6.

Service	Physical Metric	Unit	Valuation Method
Water purification (N removal)	Mass of N removed in estuary	t N/yr	Replacement cost (treatment equivalent)
Water purification (P removal)	Mass of P removed in estuary	t P/yr	Replacement cost (treatment equivalent)
Fisheries nursery	Juvenile fish production attributable to estuary	t/yr	Productivity change method
Sediment regulation	Sediment trapped/redistributed	t/yr	Avoided cost (dredging, beach nourishment)
Flood attenuation	Flood volume stored	m^3 per event	Avoided damage cost
Recreation and tourism	Visitor days	days/yr	Travel cost, contingent valuation

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¶6 For the water purification (N and P removal) services, the **default replacement-cost benchmark** is the operation and maintenance (O&M) cost of tertiary biological nitrogen removal (BNR) or chemical phosphorus precipitation at the national median wastewater treatment plant scale. Capital costs are excluded from the default to reflect the marginal cost of the substitute action rather than its full provision cost. Where national median unit costs are unavailable, compilers should draw on regional engineering cost databases and document the source. Sensitivity reporting is recommended, testing the estimate against at least one alternative cost scenario. This approach is consistent with the replacement-cost guidance in **TG-1.9 Safe Usage of Monetary Valuation**, which requires that the substitute action be credible and technically feasible under national conditions.

3.4 Integration with SEEA Water Accounts

¶1 The *SEEA-Water* provides the standardised accounting structure for inland water resources [22]. Freshwater-marine interaction accounting extends SEEA-Water to the coast by treating river discharge as the terminal outflow in the inland water balance and the opening inflow in the coastal/marine water balance.

Water supply and use tables at the basin-coast interface

¶1 SEEA-Water supply and use tables record water abstracted and returned by economic units [23]. The key entries for freshwater-marine interaction accounting are:

¶2 **Net abstraction within catchment.** Total abstraction by agriculture, industry, and households minus return flows. Net abstraction directly reduces estuarine salinity, flushing, and ecosystem condition.

¶3 **Environmental flows.** Compliance with environmental flow requirements should be tracked in the accounts, as shortfalls directly degrade estuarine and coastal ecosystem condition.

¶4 **Return flow quality.** Linking SEEA-Water quality accounts to the nutrient flow accounts in Section 3.2 requires matching discharge point locations and volumes with concentration data to derive mass loads.

SEEA-Water Entry	Unit	FMI Account Linkage
Total river discharge at mouth	m^3/yr	Opening freshwater inflow to estuarine ecosystem
Net abstraction within basin	m^3/yr	Reduction in natural freshwater delivery to coast
Environmental flow allocation	m^3/yr	Managed flow to maintain estuarine ecosystem condition
Return flow volume	m^3/yr	Component of discharge; links to quality accounts
Wastewater discharge (treated)	m^3/yr	Source term for nutrient loading account
Wastewater discharge (untreated)	m^3/yr	Source term for nutrient and contaminant loading

Water quality accounts

¶1 SEEA-Water quality accounts track parameters at the river-estuary boundary and the estuary-ocean boundary, enabling calculation of nutrient and contaminant loads as the product of flow volume and concentration [24]:

Parameter	Unit	Measurement Point	Accounting Treatment
Total nitrogen	mg/L	River mouth / estuary head	Input concentration to estuarine ecosystem
Total phosphorus	mg/L	River mouth / estuary head	Input concentration to estuarine ecosystem
Suspended sediment	mg/L	River mouth / estuary head	Input to sediment flow account
Dissolved oxygen	mg/L	Within estuary (spatial profile)	Condition variable for estuarine ecosystem
Salinity	ppt	Within estuary (longitudinal profile)	Condition variable reflecting freshwater influence
BOD_5	mg/L	River mouth / estuary head	Indicator of organic pollution load

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¶2 Compilers should establish monitoring stations at the upstream boundary (tidal limit or head of salt intrusion) and downstream boundary (estuary mouth or offshore reference point). The difference in loads between these two points approximates net estuarine processing, which can be recorded as an ecosystem service flow, though disentangling estuarine processing from tidal mixing effects remains an area of active research.

Linking water asset accounts to ecosystem asset accounts

¶1 For transitional ecosystems, the water asset is inseparable from the ecosystem asset: the estuary is simultaneously a water body (recorded in SEEA-Water [25]) and an ecosystem asset (recorded in SEEA EA). Compilers should record the physical water stock (volume) in SEEA-Water asset accounts, record the ecosystem asset (extent, condition, services) in SEEA EA accounts, and link the two through physical flow accounts. In monetary terms, water supply services (provisioning) and water purification services (regulating) from the same water body are generally additive. Double counting arises only where the same service flow is valued twice under different account frames.

Where uncertainty remains, document the potential overlap in account metadata. See **TG-3.2** for further guidance on avoiding double counting.

3.5 Land-Sea Interface Spatial Delineation

¶1 Spatial delineation of the freshwater-marine interface is a prerequisite for compiling all accounts in this Circular, and the boundaries adopted will affect the scope and content of the resulting accounts [26].

Delineation principles

¶1 **Upstream (catchment) boundary.** The watershed divide of river basins draining to the coastal zone, derivable from digital elevation models. For large continental river basins, focusing on the lower catchment may be appropriate depending on data availability. Where the full basin is included, sub-basin disaggregation following **TG-3.11** enables attribution of pressures to specific upstream areas.

¶2 **Landward (coastal) boundary.** The inland limit of marine influence, defined by the tidal limit, the extent of salt intrusion, or a fixed distance inland. The boundary should encompass all intertidal and supratidal ecosystems consistent with **TG-6.2**.

¶3 **Seaward boundary.** The offshore limit of significant freshwater influence, defined by salinity thresholds, river plume extent (satellite ocean colour), or fixed distance offshore. The 30 ppt isohaline (polyhaline/euhaline boundary in the Venice system) is an appropriate marker for estuarine extent delineation. For plume-influence delineation, a higher threshold (32-34 ppt) or relative anomaly (salinity 1 ppt below ambient) may better capture the zone of significant freshwater influence. Standardised methods are still emerging.

Spatial data requirements

Dataset	Source	Resolution	Purpose
Digital elevation model	National survey, SRTM v3 (1 arc-second), Copernicus DEM (GLO-30)	30m or better	Catchment delineation, tidal limit identification
Hydrological network	National water agencies, HydroSHEDS	Vector (stream lines)	River routing, monitoring point location
Coastline position	National mapping, satellite-derived	10-30m	Landward/seaward boundary reference
Land cover / land use	National mapping, Sentinel-2 classification	10-30m	Catchment land use for pressure attribution
Bathymetry	National hydrographic office, GEBCO	Variable	Estuary volume, nearshore delineation
Salinity distribution	In situ monitoring, ocean models	Point/gridded	Freshwater influence extent
Ocean colour	MODIS, Sentinel-3	300m-1km	River plume detection, turbidity

¶1 Compilers should document all spatial boundary decisions in account metadata, including the criteria used, the reference state adopted, and any adjustments made for local conditions. Consistency of spatial boundaries across accounting periods is essential for tracking changes in ecosystem extent and condition.

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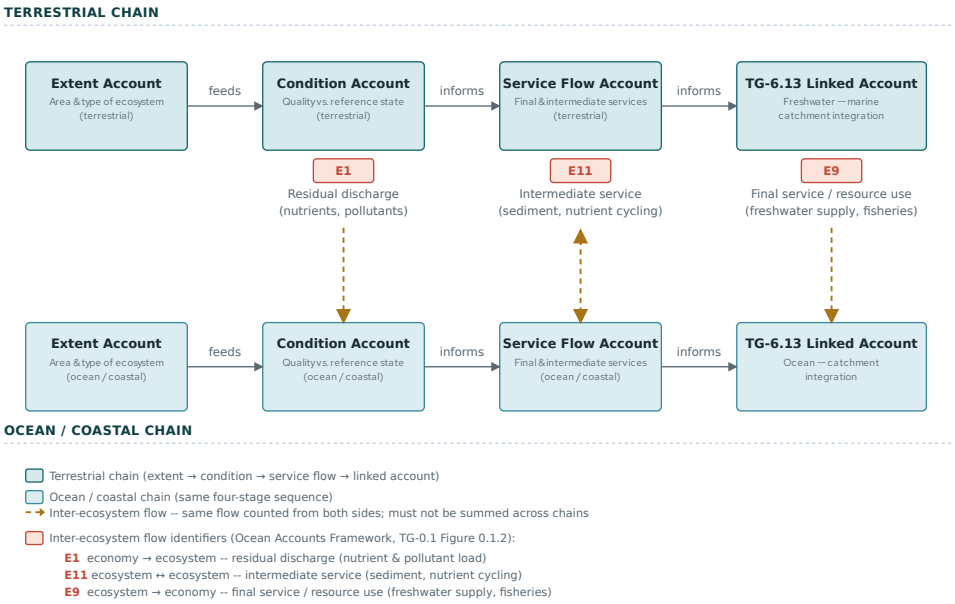


Figure 6.13.2 Parallel terrestrial and ocean/coastal SEEA EA chains linked by three inter-ecosystem flows (E1, E11, E9) that must not be cross-summed. Dashed arrows are the same flow from both sides (§5.3).

Source: TG-6.13 Framework Position table (inter-ecosystem flows E1, E9, E11) and §5.3 boundary rule; inter-ecosystem flow identifiers per the Ocean Accounts Framework (TG-0.1 Figure 0.1.2).

3.6 Compilation Procedure

¶1 The sections above describe four accounts that share a spatial frame. The order below is the one that avoids rework, because each step fixes a boundary the next step depends on.

¶2 **Step 1: Fix the spatial frame.** Delineate the contributing catchment, the tidal limit and the seaward boundary of freshwater influence using the criteria at Section 3.5, and reconcile them against the administrative units the data actually arrive in (**TG-3.11 Sub-National Ocean Accounts**). Record the criteria and the reference state in metadata now: every later step inherits this frame, and changing it afterwards invalidates the time series.

¶3 **Step 2: Compile the water flow account.** Abstraction, return flows and residual discharge to the river network, following **TG-3.2** and **TG-3.4**, with regulated flows handled per Section 3.1. This establishes the transport medium before anything is loaded onto it.

¶4 **Step 3: Compile nutrient and sediment source terms.** Apply the discharge-point test at Section 3.2 to allocate each source between this account and **TG-6.8**. Attribute loads to economic units by ISIC class so that the account can be read against the pressure it comes from, not only the substance.

¶5 **Step 4: Route loads to the receiving water.** Apply the delivery ratios and in-stream retention at Section 3.2 to convert source-term loads into loads delivered at the coast. Report delivered load with its retention assumption stated: a source-term total presented as a coastal load overstates the pressure, sometimes by a large factor.

¶6 **Step 5: Compile the estuarine and deltaic ecosystem asset account.** Extent and condition for the transitional ecosystem types at Section 3.3, using the account structure in **TG-3.1** Section

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3.5.1 and condition variables selected under **TG-4.8** and **TG-4.9**. Where the transitional system is a coastal wetland, the method is **TG-6.2** and is not duplicated here.

¶7 **Step 6: Link pressure to condition.** Relate the delivered loads from Step 4 to the condition variables from Step 5. This is the step the account exists for, and it is also the weakest: the relationship is rarely linear and is usually lagged by years. State the functional form and the lag assumed, and follow the condition-to-service scaling caution in **TG-3.1** Section 3.5.3.

¶8 **Step 7: Reconcile with the SEEA Water accounts.** Bring the basin-scale water asset and quality accounts at Section 3.4 into agreement with Steps 2 and 4, so that the same abstraction and discharge figures appear in both. A discrepancy here is normally a spatial-frame mismatch from Step 1 rather than a data error.

¶9 **Step 8: Document and quality-assure.** Record the retention assumptions, the lag, the discharge-point allocations and the spatial criteria in account metadata, and apply **TG-0.7 Quality Assurance**. Compilers should expect to publish Steps 1–4 well before Steps 5–6 are defensible; a repeatable flow account is worth more than a one-off account that reaches condition.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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- ¶12 Mayer, P.M., Reynolds, S.K., McCutchen, M.D., and Canfield, T.J. (2007). Meta-analysis of nitrogen removal in riparian buffers. *Journal of Environmental Quality*, 36(4), 1172–1180.

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- ¶13 Kirwan, M.L., and Megonigal, J.P. (2013). Tidal wetland stability in the face of human impacts and sea-level rise. *Nature*, 504(7478), 53-60.

FOOTNOTES

1. ¶1 SEEA EA, para 1.1, noting that ecosystem accounting provides a basis for compiling data on biophysical characteristics of ecosystems and their contribution to the economy and society; the freshwater-marine interface is a zone of active methodological development in environmental-economic accounting, with upstream economic activities affecting downstream ecosystem condition.
2. ¶2 United Nations (2012), *System of Environmental-Economic Accounting for Water (SEEA-Water)*, provides the framework for water supply and use tables, water quality accounts, and water asset accounts; SEEA EA (2021) extends environmental-economic accounting to ecosystem assets and services.
3. ¶3 IUCN GET describes transitional realm ecosystems as occupying the interface between two or more realms, with environmental conditions and biota reflecting the influence of both adjacent realms.
4. ¶4 IUCN GET (Keith et al. 2020), Biome MFT1 description: "associated with prograding depositional shorelines at the interface of terrestrial, freshwater, and marine realms"; SEEA EA (2021), Appendix A3.2 presents the IUCN GET reference classification.
5. ¶5 United Nations (2012), *SEEA-Water*, Chapter 2 on the hydrological cycle and its representation in accounting terms.
6. ¶6 Tidal influence, saltwater intrusion, and storm surge represent marine-to-terrestrial flows that affect freshwater quality and ecosystem condition in lower catchments.
7. ¶7 United Nations (2012), *SEEA-Water*, Chapter 3 on spatial organisation of water accounts; river basin boundaries are recommended as the primary spatial unit for water resource accounting.
8. ¶8 Episodic flood events may deliver 50-90% of annual sediment loads within a few days; see Syvitski et al. (2005) on global sediment flux dynamics.
9. ¶9 Richter, B.D., Baumgartner, J.V., Powell, J., and Braun, D.P. (1996). A method for assessing hydrologic alteration within ecosystems. *Conservation Biology*, 10(4), 1163-1174. The Indicators of Hydrologic Alteration (IHA) methodology provides 33 standardised flow statistics quantifying the five components of a flow regime (magnitude, frequency, duration, timing, rate of change); compilers requiring comprehensive flow-regime characterisation should refer to the IHA framework rather than deriving a single summary ratio.
0. ¶10 SEEA Central Framework, Chapter 3 on physical flow accounts; *SEEA-Water*, Chapter 4 on emission accounts for water.
1. ¶11 Coastal deoxygenation affects over 500 coastal hypoxic sites globally, with documented expansion in extent and severity since the mid-twentieth century; see Breitburg et al. (2018).
2. ¶12 Mayer, P.M., Reynolds, S.K., McCutchen, M.D., and Canfield, T.J. (2007). Meta-analysis of nitrogen removal in riparian buffers. *Journal of Environmental Quality*, 36(4), 1172-1180. Retention rates vary widely with buffer width, soil type, and hydrological connectivity; compilers should use site- or region-specific data where available rather than applying a single percentage.
3. ¶13 Syvitski et al. (2005) estimate that dam construction has trapped approximately 25-30% of global sediment flux that would otherwise reach the coast.
4. ¶14 Reduced sediment supply threatens coastal wetland persistence under sea-level rise; see Kirwan and Megonigal (2013) on tidal wetland stability.
5. ¶15 United Nations (2012), *SEEA-Water*, Chapter 4 addresses emission accounts; emerging contaminants require additional monitoring protocols beyond standard water quality parameters.
6. ¶16 Barbier et al. (2011) provide a comprehensive review of estuarine and coastal ecosystem service values, estimating global values in the range of USD 10,000-30,000 per hectare per year.
7. ¶17 IUCN Global Ecosystem Typology (Keith et al. 2020); SEEA EA (2021) Appendix A3.2. FM1.2 full name: "Permanently open riverine estuaries and bays."
8. ¶18 SEEA EA (2021), Chapter 4 on ecosystem extent accounts; para 4.1: "Ecosystem extent is the size of an ecosystem asset."
9. ¶19 SEEA EA (2021), Chapter 5 on ecosystem condition accounts; para 5.1: "Ecosystem condition accounts provide a structured approach to recording and aggregating data describing the characteristics of ecosystem assets."
0. ¶20 ECT class codes (A1, A2, B1, B2, B3, C1) verified against SEEA EA (2021) Table 5.1 and paras. 5.32-5.38. Classes confirmed: A1 Physical state, A2 Chemical state, B1 Compositional state, B2 Structural state, B3 Functional state, C1 Landscape and seascape characteristics.
1. ¶21 SEEA EA (2021), Chapter 6 on ecosystem services; estuarine services span multiple SEEA service categories including regulating services, provisioning services, and cultural services.
2. ¶22 United Nations (2012), *System of Environmental-Economic Accounting for Water (SEEA-Water)*. Its structure is designed for integration with the broader SEEA Central Framework and SEEA EA.
3. ¶23 United Nations (2012), *SEEA-Water*, Chapter 3 on water supply and use tables; these tables record water flows between the environment, economic units, and the rest of the world.
4. ¶24 United Nations (2012), *SEEA-Water*, Chapter 4 on quality accounts and emission accounts for water.
5. ¶25 United Nations (2012), *SEEA-Water*, Chapter 5 on water asset accounts; these record opening stocks, additions, reductions, and closing stocks of water resources.
6. ¶26 SEEA EA (2021), para 4.5-4.8 on ecosystem accounting area delineation; the choice of spatial boundaries is a foundational decision affecting all subsequent accounts.

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Marine and Coastal Tourism Accounting

Provides guidance on accounting for marine and coastal tourism, the largest ocean-economy sector by value added and employment in most coastal and small-island economies.

Version 0.2.3 **Status** Draft **Stability** Applied

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

Marine and coastal tourism is, in most coastal and small-island developing economies, the largest ocean-economy sector by gross value added and employment, yet Section 6 carries a dedicated thematic Circular for every other major ocean-economy sector and none for tourism. This Circular gives compilers an ordered method for measuring it:

- define the segment on a demand-side basis consistent with international tourism statistics;
- isolate tourism within each industry;
- apply a marine and coastal share to extract the ocean-attributable part;
- report how much of the resulting receipts the economy retains; and
- link the segment to the marine ecosystems whose recreation services it depends on, and read its economic flows against the condition of those ecosystems.

Two compilation tiers are provided — one for economies with a Tourism Satellite Account and one proxy tier for the majority that do not — so the guidance is usable across the income and data-maturity range of coastal states. The aim is a segment account that reconciles with the national accounts and, where one exists, the national Tourism Satellite Account, so that ministries of tourism, finance, and environment read consistent figures.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

Marine and Coastal Tourism Accounting (2026) (GOAP Technical Guidance on Ocean Accounting, TG-6.14, v0.2.3). GOAP Secretariat. https://guidance.oceanaccounts.org/circulars/section-6/6-14-marine-coastal-tourism/

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¶1 **Framework Position**

¶2 This Circular specialises the ocean-economy identification method of TG-3.3 Economic Activity Relevant to the Ocean for one sector: marine and coastal tourism. TG-3.3 owns the general method for identifying ocean-related industries, the ISIC concordance, and the proxy method for countries without a Tourism Satellite Account. TG-6.14 adds the tourism-specific layer: how tourism is isolated within each industry, how a marine and coastal share is then applied, how the segment is built where no Tourism Satellite Account exists, and how the result links to marine ecosystems and their recreation services.

1. Outcome

¶1 Marine and coastal tourism is, in most coastal and small-island developing economies, the largest ocean-economy sector by gross value added and employment, yet Section 6 carries a dedicated thematic Circular for every other major ocean-economy sector and none for tourism. This Circular gives compilers an ordered method for measuring it:

- ¶2 define the segment on a demand-side basis consistent with international tourism statistics;
- ¶3 isolate tourism within each industry;
- ¶4 apply a marine and coastal share to extract the ocean-attributable part;
- ¶5 report how much of the resulting receipts the economy retains; and
- ¶6 link the segment to the marine ecosystems whose recreation services it depends on, and read its economic flows against the condition of those ecosystems.

¶7 Two compilation tiers are provided — one for economies with a Tourism Satellite Account and one proxy tier for the majority that do not — so the guidance is usable across the income and data-maturity range of coastal states. The aim is a segment account that reconciles with the national accounts and, where one exists, the national Tourism Satellite Account, so that ministries of tourism, finance, and environment read consistent figures.

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2. Requirements

- ¶1 **TG-0.1 General Introduction to Ocean Accounts** — the overall framework and the ocean accounting boundary.
- ¶2 **TG-3.3 Economic Activity Relevant to the Ocean** — essential: the ocean economy ratio (ocean-related share), the ISIC–ocean-economy concordance, the interim ISIC-version protocol, the materiality decision rule, and the simplified proxy method for countries without a Tourism Satellite Account, all applied here.

¶3 Related: **TG-2.4 Environmental (including Ecosystem) Goods and Services** and **TG-2.5 Structure and Function of the Ocean Economy** for the recreation ecosystem service and the ocean-economy aggregate; **TG-3.5 Social Accounts** for tourism employment; **TG-4.2 Survey Methods for Ocean Economic Activity** and **TG-4.3 Administrative Data Sources** for the visitor-survey, arrivals-card, licensing and port data this method relies on.

¶4 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

3.1 Defining marine and coastal tourism

¶1 Tourism is a **demand-side** phenomenon: it is defined by the activities of **visitors**, not by a fixed list of industries.[1] A visitor is a traveller taking a trip outside his or her **usual environment** for less than a year, for a main purpose other than employment by a resident entity in the place visited. A visitor who stays overnight is a **tourist**, and one who does not is a **same-day visitor** (excursionist).[1] Visitor residence distinguishes the **forms** of tourism — domestic (residents within the country) and inbound (non-residents) together make up *internal* tourism — and this distinction matters for compilation, because the data sources for the two differ substantially.[1]

¶2 **Marine and coastal tourism** is the subset of this activity that takes place in, or draws its main attraction from, the coast and the sea. Two adaptations of the standard definitions are needed. First, the *purpose* test: an activity counts as marine or coastal tourism where the coast or sea is the principal reason for the visitor's presence or expenditure (beach holidays, diving and snorkelling, recreational boating and sport fishing, marine wildlife watching, cruise calls, visits to marine protected areas and aquaria). Second, the *location* test for activities that are coastal by setting rather than by motive (accommodation, food service, and local transport in coastal destinations), where only a share of output serves marine and coastal visitors. These activities sit in the **partially ocean-related** tier of TG-3.3. The indicative materiality benchmark used to admit them — around 5 per cent of establishment output — is TG-3.3's pragmatic operational choice, not a value drawn from an external standard, and this Circular adopts it by reference rather than restating the rule.[2]

> ¶3 **Key Takeaway**
> ¶4 Marine and coastal tourism is not an industry — it is the marine-and-coastal share of visitor demand falling on a set of tourism industries. Measuring it means applying *two* shares — a tourism share and a marine and coastal share — and the two must be measured on the same population of visitors (Section 3.3).

3.2 ISIC classification and apportionment — concordance backing Figure 6.14.1

¶1 Marine and coastal tourism is reconstructed across four ISIC Rev.4 sections. The concordance below **extends** the ISIC–ocean-economy concordance in TG-3.3 (its Table 2) to the full set of tourism characteristic activities of the Tourism Satellite Account. It does not duplicate the general concordance method, which remains with TG-3.3. Each class carries an apportionment status: **wholly marine** (ocean ratio = 1.0, the entire class is sea- or coast-defined) or **coastal-apportioned** (ocean ratio < 1.0, set by the marine and coastal-purpose visitor share). Figure 6.14.1 presents the same disaggregation visually.

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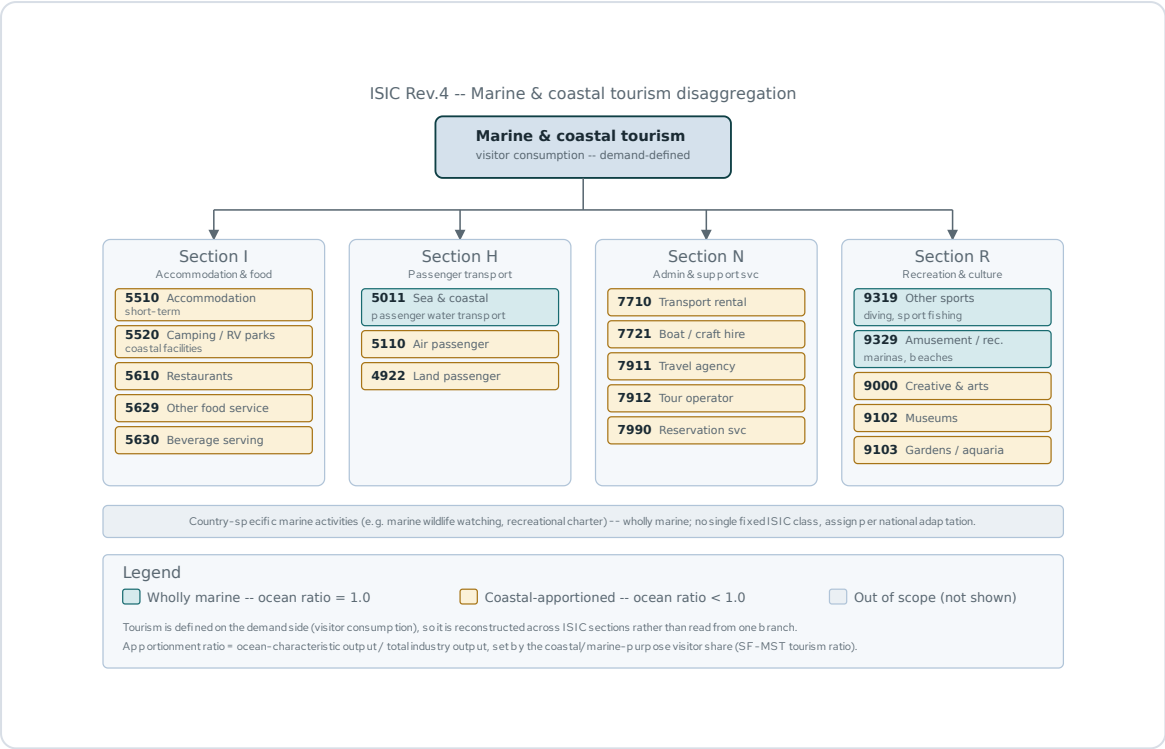


Figure 6.14.1 Demand-side marine tourism reconstructed across ISIC Sections I, H, N, and R by ocean-economy apportionment ratios on visitor expenditure. Row fill encodes apportionment status. Inland/non-coastal classes omitted; use UNSD Rev.5--Rev.4 correspondence where needed.

Source: ISIC Rev.4 (Sections H, I, N, R); UNWTO Tourism Satellite Account: Recommended Methodological Framework 2008 (tourism characteristic activities, paras 4.50--4.53); IRTS 2008; SF-MST 2024 (tourism ratio).

ISIC Rev.4	Description	ISIC Section	TSA characteristic-activity category	Apportionment
5510	Short-term accommodation activities	I	Accommodation for visitors	Coastal-apportioned
5520	Camping grounds, recreational vehicle parks	I	Accommodation for visitors	Coastal-apportioned
5610	Restaurants and mobile food service	I	Food and beverage serving	Coastal-apportioned
5629	Other food service activities	I	Food and beverage serving	Coastal-apportioned
5630	Beverage serving activities	I	Food and beverage serving	Coastal-apportioned
5011	Sea and coastal passenger water transport	H	Water passenger transport	**Wholly marine (1.0)**
5110	Passenger air transport	H	Air passenger transport	Coastal-apportioned
4922	Other passenger land transport	H	Road passenger transport	Coastal-apportioned
7710	Renting and leasing of motor vehicles	N	Transport equipment rental	Coastal-apportioned
7721	Renting of recreational and sports goods (incl. marine craft)	N	Transport equipment rental	Coastal-apportioned

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ISIC Rev.4	Description	ISIC Section	TSA characteristic-activity category	Apportionment
7911	Travel agency activities	N	Travel agencies and reservation	Coastal-apportioned (margin)
7912	Tour operator activities	N	Travel agencies and reservation	Coastal-apportioned (margin)
7990	Other reservation service activities	N	Travel agencies and reservation	Coastal-apportioned (margin)
9319	Other sports activities (incl. sport fishing, diving operators)	R	Sports and recreational activities	Coastal-apportioned
9329	Other amusement and recreation activities (incl. beaches, marinas)	R	Sports and recreational activities	Coastal-apportioned
9000	Creative, arts and entertainment activities	R	Cultural activities	Coastal-apportioned
9102	Museums activities	R	Cultural activities	Coastal-apportioned
9103	Botanical and zoological gardens, nature reserves (aquaria, marine parks)	R	Cultural activities	Coastal-apportioned

¶2 Only **5011 Sea and coastal passenger water transport** is treated as wholly marine: its official ISIC Rev.4 scope is defined entirely by transport over seas and coastal waters (ferries, water taxis, excursion, cruise and sightseeing boats), so an ocean ratio of 1.0 is defensible.[3] Note, however, that for 5011 the *tourism* ratio (Section 3.3, step 1) is doing the work of separating visitor travel from resident ferry commuting, which is everyday transport and not tourism. Where no Tourism Satellite Account fixes that ratio, a defensible tourism ratio for coastal ferries should be estimated separately from passenger-purpose data rather than assumed. By contrast **9319 Other sports activities** and **9329 Other amusement and recreation activities** are *broad* classes: 9319 also covers athletes, leagues, racing stables and land-based sport, and 9329 covers fairs, ski hills, discotheques and amusement arcades.[4] Assigning either class an ocean ratio of 1.0 would over-attribute the bulk of its output to the ocean economy and break the demand-side logic, so both are coastal-apportioned, consistent with TG-3.3.

¶3 **Margin basis for travel agencies and tour operators.** Travel agency, tour operator and reservation services (7911/7912/7990) must enter on a **margin (net) basis** — the service fee or mark-up, not the gross package price — following Tourism Satellite Account convention. If gross package revenue is used, the accommodation and transport bundled inside a package are counted twice: once in 5510/5011 and again in the tour operator's turnover.[5]

¶4 **Marine activities without a dedicated ISIC class.** Marine wildlife watching, recreational dive operators and recreational charter are wholly marine but have no single fixed ISIC class and are often informal or under-covered in the business register. Assign them by national adaptation as follows:

- ¶5 identify the operators from tourism-board licensing, marine-park concession records, or dive- and charter-association membership (per TG-4.3);
- ¶6 estimate their receipts and employment from those administrative sources where the register under-covers them; and
- ¶7 record them as a wholly-marine (1.0) add-on line to the apportioned 9319/9329 total, taking care not to double-count operators already captured in the register.

¶8 Out-of-scope classes with no material ocean-attributable share are not shown.

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> ¶9 ⚠ **Common Misconception**
> ¶10 A class that contains marine examples is not a wholly marine class. Diving and beach-recreation receipts sit inside ISIC 9319 and 9329, but so does most non-marine sport and amusement — so these classes must be apportioned, not set to 1.0.

¶11 **ISIC version note.** ISIC Rev.5 was adopted by the UN Statistical Commission at its 54th session (28 February–3 March 2023). Its explanatory notes and implementation plan were endorsed at the 55th session (2024), with national implementation expected from 2027.[6] Where the national business register has transitioned, apply the UNSD ISIC Rev.5–Rev.4 correspondence before using this concordance, following the interim ISIC-version protocol set out in TG-3.3 (use the operative register version; adapt via the correspondence table; document the version used in compilation metadata).

3.3 Compiling the marine and coastal tourism segment

¶1 The segment is built from two apportionment shares — a tourism share and a marine and coastal share — followed by a reconciliation step. Two tiers are provided according to data availability.

Tier 1 — where a national Tourism Satellite Account exists

1. ¶1 **Isolate tourism within each industry using the tourism ratio.** The **tourism share** of an industry is the part of its output acquired by visitors (internal tourism consumption), and the **tourism ratio** expresses that share as a fraction of the industry's total output.[5] The ratio is applied to output and intermediate consumption to derive the tourism-attributable value added of each industry. The headline aggregates — **tourism direct gross value added (TDGVA)** and **tourism direct gross domestic product (TDGDP)** — are then obtained through the Tourism Satellite Account Table 6 reconciliation of internal tourism consumption against domestic supply, with TDGDP adding the net taxes on tourism products. TDGVA/TDGDP are therefore *not* simply value added multiplied by a ratio, and TDGDP in particular cannot be apportioned by a single per-industry multiplier.[7] Where a national Tourism Satellite Account exists, start from its published tourism ratios rather than re-estimating them.
2. ¶2 **Apply the marine and coastal share.** Multiply each industry's derived tourism aggregate by the marine and coastal-purpose share for that class — 1.0 for wholly marine classes, and the coastal/marine visitor-purpose share otherwise. This second share is the TG-6.14-specific contribution and is the operational form of the per-class apportionment in Section 3.2. Two cautions apply. First, **measure both shares on the same population:** the tourism ratio covers *internal* tourism (domestic + inbound), so the marine and coastal share must also be measured on internal tourism, or estimated separately for domestic and inbound demand and recombined — applying an inbound-only share (for example one read straight off international arrivals cards) to an internal-tourism aggregate will misstate the segment wherever domestic and inbound marine propensities differ. Second, applying the share directly to value added assumes the marine and non-marine portions of a class carry the same value-added ratio. Where establishment data allow, apply the share at the output level and derive value added from class-specific margins.
3. ¶3 **Reconcile.** The national-accounts industry totals are the binding control, and the Tourism Satellite Account is the cross-check where it exists, with the two themselves required to be mutually consistent. Anchor the segment to the reliable supply-side total and adjust the apportioned demand-side estimate to it. Following TG-3.3, flag any discrepancy exceeding about 10 per cent of the initial estimate for investigation rather than silent absorption, and document the residual.

¶4 **Sourcing the marine and coastal share.** This is the single hardest number in the method, and the available sources are not interchangeable. A visitor expenditure survey is best — it gives the marine and coastal *expenditure* share directly, and the share should be expenditure-weighted rather than arrival-count-weighted, since high-spend marine activities (diving, charters) and low-spend beach visits differ. Arrivals-card purpose data are a national-level proxy only. They do not resolve

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to the industry or destination level, and they systematically miss same-day, cruise and domestic visitors — precisely the visitors most concentrated in marine recreation — so they must be supplemented for those segments. Emerging sources — e-VISA records and mobile-positioning data — are increasingly used to allocate where visitors actually go and can support destination-level shares (see TG-4.2 and TG-4.3).

Tier 2 — where no Tourism Satellite Account exists (proxy method)

¶1 Most coastal and small-island developing states have no operational Tourism Satellite Account, and their visitor surveys often do not separate marine from non-marine purposes. In these contexts the segment is built using the simplified proxy method of TG-3.3 (its Section 3.7), which this Circular adopts as the default Tier 2 path:

- ¶2 obtain accommodation receipts by district and identify coastal districts;
- ¶3 calculate the marine-purpose arrivals share from arrivals cards or port-of-entry surveys;
- ¶4 multiply coastal accommodation, food-service and local-transport receipts by that share; and
- ¶5 add explicitly marine recreational expenditure (diving, charters, sport fishing) from operator licensing records.[8]

¶6 In the proxy case the two shares of Tier 1 collapse into the single applied marine-purpose share — the proxy already conflates the tourism and marine-purpose steps — so compilers should not additionally apply a tourism ratio and double-discount. A Tier 2 estimate is a legitimate first account, to be upgraded to Tier 1 as a Tourism Satellite Account and visitor-expenditure surveys become available.

3.4 Value added, employment, and trade

¶1 **Production account.** Compile output, intermediate consumption, gross and net value added for the segment, carrying the marine and coastal share into the derived tourism aggregates as set out in Section 3.3 (and observing that TDGDP, which includes product taxes, is reconciled rather than scaled). Marine tourism-specific fixed assets — cruise ships and yachts, marinas, dive boats and charter vessels — are the capital counterpart and should be identified in the gross fixed capital formation of the segment.[9]

¶2 **Cruise and international visitors.** Cruise is the hardest case and warrants explicit treatment. Cruise passengers entering the economic territory are visitors, and unless they overnight ashore they are international **same-day visitors (excursionists)**. Whether their ashore expenditure is recorded as internal tourism consumption of the country of reference depends on applying the residence and economic-territory concepts to the ship they arrive and leave on: it is conditional, not automatic.[10] In practice, ashore expenditure is estimated as **passengers landed x average per-passenger shore expenditure** from port-of-call intercept surveys, passenger and port taxes are recorded separately as government revenue, and fares and on-board spending accrue to the cruise operator, which is typically non-resident (a balance-of-payments leakage). Note that under the balance-of-payments standard **cruise fares are recorded in the travel item**, not in passenger transport, distinguishing them from ordinary international passenger fares.[10] Inbound visitor expenditure is recorded as exports of travel services and outbound as imports, and the segment's inbound component should be aligned with the balance-of-payments travel credit so the two are not estimated independently and inconsistently.

¶3 **Employment.** Employment is first measured *in the tourism industries* on a domestic, establishment basis — the standard Tourism Satellite Account Table 7 measure — because labour is associated with the establishment in which output is produced, not with the residence of the visitor served.[11] The tourism-attributable portion is obtained by applying each industry's tourism ratio to its employment, and the marine and coastal segment by applying the marine and coastal share. Applying the ratio to employment carries the stated assumption that the visitor-serving fraction of

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output has the same labour intensity (production function) as total output, which should be made explicit.[11] Coastal tourism labour markets are strongly **seasonal** and carry a high incidence of **informal employment**. Because the establishment survey is exactly what misses informal dive guides, beach vendors and seasonal crew, in high-informality settings the labour-force survey (ideally a peak-season round) and operator licensing should be the primary employment source, with the establishment survey as a lower bound. Report both peak-season and annual-average employment so the seasonal swing is visible. See TG-3.5 Social Accounts for the wider tourism-employment treatment.

¶4 **Trade and retention.** Beyond gross value added and export earnings, the question finance ministries ask first is how much of tourism receipts the economy actually keeps. Gross value added measures production within the economic territory, not the income that remains there, and for a marine tourism segment built on foreign-owned resorts, foreign-flagged vessels and imported supply the two can diverge widely. The SF-MST treats this as **tourism leakage** and identifies two distinct channels, which should be reported separately rather than combined into a single headline number.[12] Figure 6.14.2 sets out the reduction from gross segment receipts to retained value.

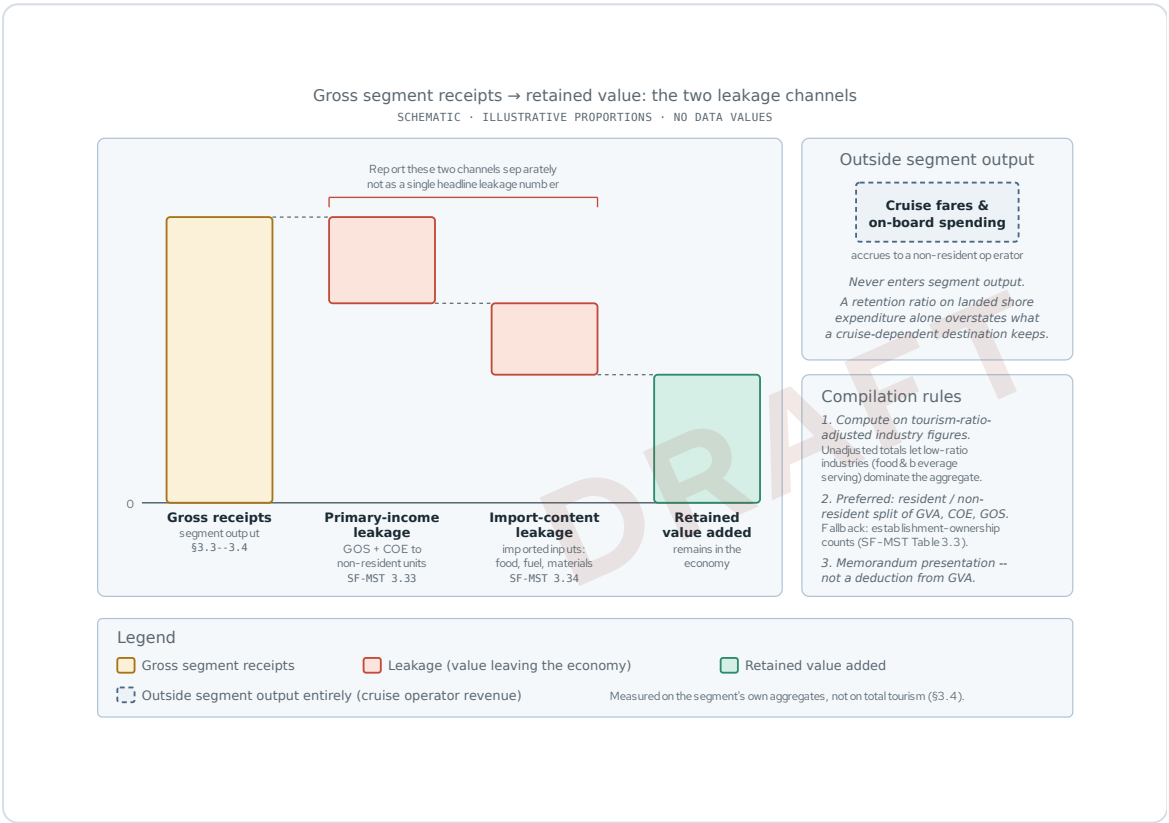


Figure 6.14.2 Schematic waterfall from gross marine tourism receipts to retained value via primary-income and import-content leakage channels. Bar heights illustrative (no data). Retention is a memorandum beside segment GVA, not a deduction from it.

Source: SF-MST (2024) paras 3.33--3.34 and Tables 3.3--3.5; this Circular §3.4 ("Trade and retention").

- ¶5 **Primary-income leakage.** Gross operating surplus generated by the segment that accrues to non-resident economic units and is not reinvested locally. The SF-MST's preferred treatment is to split the segment's gross value added, compensation of employees and gross operating surplus between resident and non-resident units. Splitting compensation of employees as well as operating surplus matters in this sector, because non-resident managerial and specialist labour is common in resort and dive operations. Where that split is unavailable, the count of resident- and non-resident-owned establishments supports a coarser ownership-based indicator.

- ¶6 **Import-content leakage.** Value added that does not remain in the economy because the inputs to tourism production (food, fuel, construction materials, vessel maintenance) are imported. This is derivable from the supply-and-use reconciliation and is characteristically high in small-island settings.

¶7 One caution governs both. The retention indicators must be computed on **tourism-ratio-adjusted** industry figures. Applying them to unadjusted industry totals allows industries with a low tourism ratio, food and beverage serving being the standard case, to dominate the aggregate and misstate retention for the segment as a whole.[12] Marine tourism adds a further channel not present in inland tourism: cruise fares and on-board expenditure accrue to a typically non-resident operator and never enter the segment's output at all (see the cruise treatment above), so a retention ratio computed on landed shore expenditure alone will overstate what a cruise-dependent destination retains. Report the retention indicators as a memorandum presentation alongside the segment's gross value added rather than as a deduction from it.

¶8 **Visitor-paid conservation levies and access fees.** Marine protected area entry fees, dive-site levies, reef taxes and operator conservation surcharges are a material receipt in marine destinations, and their treatment is a consumption-boundary question that belongs to this Circular. A fee paid by a visitor during a trip is part of that visitor's tourism expenditure and therefore enters **internal tourism consumption** and the segment aggregates of Sections 3.3 and 3.4, on the same basis as any other product acquired on the trip. An operator conservation surcharge that is a component of the price of a dive or excursion is not separable: it is part of the operator's output and flows through the supply-and-use reconciliation before it ever reaches a conservation fund. The destination of the money does not change the recording of the transaction.

> ¶9 ⚠ **Common Misconception**
> ¶10 A conservation levy paid by a visitor is one transaction with two sides, and the two must never be summed. It is visitor expenditure inside the tourism aggregates of Section 3.4, and it is government or institutional revenue in the governance accounts. Adding the segment's tourism direct gross value added to the conservation revenue it generated double-counts the levy.

¶11 For the recording of the revenue itself, the environmentally related taxes and fees account, and the conservation expenditure it finances, see **TG-3.7 Governance Accounts**, which carries marine protected area access fees as an account line and sets out the test that determines whether a given levy is recorded as an environmental tax, as rent, or as a sale of services.[13] For capital expenditure on marine conservation and the rule preventing the same outlay entering both gross fixed capital formation and environmental protection expenditure, see **TG-2.6 Ocean-related Investment**. For the design of conservation finance instruments, see **TG-1.8 OA and Project-Level Finance**.

3.5 Environmental interactions

¶1 The connection between tourism and the environment runs both ways. For marine and coastal tourism the marine ecosystem asset *supplies the service that visitors consume*: reefs, seagrass meadows, beaches and clear coastal water are the biophysical basis of the attraction, but it is the service flow they yield — not the asset stock itself — that links them to tourism.[14] This Circular adapts the environmental dimension of the SF-MST to the marine case rather than restating it. Figure 6.14.3 sets out the asset -> service -> account linkage.

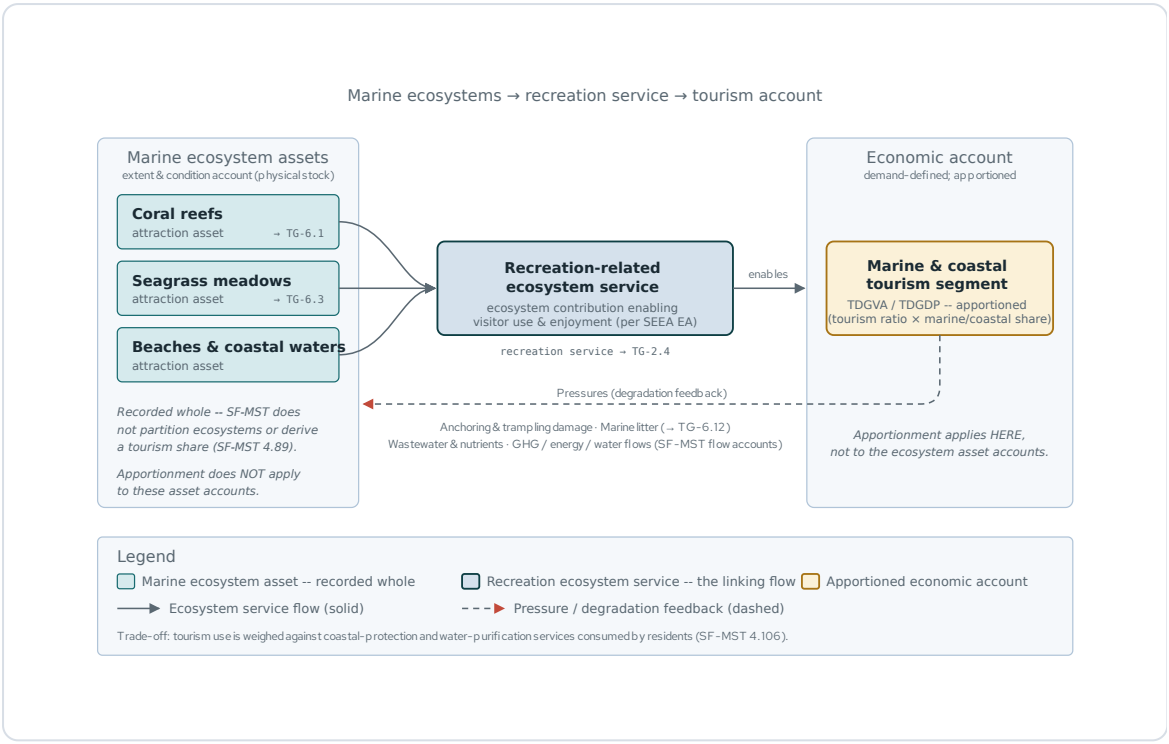


Figure 6.14.3 Recreation-related ecosystem services link marine assets to the tourism segment; assets stay whole while only the economic account is apportioned. Dashed arrows = tourism pressures returning to assets.
Source: adapted from SF-MST (2024) §4.3; SEEA EA Chapters 6 and 9.

¶2 **Recreation ecosystem services.** The flow that links marine ecosystems to tourism is the **recreation-related ecosystem service** — the contribution of an ecosystem's biophysical characteristics that enables visitors to use and enjoy it — recorded following the SEEA Ecosystem Accounting.[15] It is a **final** ecosystem service whose beneficiary is the visitor, recorded in the physical ecosystem-service account and conceptually distinct from, and must not be added to, the tourism direct gross value added of Sections 3.3–3.4 (the former values the ecosystem's contribution, the latter the produced output of tourism industries). For marine and coastal tourism these services are supplied by coral reefs, seagrass and coastal waters, and their measurement should draw on, and not duplicate, TG-6.1 Coral Reef Ecosystem Accounting, TG-6.3 Seagrass Ecosystem Accounting, and the recreation-service treatment in TG-2.4. A measure of total recreation services in a destination, set against ecosystem carrying capacity, indicates how dependent the local tourism economy is on the condition of its marine ecosystems, and the carrying-capacity measure should itself consider both the number of visitors and the change in condition of the ecosystem.[15] The framework directs compilers to make that comparison; it does not supply the threshold values against which a compiled figure could be judged, and expressly holds that it does not establish thresholds, since these vary by location and over time.[16]

¶3 **Extent and condition of marine tourism assets.** Compile a tourism-related ecosystem asset register and regional extent account that includes the relevant marine ecosystem types — for example marine shelf systems, coral reefs and seagrass meadows — using a national classification cross-walked to the IUCN Global Ecosystem Typology as the reference, with condition measures for each marine asset.[17] Condition characteristics should be organised under the SEEA EA **ecosystem condition typology (ECT)** and its six condition-characteristic classes, so that marine variables (live-coral cover, water clarity and turbidity, seagrass density) are mapped to ECT classes rather than chosen ad hoc.[18] A disturbance layer is not a condition account, and the distinction is easily lost in practice: the European Union nature-based tourism account carried the effect of major fires by excluding burnt areas from its service-providing areas, which is an event-extent adjustment standing in for the condition account the architecture calls for.[19] The marine analogue is to treat bleaching-

event extent, or a raw degree-heating-week series, as though it were a condition account. Both are exposure or disturbance measures and must be **rescaled** against reference levels before they are condition indicators; the rescaling for marine variables, including the Maximum Monthly Mean and degree-heating-week method for reefs, belongs to **TG-4.8 Physical Condition Measurement** and is not restated here. The SF-MST does **not** recommend partitioning ecosystems or deriving a tourism share of an ecosystem asset. The asset is recorded whole, and its extent and condition are tracked as a physical stock.[17] This is a key contrast with the economic accounts of Sections 3.2–3.4, where apportionment is central, and compilers should not carry the marine and coastal share into the ecosystem asset accounts.

> ¶4 ⚠ **Valuation Caution**
> ¶5 Recreation valuation studies for reefs and beaches are dominated by contingent valuation and choice experiments, which estimate total willingness to pay including consumer surplus. These are welfare measures, and they are not consistent with the exchange-value basis of the accounts. They must not be entered directly as account values, and gross visitor expenditure must not be substituted for the ecosystem contribution either, since it overstates it. The exchange-value rule, the valuation preference hierarchy, and the simulated exchange value adjustment that stated-preference data require are owned by **TG-1.9 Safe Usage of Monetary Valuation** and are not restated here.[20]

¶6 **Pressures specific to marine tourism.** Record the marine-specific pressures the activity places on these assets:

- ¶7 physical damage to reefs and seagrass from anchoring, trampling and dive contact;
- ¶8 marine litter from vessels and beach use (cross-reference TG-6.12 Marine Litter and Plastics Accounting);
- ¶9 wastewater and nutrient discharge to coastal waters;
- ¶10 freshwater abstraction by coastal resorts in water-scarce settings; and
- ¶11 greenhouse-gas, energy, water and solid-waste flows.

¶12 The flow side and the asset side are apportioned *differently*, and the contrast must be kept explicit: the physical pressure flows are SEEA Central Framework accounts and **do** carry a tourism share — only the tourism share of the environmental flow is included — whereas the marine *asset* is recorded whole, with no tourism share, its degradation tracked as a change in ecosystem condition.[21] How that tourism share is derived matters. The SF-MST's preferred route estimates the share from physical factors specific to the activity — passenger kilometres and fuel volumes, for example — and its stated fallback, used only where neither direct data nor modelled estimates exist, is to compile the flow at industry level and scale it by the industry's tourism output ratio.[22] Compilers should note a corollary the framework does not state: where the fallback is used, the environmental flow per unit of tourism output equals the flow per unit of industry output *by construction*, so the resulting tourism environmental intensity is the whole-industry intensity and cannot reveal that visitors are more or less flow-intensive than other customers. This is the same class of assumption as the labour-intensity caveat in Section 3.4, and for marine pressures — where resort water abstraction and vessel fuel use are typically far more visitor-concentrated than the industry averages containing them — the physical-factor route should be preferred wherever the data allow. Where these pressures degrade the ecosystems that supply the recreation service, the joint economic-environmental account is meant to make the resulting trade-off visible, for example between tourism use and the coastal-protection or water-purification services consumed by residents.[15]

¶13 **Attributing degradation to tourism.** Coral and seagrass decline in a tourism destination is rarely caused by tourism alone. Bleaching driven by marine heatwaves, agricultural and urban runoff, coastal development and fishing pressure act on the same assets at the same time, and a condition series alone cannot separate them. Two rules follow. First, the attribution question is asked of the *flow*, not the asset: the SF-MST recommends estimating the contribution tourism activity makes to changes in an environmental asset, whilst holding that this contribution must not be read as a share of the asset itself.[23] Second, the attribution should rest on localised measurement

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rather than assumption. The SF-MST recommends that pressure and condition measurement be concentrated in the specific locations where the issue is apparent and potentially attributable to tourism, rather than compiled at national scale, and that stock data (asset quality) be combined with flow data (pollutants and emissions) so that the two can be read together.[23] For marine tourism this means site-level monitoring at the dive sites, anchorages and beaches carrying the visitor load, with an unvisited or lightly visited reference site of comparable exposure where one is available. Where the pressure cannot be separated from other drivers, record the pressure flow and the condition change and state the limitation, rather than asserting a tourism-attributable share the data do not support.

¶14 **Reading economic flows against ecosystem condition.** The joint account allows a diagnostic that neither the economic nor the ecosystem account yields alone: the segment's tourism direct gross value added series read against the condition series for the reef and seagrass assets that supply its recreation service. Figure 6.14.4 sets out the pairing and the constraints on it.

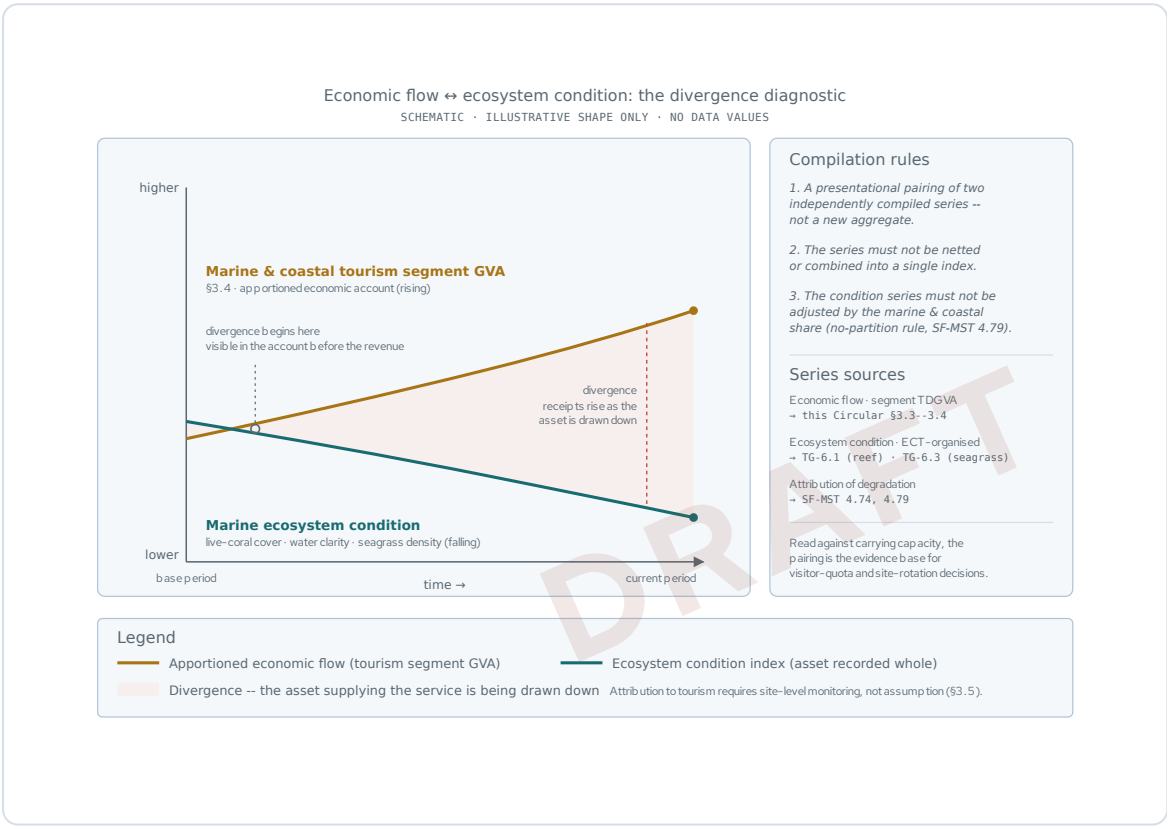


Figure 6.14.4 Presentational pairing of tourism economic flows against ecosystem condition series; the two are compiled independently and never netted. Curves illustrative (no data). Condition series carries no marine/coastal share.
Source: this Circular §3.4--3.5; series construction follows SF-MST (2024) 4.74 (combining stock and flow data) and 4.79 (no tourism share of environmental assets); condition characteristics organised under the SEEA EA ecosystem condition typology.

¶15 A destination in which segment gross value added rises whilst live-coral cover, water clarity or seagrass density falls is drawing down the asset that underpins the receipts, and the account makes the divergence visible before it appears in the revenue. That divergence is not hypothetical: the pilot provincial accounts for KwaZulu-Natal record that nature-based tourism value "increased in spite of general evidence of a decline in the extent and condition of natural areas".[24]

¶16 The diagnostic is a presentational pairing of two independently compiled series, not a new aggregate. The two must not be netted or combined into a single index, and the condition series must not be adjusted by the marine and coastal share, consistent with the no-partition rule above. Four limits govern how the pairing may be read, and they are the reason it remains a pairing.

- ¶17 **It is not an estimated response.** The account states two quantities against one asset; it does not estimate how the tourism aggregate would move were condition to change. The same KwaZulu-Natal authors, having assembled extent, condition and a tourism value added figure in one account, record the missing step as outstanding — that "it would be useful to consider the counterfactual or what tourism value might have been in the absence of the negative ecological trends".[24] Compilers should not present the pairing as though that counterfactual had been supplied.
- ¶18 **The relation is not necessarily linear or monotonic.** Marine assets follow recovery trajectories, so a condition decline and the visitation it affects need not move together within a reference period, and a destination may sustain or even raise receipts through a decline. Read the pairing as a divergence to be investigated, not as a dose-response curve.
- ¶19 **Displacement can leave a national aggregate unmoved.** Visitors deterred from a degraded site frequently travel elsewhere in the same country. A site or destination account will register the loss where a national aggregate does not, so the scale at which the pairing is struck determines what it can detect.
- ¶20 **Periodicity follows the coarser side.** Condition accounts are ordinarily compiled less frequently than the Tourism Satellite Account, so the paired statement can be made only for the reference years the condition account actually covers. Interpolating the condition series to the tourism cadence manufactures precisely the movement the pairing exists to record, and must not be done.

¶21 Scale is also bounded by the data. Physical attribution is sensitive to the spatial unit it is compiled on — the European Union account found allocated service use shifting by 0.89 per cent between NUTS 2 and NUTS 3 aggregations of the same tourism statistics[19] — whilst the economic side rarely resolves below the national level. Destination scale is therefore the outer bound of a defensible paired statement, and any finer attribution should be presented as indicative with its aggregation sensitivity documented.

¶22 Read with those limits, the pairing is the evidence base a tourism ministry needs for visitor-quota and site-rotation decisions. It is not an answer to whether current visitor volumes are sustainable, because neither standard supplies the referent that question requires: the account can show whether a destination's position is improving or deteriorating against itself over time, and the threshold that separates acceptable from unacceptable has to be set by the destination. The Austrian pilot study on measuring sustainable tourism reached the same conclusion, holding that benchmarking with fixed quantitative target values for each indicator is not possible and locating sustainability as a regional phenomenon whose targets regional policy-makers must establish.[25]

¶23 **Reef-dependent tourism indicator.** The marine-tourism segment gross value added of Section 3.4 can be set against the reef- and seagrass-dependent recreation share to give an indicative *reef-dependent tourism value* — the most policy-salient output for an environment ministry. This is an **attribution** of economic value to ecosystem condition, not a partition of the ecosystem asset, and is therefore consistent with the no-partition rule above.

¶24 The attribution runs in two stages, and only the second belongs to this Circular. The first stage separates the ecosystem's contribution from the produced and human inputs assembled around it — accommodation, transport, guiding and gear hire — attributing the residual to the ecosystem. That residual construct is owned by **TG-6.1 Coral Reef Ecosystem Accounting** (its Section 3.4, simulated exchange value) and is not restated here. The second stage is required wherever a destination's recreation service is supplied by more than one marine asset, which is the normal case: reefs, seagrass meadows and beaches typically serve the same visitors, and TG-6.1 resolves a single asset only. Allocate the nature-attributable component across the destination's marine assets **in proportion to the physical recreation-service use attributed to each asset in the ecosystem services use table**, so that the weights are the account's own compiled physical quantities rather than an assumed split, and a non-ecosystem residual remains outside the allocation. Two con-

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straints follow. The allocation distributes a compiled total between assets; it does not estimate what that total would be were one asset's condition to change, which is the limit recorded in the pairing above. And it inherits the aggregation sensitivity noted there, which is the second reason to fix the exercise at destination scale. Any monetary ecosystem-service estimate (SEEA EA Chapters 9–11, which have recommendation rather than standard status) is complementary to, and must not be summed with, the segment's tourism direct gross value added. [26]

¶25 **Compiled precedents and their limits.** Compilers should know that the account specified above has been attempted, that no attempt has yet completed it, and where each stopped. The nearest **marine** precedent is an Italian compilation of ecosystem accounts for marine-based tourism supplied by *Posidonia oceanica*, which estimated marine ecosystem extent and condition — shoot density as a health proxy, with nitrogen and phosphorus concentrations as pressure proxies — carried the physical contribution through to monetary terms, and reported values of EUR 6.1 million for 2019 and EUR 3.7 million for 2021. [27] Three limits qualify it as a model. No formal condition account table was constructed, condition entering at the extent-and-condition assessment stage instead; no Tourism Satellite Account aggregate appears anywhere, so there is no tourism direct gross value added to pair with; and the monetary step applies travel cost as a price proxy to ecosystem-dependent arrivals whilst describing the result as an exchange value. That last point is the boundary case governed by **TG-2.4 Environmental (including Ecosystem) Goods and Services** (its Section 3.10.4), which distinguishes the consumer expenditure method, yielding exchange values, from the traditional travel cost method, which estimates total willingness to pay including consumer surplus. Compilers adopting this precedent should satisfy themselves which of the two they are implementing and label it accordingly.

¶26 The nearest **full-account** precedent is the pilot provincial accounts for KwaZulu-Natal, which assembled ecosystem extent and condition accounts, a tourism valuation using resource-rent ratios drawn from the national Tourism Satellite Account, and a direct value added figure consistent with the national accounts, in one place. [24] Its limit is instructive: the tourism value was spatially allocated by geotagged photo-user density, so ecosystem condition, although compiled in the same account, never entered the tourism valuation — which is why value could rise whilst extent and condition fell. The **physical** precedents are more advanced than the monetary ones. An exploratory Italian account allocated 246 million overnight stays, 56.69 per cent of the 2019 national total, to nature-based tourism, whilst disclaiming official status for the result, [28] and the same architecture extended across the European Union attributed 1,560.38 million overnight stays, 58.1 per cent of all overnight stays in 2018, over eleven ecosystem types. [19] That classification is directly relevant here: it includes a coastal beaches, dunes and wetlands class crosswalked to the IUCN Global Ecosystem Typology, which is an implemented instance of the crosswalk recommended above. It is also where the precedent runs out for this Circular's purposes, since its coastal coverage is derived from land-cover classes and its authors identify marine ecosystems as an outstanding gap. No compilation reviewed here covers reefs or seagrass on the asset side and a Tourism Satellite Account aggregate on the economic side, so a marine destination attempting the pairing is extending the practice rather than following it, and should document its choices accordingly.

3.6 Worked example

¶1 This example **extends** the Country B coastal-tourism illustration in TG-3.3 Section 3.7 rather than re-deriving it from scratch. Country B has no Tourism Satellite Account, so it is a **Tier 2 (proxy)** case. The inputs are as follows:

- ¶2 coastal-district accommodation receipts of USD 120M;
- ¶3 arrivals cards indicating that 55 per cent of visitors cite beach or marine recreation as the primary purpose;
- ¶4 coastal food-service and local-transport receipts of USD 45M; and
- ¶5 licensed marine-recreation operators (diving, charters) reporting USD 8M.

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¶6 The proxy applies the single marine-purpose share to the setting-based categories and adds the wholly marine line:

Category	Coastal receipts (USD M)	Marine/coastal share	Marine tourism (USD M)
Accommodation (5510/5520)	120	0.55 (arrivals-card proxy)	66
Food and beverage serving (5610/5629/5630)	45 (with transport)	0.55	25
Marine recreation operators (9319/9329 add-on)	8	1.0 (wholly marine)	8
Total marine tourism contribution			**99**

¶7 In a **Tier 1** economy the same destination would instead start from the Tourism Satellite Account tourism ratio for each class to isolate the tourism part of output, then apply the marine and coastal share — measured on the same internal-tourism population (Section 3.3) — with sea and coastal passenger transport (ISIC 5011) and the licensed marine operators entering at 1.0, and reconcile the resulting tourism direct gross value added to the national accounts and the Tourism Satellite Account. Either way, the proxy assumptions — particularly the arrivals-card share and the receipts source — should be documented in compilation metadata so users can assess sensitivity, and the segment's recreation-service dependence read against the condition of the reef and seagrass assets in the destination's ecosystem register. A fuller synthetic application adding the greenhouse-gas, water and solid-waste flow accounts of Section 3.5 will be developed as those flow accounts mature.

4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

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5. References

1. ¶1 United Nations & World Tourism Organization (2008). *International Recommendations for Tourism Statistics 2008 (IRTS 2008)*. Statistical Papers, Series M No. 83/Rev.1. New York and Madrid. Visitor, tourist, same-day visitor, and usual environment: paras 2.9, 2.13, 2.21–2.25; forms of tourism (domestic, inbound, internal): paras 2.39–2.40; tourism as a demand-side phenomenon: para 1.1.
2. ¶2 TG-3.3 Economic Activity Relevant to the Ocean, Section 3.2 ("Operational decision rule for partially ocean-related activities"). The ~5 per cent of establishment output benchmark is described there as a pragmatic operational choice, not a value drawn from an external standard.
3. ¶3 United Nations (2008). *International Standard Industrial Classification of All Economic Activities, Rev.4 (ISIC Rev.4)*. Series M No. 4/Rev.4. Class 5011 (Sea and coastal passenger water transport) is defined by transport over seas and coastal waters; inland water passenger transport is class 5021.
4. ¶4 ISIC Rev.4, classes 9319 (Other sports activities) and 9329 (Other amusement and recreation activities n.e.c.); official scope notes confirm both are broad classes containing substantial non-marine activity.
5. ¶5 United Nations, World Tourism Organization, Eurostat & OECD (2008). *Tourism Satellite Account: Recommended Methodological Framework 2008 (TSA:RMF 2008)*. Studies in Methods, Series F No. 80/Rev.1. Tourism share: para 4.51; tourism ratio: para 4.56 (carried in Table 6). Travel agency, tour operator and reservation services are measured on a margin basis as a distinct tourism characteristic product.
6. ¶6 UN Statistical Commission, 54th session (2023) — adoption of ISIC Rev.5; 55th session (2024) — endorsement of explanatory notes and implementation plan, with national implementation expected from 2027. UNSD publishes an ISIC Rev.5–Rev.4 correspondence table.
7. ¶7 TSA:RMF 2008, paras 4.47 and 4.58–4.59 (derivation of tourism direct gross value added and tourism direct gross domestic product via the Table 6 reconciliation; TDGDP adds net taxes on tourism products), 4.81 (recommended-aggregates list) and 4.88–4.94 (definitions of TDGVA and TDGDP).
8. ¶8 TG-3.3 Economic Activity Relevant to the Ocean, Section 3.7 ("Simplified proxy method for countries without TSA infrastructure"), including the Country B worked mini-example extended in Section 3.6 here.

9. ¶9 TSA:RMF 2008, tourism characteristic products (water passenger transport: passenger line and ferry, cruise ship, yacht) and tourism specific fixed assets (para 2.47, e.g. cruise ships, marinas).
0. ¶10 IRTS 2008, paras 2.13 and 2.61–2.63 (classification of cruise passengers as visitors, generally same-day visitors/excursionists, with treatment conditional on applying residence and economic-territory concepts to the ship) and para 10.77 (cruise fares recorded in the travel item of the balance of payments). Consistent with BPM6.
1. ¶11 TSA:RMF 2008, Table 7 and paras 4.62–4.68: employment in the tourism industries is measured on an establishment basis; seasonality and informality are identified as the major measurement challenges; the tourism-attributable portion is obtained by applying the industry tourism ratio (para 4.64), which assumes the visitor-serving fraction of output has the same production function as total output. See also OECD/UN Tourism guidance on the Employment Module linking employment data to the TSA.
2. ¶12 SF-MST (2024), paras 3.33–3.34 and Tables 3.4–3.5. Para 3.33 defines tourism leakage as operating surplus generated from tourism activities that does not fully accrue to local economic units, sets out the preferred resident/non-resident split of gross value added, compensation of employees and gross operating surplus, offers establishment-ownership counts (Table 3.3) as the fallback indicator, and warns that indicators derived from Table 3.5 must be adjusted using the tourism ratio for each industry or industries with a relatively lower tourism ratio (food and beverage serving is the cited example) may inappropriately dominate aggregated results. Para 3.34 covers the imported-input channel and the related OECD trade-in-value-added work.
3. ¶13 TG-3.7 Governance Accounts, Section 3.3.5 "Compilable governance account tables": the environmental protection expenditure account adapted from SEEA CF Table 4.4 (SEEA CF paras 4.49–4.50, 4.85), and the governance revenue tables that record environmental taxes by tax base (Table 3.7.10a, following SEEA CF paras 4.148–4.155), rent on marine natural resources (Table 3.7.10b), and sales of marine administrative services (Table 3.7.10c). A visitor-paid conservation levy is not automatically a tax: marine protected area access and visitor fees are carried at Table 3.7.10c where the payer receives site access and facilities commensurate with the amount paid, and the three-way test at TG-3.7 Section 3.3.5 governs the classification. That Circular also sets the rule that governance revenue and governance expenditure are recorded gross and are never netted, which is the accounting counterpart of the misconception noted above. Coastal and marine tourism also appears there under COFOG 04.7.3.
4. ¶14 UN Tourism (formerly UNWTO) & United Nations Statistics Division (2024). *Statistical Framework for Measuring the Sustainability of Tourism (SF-MST)*, adopted by the UN Statistical Commission at its 55th session (2024). Tourism–environment connection: paras 4.1–4.6.
5. ¶15 SF-MST (2024), paras 4.99–4.107: recreation-related ecosystem services defined following the SEEA Ecosystem Accounting (a final service to the visitor); carrying capacity (para 4.103); trade-offs with non-tourism ecosystem services such as coastal protection and water purification (para 4.106). See also SEEA Ecosystem Accounting (United Nations et al., 2021), Chapter 6.
6. ¶16 SF-MST (2024), para 6.50: "SF-MST does not inherently establish relevant thresholds since these will vary by location and over time", whilst noting that its concepts and definitions can be used to describe thresholds and to monitor whether they are being approached or passed. Read with para 4.103, which recommends the comparison of total recreation-related services to measures of ecosystem carrying capacity and holds that the carrying-capacity measure should consider both the number of visitors and the change in condition of the ecosystem.
7. ¶17 SF-MST (2024), paras 4.82–4.94: tourism-related ecosystem asset register and regional ecosystem extent and condition accounts, including marine areas, with national classifications cross-walked to the IUCN Global Ecosystem Typology (paras 4.84, 4.86); para 4.89 – SF-MST does not recommend partitioning ecosystems or deriving a tourism share of an ecosystem asset.
8. ¶18 SF-MST (2024), para 4.93: ecosystem condition characteristics should cover the six classes of the SEEA EA ecosystem condition typology (ECT).
9. ¶19 Zulian, G., La Notte, A., Grammatikopoulou, I. and Zurbaran Nucci, M. (2024). *Nature-Based Tourism Accounting*. EUR 32029. Publications Office of the European Union, Luxembourg. JRC138538. https://doi.org/10.2760/762803 (https://doi.org/10.2760/762803). Nature-based tourism is one of the services EU Member States are required to quantify under the amended Regulation (EU) No 691/2011. At EU level in 2018, 1,560.38 million overnight stays (58.1 per cent of all overnight stays) allocated to nature-based tourism across the eleven ecosystem types of Table 9, whose coastal beaches, dunes and wetlands class integrates the IUCN Global Ecosystem Typology. Major fires in 2018 reduced service use by 1.82 per cent, Portugal most affected at 15.9 per cent; burnt areas enter by exclusion from service-providing areas in the recreation opportunity map rather than through a condition account. Aggregating the same tourism statistics at NUTS 3 rather than NUTS 2 changes service use by 0.89 per cent. Marine ecosystems are identified as an outstanding gap.
0. ¶20 TG-2.4 Environmental (including Ecosystem) Goods and Services, Section 3.10.1 (exchange value versus welfare value, and the SNA production boundary) and Section 3.10.5 (methods inappropriate for accounts, including consumer surplus measures and directly applied stated preference results). TG-1.9 Safe Usage of Monetary Valuation Section 3.3 states the same distinction in summary for decision-makers.
1. ¶21 SF-MST (2024), Section 4.2 and Tables 4.1–4.6 (tourism GHG emissions, solid waste, water and energy flow accounts), and Section 4.6 (para 4.161): only the tourism share of an environmental flow is included – in contrast to the whole-asset treatment of ecosystems in paras 4.79/4.89.
2. ¶22 SF-MST (2024), paras 4.143–4.145 (Annex 4.1). Para 4.144 recommends estimating the tourism share from physical factors specific to the activity (the example given is passenger kilometres and fuel volumes for energy use in passenger transport). Para 4.145 applies only "in the absence of directly collected data or modelled estimates" and computes the flow at industry level before applying the industry tourism output ratio, that ratio being an industry's output sold to visitors divided by its total output, generally via a TSA following TSA:RMF 2008 Table 6. The by-construction identity noted in the text is a corollary of para 4.145 and is not stated in the framework.

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3. ¶23 SF-MST (2024), para 4.79 (no tourism share of environmental assets; the contribution tourism activity makes to changes in an environmental asset may be determined but must not be interpreted as a share of the asset itself), para 4.74 (combining stock data on the quality of ecosystem assets with flow data on pollutants and emissions, with measurement concentrated in locations where the issue is apparent and potentially attributable to tourism rather than compiled across the whole country), paras 4.71–4.73 (pairing emissions to water with water quality in coastal and marine areas, recorded through an ecosystem condition account), and Annex 4.1 (paras 4.143–4.145) on the attribution of environmental flows to tourism.
4. ¶24 Turpie, J.K., Letley, G.K., Weiss, J. and Schmidt, K. (2022). Accounting for ecosystem services and asset value: pilot accounts for KwaZulu-Natal, South Africa, 2005–2011. *One Ecosystem* 7: e86392. https://doi.org/10.3897/oneeco.7.e86392 (https://doi.org/10.3897/oneeco.7.e86392). Nature-based tourism valued as the direct value added from domestic and international tourism expenditure as reflected in the national accounts, with resource rent estimated using ratios from the South African Tourism Satellite Accounts and spatially allocated by photo-user density using the InVEST Recreation Model. The quoted statements on value increasing despite declining extent and condition, and on the outstanding counterfactual, are the authors' own.
5. ¶25 Laimer, P. and Weiss, J. (2016). *Pilot Study "Measuring Sustainable Tourism" (MST) Austria*. Statistics Austria, Vienna, for the World Tourism Organization. The study holds that benchmarking with fixed quantitative target values for each indicator is not possible, that sustainability and its measurement is a regional phenomenon for which evaluation at higher aggregated national levels is not feasible given regional heterogeneity, and calls on regional policy-makers to establish target values.
6. ¶26 SF-MST (2024), para 4.107, and SEEA Ecosystem Accounting Chapters 9–11 (monetary valuation, recommendation rather than standard status): monetary ecosystem-service values are complementary to, and must not be summed with, tourism direct gross value added.
7. ¶27 Bartolini, A., Di Gennaro, V., Reas, V., Mascolo, R.A., La Notte, A., Capriolo, A. and Ferrini, S. (2024). Ecosystem accounting for marine-based tourism provided by *Posidonia oceanica* in Italy. *One Ecosystem* 9: e129751. https://doi.org/10.3897/oneeco.9.e129751 (https://doi.org/10.3897/oneeco.9.e129751). Condition proxied by shoot density (shoots/m²), with nitrogen and phosphorus concentrations as anthropogenic pressure proxies; no separate condition account table constructed; monetary results of EUR 6.1 million (2019) and EUR 3.7 million (2021), derived by applying travel cost as a price proxy to *Posidonia*-dependent arrivals and reported as exchange values. No Tourism Satellite Account aggregate is compiled.
8. ¶28 Zulian, G. and La Notte, A. (2022). How to account for nature-based tourism in Europe. An operational proposal. *One Ecosystem* 7: e89312. https://doi.org/10.3897/oneeco.7.e89312 (https://doi.org/10.3897/oneeco.7.e89312). Exploratory SEEA EA supply and use account for Italy on Corine Land Cover Level 1 classes, compiled at national, NUTS 2, provincial and municipal scales; 56.69 per cent (246 million) of 2019 overnight stays allocated to nature-based tourism. Wholly physical — no monetary valuation. The authors state that the results are not intended to be used in any official documents or national statistics.

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Ocean Accounting for Nature-based Solutions

Provides technical guidance for accounting for nature-based solutions as deliberate interventions across their full lifecycle, and for comparing them with engineered alternatives.

Version 0.2.1 **Status** Draft **Stability** Emerging

Last updated September 2026 **Responsible officer** Dr Jordan Gacutan

Drafting AI-assisted drafting from GOAP Secretariat source materials; source list to be published at the close of consultation.

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OUTCOME

TG-2.4 Environmental (including Ecosystem) Goods and Services Section 3.10.5 prohibits valuing an ecosystem asset at restoration cost, on the grounds that doing so "would make it impossible to separately assess the benefits of ecosystem restoration: they would by definition equal the costs." The Technical Guidance therefore protects the separation between what an intervention cost and what it achieved, and nowhere sets out how to measure the second. This Circular does.
Its unit is the intervention. TG-6.11 Coastal Infrastructure Accounting records the structures built on a coast and values them as produced assets. The question here is different: an agency has decided to spend public or blended money on an ecosystem, in the expectation of a return. What must the accounting system record, over what horizon, against what counterfactual, and what must it publish so the decision can be defended, compared against an engineered alternative, and audited later?
Upon completing this guidance, practitioners will be able to:

- Determine whether an intervention qualifies as a nature-based solution (NbS) for accounting purposes, and record that determination auditably
- Route a single intervention to its entry points across expenditure, produced asset, ecosystem asset, ecosystem service and social accounts without double counting
- Select a counterfactual tier appropriate to available data, applying the designs in TG-1.3 Marine Spatial Management to the harder restoration case
- Record benefit lag, survival probability and reversal in the monetary ecosystem asset account
- Compile the full lifecycle cost of an intervention, including opportunity and non-market stewardship costs
- Compare nature-based, engineered and hybrid options on equivalent service units
- Publish the metadata a user needs to construct a risk-adjusted figure for themselves

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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1. Outcome

¶1 **TG-2.4 Environmental (including Ecosystem) Goods and Services** Section 3.10.5 prohibits valuing an ecosystem asset at restoration cost, on the grounds that doing so "would make it impossible to separately assess the benefits of ecosystem restoration: they would by definition equal the costs."[1] The Technical Guidance therefore protects the separation between what an intervention cost and what it achieved, and nowhere sets out how to measure the second. This Circular does.

¶2 Its unit is the intervention. **TG-6.11 Coastal Infrastructure Accounting** records the structures built on a coast and values them as produced assets. The question here is different: an agency has decided to spend public or blended money on an ecosystem, in the expectation of a return. What must the accounting system record, over what horizon, against what counterfactual, and what must it publish so the decision can be defended, compared against an engineered alternative, and audited later?

¶3 Upon completing this guidance, practitioners will be able to:

- ¶4 Determine whether an intervention qualifies as a nature-based solution (NbS) for accounting purposes, and record that determination auditably
- ¶5 Route a single intervention to its entry points across expenditure, produced asset, ecosystem asset, ecosystem service and social accounts without double counting
- ¶6 Select a counterfactual tier appropriate to available data, applying the designs in **TG-1.3 Marine Spatial Management** to the harder restoration case
- ¶7 Record benefit lag, survival probability and reversal in the monetary ecosystem asset account
- ¶8 Compile the full lifecycle cost of an intervention, including opportunity and non-market stewardship costs
- ¶9 Compare nature-based, engineered and hybrid options on equivalent service units
- ¶10 Publish the metadata a user needs to construct a risk-adjusted figure for themselves

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1.1 Decision Use Cases

¶1 Coastal protection portfolio choice; national adaptation planning and Nationally Determined Contribution reporting; Kunming-Montreal Global Biodiversity Framework Targets 2 and 3; blue bond and blue carbon due diligence; public investment appraisal and budget classification; disaster risk reduction programming; and the design of offsets and compensation under environmental impact assessment.

1.2 Upward Connections

¶1 **TG-1.1 National Ocean Budgets**, **TG-1.4 Sustainable Ocean Planning**, **TG-1.6 Environmental Impact Assessment**, **TG-1.8 Project-Level Finance**, **TG-2.6 Ocean-related Investment** and **TG-2.9 Disaster Risk Indicators**.

¶2 ⓘ **Framework Position**

¶3 This Circular owns the accounting treatment of **nature-based solutions as an intervention class**: the eligibility test, the six-entry ledger a single intervention generates, counterfactual and additionality tiers, survival and lag, permanence and reversal risk, full lifecycle cost, and the layered method for comparing nature-based, engineered and hybrid options.

¶4 It cross-refers for the ecosystem asset and service accounts an intervention changes (**TG-3.1** and the ecosystem circulars **TG-6.1**, **TG-6.2**, **TG-6.3**), the produced-asset cost stream it is compared against (**TG-6.11**), valuation principles (**TG-1.9**) and the financing instruments themselves (**TG-1.8**, **TG-2.6**).

¶5 The distinction from **TG-6.11** is deliberate and the two may classify the same item differently: TG-6.11's typology classifies a structure for recording, whereas the eligibility test at Section 3.1 decides whether an intervention enters this ledger. Both positions hold, and Section 3.1 states where they diverge.

2. Requirements

¶1 This Circular assumes the foundational concepts in **TG-0.1 General Introduction**, the asset framework in **TG-3.1 Asset Accounts**, and the ecosystem services framework in **TG-2.4 Environmental (including Ecosystem) Goods and Services**.

2.1 Data Requirements

¶1 An intervention register recording site, area, date, technique, cost, implementing entity and land or sea tenure; the pre-intervention state of the ecosystem; a counterfactual or control; a time series of extent and condition; survival and failure monitoring; expenditure records split between capital and recurrent; service-flow indicators; and a mapping of beneficiaries.

2.2 Classification Frameworks

¶1 The IUCN categories of NbS approach (Section 3.1.3) and the IUCN Global Standard criteria (Section 3.1.4); the Classification of Environmental Protection Activities (CEPA) and the Classification of Resource Management Activities (CReMA); the Classification of the Functions of Government (COFOG), for which the primary-purpose rule distinguishing coastal protection under Group 05.6 from transport infrastructure under Division 04 is set out at TG-6.11 footnote 67 and is not restated here; the IUCN Global Ecosystem Typology; and the restoration, rehabilitation and reclamation distinctions at TG-6.11 Section 3.4.2.

¶2 **Readiness and sequencing.** Whether a country is positioned to compile this account at all — mandate, data architecture, capacity and the order in which to build — is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 Concepts stated in TG-6.11 are cross-referenced, not summarised, so that each concept has one statement across the two Circulars.

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3.1 What Counts as a Nature-based Solution

3.1.1 Definitions

¶1 The first multilaterally agreed definition is United Nations Environment Assembly resolution 5/5 (2022), which defines nature-based solutions as:

> *"actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits."*[2]

¶2 The IUCN Global Standard (2020), operationalising IUCN Resolution WCC-2016-Res-069, defines them as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."[3]

¶3 Four points of convergence run across the institutional definitions, including those of IUCN, UNEA, the World Bank and the OECD. An NbS must involve ecosystem actions, deliver multiple benefits, link human wellbeing to biodiversity outcomes, and provide measurable ecosystem services.[4]

¶4 ⚠ **Biodiversity is a necessary condition**

¶5 All post-2020 definitions treat biodiversity benefit as a necessary condition and not an optional co-benefit. An intervention that delivers a regulating service whilst degrading biodiversity does not satisfy the definition, however favourable its service account appears. Compilers should record the biodiversity outcome alongside the service outcome, and should not net the two.

3.1.2 Distinguishing NbS from adjacent categories

¶1 TG-6.11 Section 1 defines grey, green and blue infrastructure, and that vocabulary is inherited here without restatement. TG-6.11 Section 3.4.2 sets out the restoration, rehabilitation and reclamation distinctions, which turn on whether the objective is pre-existing structure and function, functionality for service supply, or a useful state. Table 3.1.2 records only the distinctions those sources do not carry.

¶2 **Table 3.1.2: Categories adjacent to NbS, and their accounting consequence**

Category	Relationship to NbS	Accounting consequence
Ecosystem-based adaptation	A subset of NbS, defined by the challenge addressed	Recorded as an NbS; also enters adaptation investment tracking at TG-6.11 Section 3.5.2. The two entries are not additive
Blue or green infrastructure	Overlapping but not identical. An item may be blue infrastructure without satisfying the instrumental test at Section 3.1.4	Classified for recording under TG-6.11; eligibility for this Circular's ledger is decided separately
Biodiversity offset	May be delivered through an NbS, but is compensatory, not additive, at the landscape scale	The counterfactual differs: an offset is measured against a permitted loss, not against a no-intervention baseline. See TG-1.6
Co-benefit activity	Not an NbS	Expenditure is recorded; no attributable ecosystem enhancement arises from the activity itself

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3.1.3 A typology for accounting

¶1 Two axes are used, and an ownership mapping. The typology below is adopted, not devised here.

¶2 **The primary axis** is the five categories of NbS approach set out by Cohen-Shacham et al. (2016), which group interventions by their primary ecological approach.[5] Each category carries a distinct accounting consequence, which is what earns the axis its place here.

¶3 **Table 3.1.3: Categories of NbS approach, and their accounting consequence**

Category of NbS approach	Examples	Accounting consequence
Ecosystem restoration approaches	Ecological restoration; ecological engineering; forest landscape restoration	Empirical net gain, measurable against a pre-intervention baseline. Ecological engineering is where this category meets the hybrid attribution rule at TG-6.11 Section 3.4.1
Issue-specific ecosystem-related approaches	Ecosystem-based adaptation; ecosystem-based mitigation; climate adaptation services; ecosystem-based disaster risk reduction	Defined by the societal challenge rather than by the intervention, so the category cuts across the others. Interfaces with **TG-2.8 Climate Change Indicators** and TG-2.9
Infrastructure-related approaches	Natural infrastructure; green infrastructure	Produced-asset components arise, and the TG-6.11 hybrid attribution rule is engaged

Category of NbS approach	Examples	Accounting consequence
Ecosystem-based management approaches	Integrated coastal zone management; integrated water resources management	A change in management regime rather than in the asset. Frequently catchment-to-coast, so **TG-6.13 Freshwater-Marine Interaction** applies
Ecosystem protection approaches	Area-based conservation approaches including protected area management	Avoided loss against a modelled counterfactual, never empirical gain. TG-1.3 owns effectiveness measurement

¶4 **The second axis** is intensity of ecosystem management, which predicts which entry points at Section 3.2 an intervention will touch: Type 1 conservation and monitoring, Type 2 restoration and rehabilitation, and Type 3 creation and engineering.[6] The two axes are not redundant, since a single IUCN category can contain interventions of differing intensity.

¶5 **The ownership mapping** is a lookup, not a typology. It records which thematic Circular owns the ecosystem an intervention acts on: shoreline protection to TG-6.11 and **TG-6.2 Mangrove and Coastal Wetland Accounting**; habitat and fisheries to TG-6.2, **TG-6.3 Seagrass** and **TG-6.7 Fisheries Accounting**; carbon to TG-2.8; land-sea interaction to TG-6.13; productive systems to **TG-3.9 Aquaculture Accounts** and **TG-6.8 Aquaculture Thematic Methods**; and nature-positive built development to **TG-6.9 Offshore Energy**, **TG-6.10 Maritime Transport and Ports** and TG-6.11.

3.1.4 The eligibility screen

¶1 Eligibility turns on one question of mechanism.

> *Does an ecosystem process provide the primary functional mechanism addressing the challenge?*

¶2 An intervention passes where the ecosystem or ecological process is the primary mechanism, such that removing the ecosystem causes the solution to stop working. An activity relying on a non-ecological primary mechanism is a co-benefit activity: nature may supply the setting or an ancillary value, but not the solution.[7]

¶3 Wetland restoration for flood regulation passes, because water absorption and flow attenuation are ecosystem processes. Ecotourism in a wetland does not, because the primary mechanism is a business model and the ecosystem is the attraction. The distinction has a direct accounting consequence: an activity that fails the test is not routed through the ledger at Section 3.2. Its expenditure is recorded, whilst no attributable ecosystem enhancement arises from it, and treating it as an NbS would overstate the intervention's ecosystem effect.

¶4 The test is auditable in a way an eight-criteria design standard is not, since it turns on a single factual question. The IUCN Global Standard is retained as a secondary quality screen recorded in compilation metadata: design quality and account eligibility are different questions, and the Standard governs the first.[8]

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¶5 **For the implementer's consideration**

¶6 Adopting mechanism as the eligibility screen is a position this Circular takes, and not a requirement of any statistical standard. Neither the SEEA EA nor the UNEA definition supplies an operational test, and an implementer may reasonably conclude that a different screen suits their institutional setting: the full eight IUCN criteria where an NbS register must also serve programme quality assurance, or a broader screen where the accounting purpose is to capture all nature-related expenditure irrespective of mechanism.

¶7 Two consequences are worth weighing before departing from the test. A broader screen admits activities with expenditure but no attributable enhancement, so the ratio of spend to recorded ecosystem outcome will fall for reasons that are definitional rather than substantive. A narrower or quality-based screen excludes interventions that are delivering ecosystem outcomes but were not well designed, which understates the ecosystem effect of the portfolio. Whichever screen is applied should be recorded in compilation metadata and held constant across periods, since a changed screen breaks the time series more thoroughly than a changed valuation method.

¶8 **Where this Circular and TG-6.11 may classify differently**

¶9 TG-6.11 treats beach nourishment as blue infrastructure. Under the instrumental test a nourishment scheme may fail, because the mechanism is placed sediment rather than an ecosystem process. Both positions hold: the eligibility test here is narrower than the infrastructure typology at TG-6.11, and an item can be blue infrastructure without being an NbS. The classification decision tree at TG-6.11 Figure 6.11.1 classifies a structure for recording, whilst the test above decides whether an intervention enters this Circular's ledger.

3.2 The NbS Ledger

¶1 A single intervention generates entries in up to six places, recorded in parallel, not in sequence.

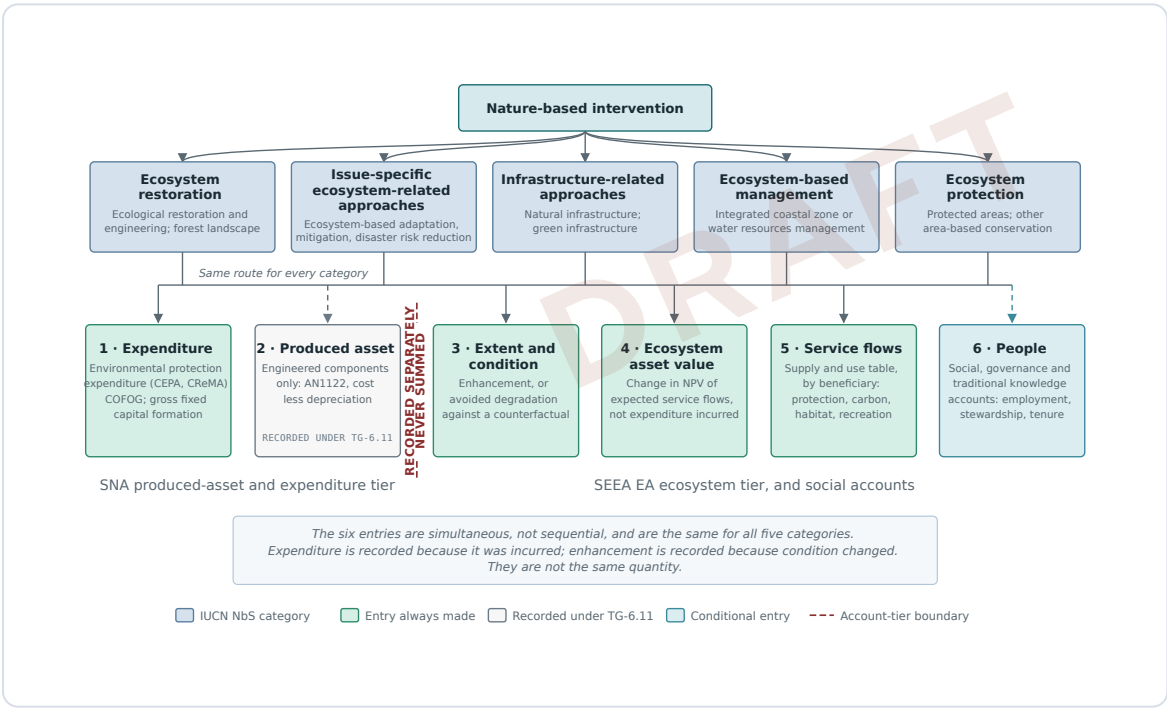


Figure 6.15.1 Five IUCN categories of NbS approach, all routed to the same six account entry points and recorded in parallel. The categories are restoration, issue-specific ecosystem-related, infrastructure-related, management and protection approaches. The produced-asset entry belongs to TG-6.11 and is separated from the ecosystem entries by a non-summation boundary. Dashed edges mark entries made only where the relevant component is present.

Source: Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) (2016). *Nature-based Solutions to address global societal challenges.* Gland: IUCN, Table 4, p. 10 (categories and examples of NbS approaches); SEEA EA (2021), Chapter 5 (extent and condition accounts), Chapter 7 (supply and use), Chapter 10, para. 10.15 (ecosystem enhancement) and paras 10.44--10.51 (net present value); SEEA Central Framework (2012), Chapter 4 (environmental protection expenditure) and Chapter 5; SNA 2025, Chapter 11, para. 11.85 (AN1122 other structures).

Note: The categories are not mutually exclusive and a single intervention may sit in more than one; the routing does not depend on which is chosen. Entry 2 is shown to place it within the routing and is compiled under TG-6.11, not under this Circular. Expenditure and enhancement are distinct quantities and no relationship between their magnitudes should be assumed.

3.2.1 The routing rule

¶1 **Table 3.2.1: Entry points for a single intervention**

Entry point	Account	What is recorded
1. Expenditure	Environmental protection expenditure (CEPA, CReMA); COFOG; gross fixed capital formation	Capital and recurrent outlay
2. Produced asset	Produced asset account (TG-3.1, TG-6.11)	Engineered components, AN1122, at cost less depreciation. Entered only where such components exist
3. Extent and condition	Ecosystem extent and condition accounts	Enhancement, or avoided degradation, attributable to the intervention
4. Ecosystem asset value	Monetary ecosystem asset account	The change in net present value of expected service flows
5. Service flows	Ecosystem service supply and use tables	Protection, carbon, habitat and recreation flows, by beneficiary
6. People	Social, governance and traditional knowledge accounts	Employment, stewardship labour and tenure change, where these arise

¶2 Entry 2 is compiled under TG-6.11 and appears here only to place it within the routing. The produced-asset and ecosystem-asset entries are recorded in separate account tiers and are never summed, although they may be presented together in an integrated asset table.

3.2.2 Expenditure is not enhancement

¶1 The SEEA EA defines ecosystem enhancement as "the increase in the value of an ecosystem asset over an accounting period that is associated with an improvement in the condition of the asset during that accounting period."[9] Enhancement is therefore measured through the change in the net present value of expected service flows, and not as the expenditure incurred. The SEEA EA is explicit that there should be "no prior expectations regarding the results of such a comparison" between the two.[10]

¶2 Both are recorded, and neither substitutes for the other. Expenditure is recorded because it was incurred, and enhancement because condition changed. An intervention may spend heavily and enhance little, which is a finding and not an error, and it is the finding TG-2.4 Section 3.10.5 exists to keep visible.

3.2.3 Attributing extent and condition change

¶1 The rule for attributing change is established, and is applied here without restatement. Extent accounts attribute every addition and reduction by cause, distinguishing managed change arising from direct human activity from unmanaged change arising from natural processes.[11] Condition change is attributed on the same basis, and where causality cannot be reliably attributed compilers should not attempt to disaggregate the change: the total should be recorded without attribution and the limitation documented in account metadata.[12]

¶2 For an intervention, the managed share is the quantity of interest, and the counterfactual machinery at Section 3.3 is what separates it from ambient change.

3.2.4 Avoided degradation

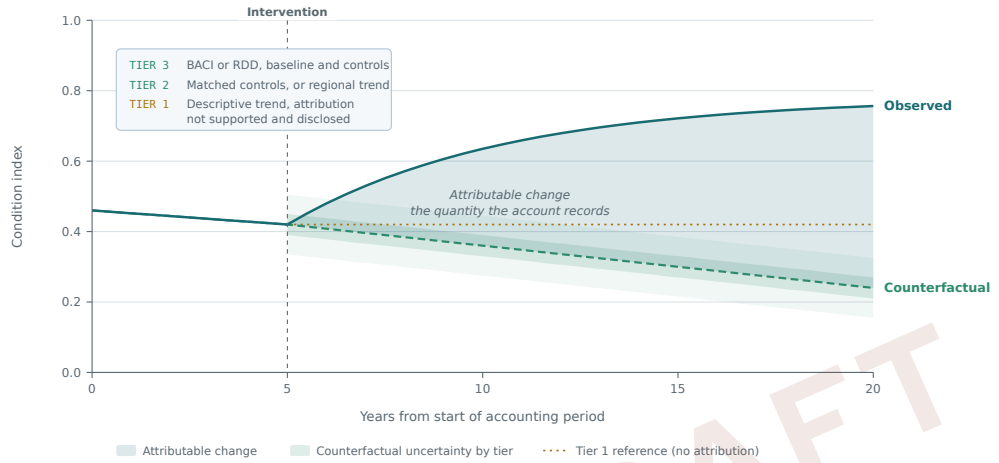
¶1 Type 1 conservation interventions and ecosystem protection approaches produce avoided loss rather than empirical gain. This is the hardest case in the ledger, because a successful intervention may leave the observed state unchanged: the benefit is the difference between the observed state and a decline that did not occur.

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¶2 Avoided degradation is a recordable outcome, and it requires a modelled counterfactual, not an observed one. The method is at Section 3.3.4, since it depends entirely on the counterfactual construction and cannot be separated from it.

3.3 Baselines, Counterfactuals and Additionality

¶1 Counterfactual design is established in the Technical Guidance and is not re-derived here. TG-1.3 Section 3.4.3 specifies control-site selection, before-after-control-impact (BACI) designs, matching-based approaches and regression discontinuity designs, together with the instruction that where no design is feasible compilers should report descriptive condition trends with an explicit caveat that causal attribution is not supported.[13] This section covers only what is specific to an intervention.



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Figure 6.15.2 Observed against counterfactual condition, with the attributable change shaded. Only the gap between what monitoring reports and what condition would have done anyway is attributable. On the illustrative values: a site at 0.42 when the intervention begins in year 5 reaches 0.76 by year 20, an observed gain of 0.34, but the counterfactual declines to 0.24, so 0.52 is attributable -- the difference is loss averted. The tiers set how tightly the counterfactual can be pinned down: Tier 3 (pre-intervention baseline and matched controls) narrows it, Tier 2 (controls or a regional trend alone) widens it, and Tier 1 substitutes a flat reference at the pre-intervention value, with attribution disclaimed.

Source: TG-1.3, Section 3.4.3 (counterfactual designs: control-site selection, before-after-control-impact, matching, regression discontinuity) and Section 3.4.1 (attribution, and the treatment of change that cannot be attributed); TG-0.7, Section 3.8 (tiered implementation frameworks).

Note: Tier designations are GOAP conventions under TG-0.7, Section 3.8, where Tier 1 is the minimum viable approach and higher tiers are more rigorous; they are not a SEEA EA construct, and are distinct from the valuation tiers in TG-1.3, Section 3.2.3, which run in the opposite order. Curve shapes and band widths are illustrative and are not parameterised for any ecosystem type.

3.3.1 The restoration counterfactual is harder than the protection counterfactual

¶1 An MPA counterfactual can draw on comparable unprotected sites, which usually exist. A restoration counterfactual requires a comparable *degraded and unrestored* site, and such sites are systematically scarce for a structural reason: sites are selected for restoration precisely because they are degraded, and often because they are the most degraded available. The pool of candidate controls is therefore biased by the same variable the design is trying to control for.

¶2 Three practical responses are available. A staged rollout across sites creates a natural experiment, where sites scheduled for later intervention serve as controls for earlier ones. Matched de-

graded sites can be drawn from a wider region, at the cost of weaker environmental comparability. A restoration-gradient design uses variation in intervention intensity across a single site, in place of a treated-untreated contrast.

3.3.2 Counterfactual tiers

¶1 Tiers follow the graduated convention used throughout the Technical Guidance, under which Tier 1 represents the minimum viable approach and higher tiers require greater data or capacity.[14]

¶2 **Table 3.3.2: Counterfactual tiers for intervention accounting**

Tier	Design	Applicability
Tier 3	BACI or regression discontinuity, with a pre-intervention baseline and matched controls	Where the intervention was monitored from before it began
Tier 2	Matched control sites without pre-intervention data, or a regional trend counterfactual	The common case for restoration
Tier 1	A documented descriptive trend, with causal attribution explicitly disclaimed	Minimum viable. The account must state that the attributable change is not established

¶3 The tier is not a presentational choice. It determines the width of the uncertainty band on the attributable change, and a Tier 1 account should not report an attributable change as a point estimate.

3.3.3 Establishment-phase attribution

¶1 During the years in which a benefit is still maturing, the intervention effect and ambient recovery are confounded. A site that would have partially recovered without intervention will show gains that are not wholly attributable, and the maturation profile at Section 3.4 means the intervention's own contribution is at its smallest in exactly the period when monitoring is most intensive.

¶2 Compilers should not report an attributable change over the establishment period alone. Where the accounting period falls inside that window, the change should be reported with the establishment status stated, and the counterfactual extended over the full maturation horizon before an attributable total is drawn.

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3.3.4 Restoration against protection, and the two additionality tests

¶1 Whether a benefit is verifiable at all turns on which limb the intervention sits in.

¶2 **Restoration** produces an empirical net gain. The intervention is measured at a later period and differenced against the baseline, so both terms are observed.

¶3 **Protection** produces avoided loss. The later term is a modelled expected state that never occurred, so the two limbs cannot share a method. A protection account is therefore only as good as its model, and the model's assumptions belong in compilation metadata alongside the result.

¶4 Both differ from additionality as used in crediting. TG-1.8 Section 3.4 records that crediting standards differ in their requirements for baseline setting, additionality demonstration, permanence buffers and leakage assessment.[15] Crediting additionality asks whether an activity would have happened without the revenue from credits, and its consequence is eligibility. Accounting additionality asks whether an observed change is attributable to the intervention, and its consequence is which account entry the change belongs in. An intervention can be attributable and not creditable, or creditable and only weakly attributable. The two tests should never be conflated, and a compiler asked for one should not supply the other.

3.4 Time, Lag and Survival

¶1 An intervention does not deliver its design capacity on the day it is completed, and it may never deliver it. Neither fact is currently reflected in ecosystem asset accounting, and both are material to the value recorded.

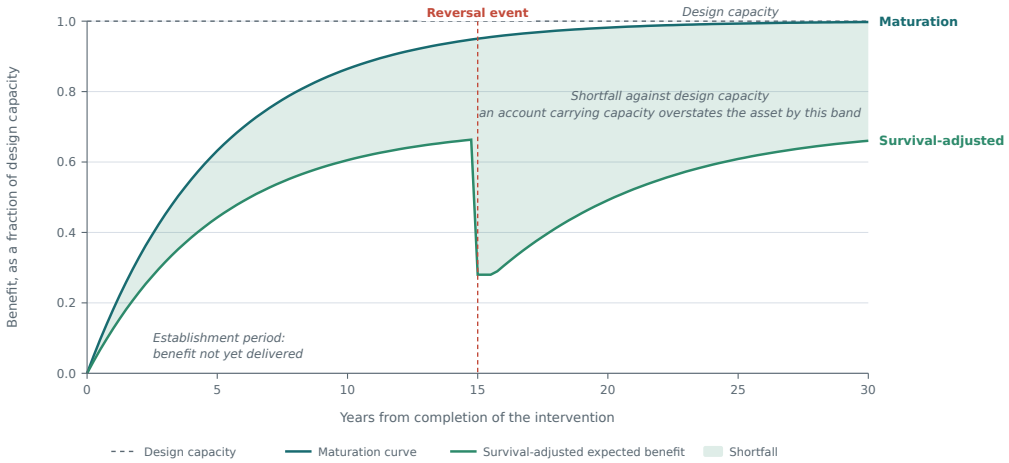


Figure 6.15.3 Design capacity, benefit maturation and survival-adjusted expected benefit over thirty years, with a reversal event at year fifteen. The shaded shortfall is the amount by which an account carrying design capacity overstates the ecosystem asset. For example, a mangrove planting designed to deliver 100 hectares of protective cover has reached 0.86 of that capacity ten years after completion; applying a survival probability of 0.70 to the maturation path gives an expected 61 hectares, so an account carrying the design capacity overstates the asset by 39 hectares in that year alone.

Source: Bayraktarov, E. et al. (2016), The cost and feasibility of marine coastal restoration, *Ecological Applications* 26(4), 1055--1074, for survival and failure rates by ecosystem type; SEEA EA (2021), Chapter 10, paras 10.44--10.51 (net present value of expected service flows).

Note: Curve shapes are illustrative and are not parameterised for any ecosystem type or intervention. Maturation periods, survival factors and recovery rates are to be drawn from the evidence note at drafting.

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3.4.1 Survival, and what the evidence supports

¶1 The largest synthesis of marine coastal restoration cost and feasibility covers 235 studies and 955 observations across coral reef, seagrass, mangrove, saltmarsh and oyster reef restoration, and records average survival of restored organisms alongside cost and project duration.[16] Median average survival by ecosystem, computed from that dataset, is set out in Table 3.4.1.

¶2 **Table 3.4.1: Median reported survival of restored organisms, by ecosystem**

Ecosystem	Observations	Observations reporting survival	Median average survival
Saltmarsh	133	35	75%
Mangrove	217	73	72%
Coral reef	286	17	56%
Oyster reef	126	21	54%
Seagrass	193	90	36%

¶3 Three cautions apply to any use of these figures.

¶4 Coverage is uneven. Survival is reported for between 6 and 47 per cent of observations depending on ecosystem, and the coral figure rests on 17 observations against 286 records. The coral

literature separately reports transplant and post-transplant survival, better populated at 77 and 87 observations with medians of 45 and 70 per cent, but these measure different stages and must not be pooled with each other or with the headline figure. Compilers using a coral survival rate should state which stage it refers to.

¶5 The distributions are wide. Reported survival spans zero to 100 per cent in every ecosystem, so a median is a central tendency across heterogeneous techniques, sites and monitoring periods, and not a design expectation for any particular project.

¶6 Survival is not permanence. These figures describe the survival of restored organisms over project monitoring periods, whose reported median duration is one to three years. They do not describe persistence over an asset life, which is the subject of Section 3.5.

3.4.2 Recording expected rather than design benefit

¶1 The quantity the monetary ecosystem asset account should carry is the expected delivered benefit, not the design capacity. Where a site-specific survival estimate exists it should be used. Where none exists, an ecosystem-level rate from Table 3.4.1 may be applied as a Tier 1 estimate, with the source and the coverage caution documented.

¶2

$$B_{expected} = B_{capacity} \times p_{survival} \times m(t)$$

¶3 where $p_{survival}$ is the probability of persistence and $m(t)$ is the maturation factor at time t, taking values between zero and one. A compiler applying no survival adjustment is implicitly setting $p_{survival}$ to one, which is not a neutral choice and overstates the asset.

3.4.3 Maturation

¶1 The evidence base for survival does not extend to maturation. The duration fields in the restoration cost synthesis record how long projects ran, not how long a benefit took to reach a stated fraction of design capacity, and no comparable cross-ecosystem synthesis of time-to-benefit is available.

¶2 Compilers should therefore treat the maturation profile as a documented assumption, not an evidenced parameter. Ecosystem-specific reviews give indicative establishment periods for coral, seagrass and mangrove systems and should be cited where used.[17] Where no defensible profile is available, the account should report the benefit as not yet established and should not interpolate one. The shortfall against design capacity belongs in the account, not absorbed into it.

3.4.4 Discounting, and the accounting period

¶1 Discount rate selection is governed by TG-1.9 Section 3.1.2, including its treatment of social against market rates, its fallback where no published social discount rate exists, and its requirement for sensitivity analysis across a plausible range.[18] No further guidance is offered here, and compilers should not adopt a different rate for NbS interventions than for other ecosystem assets in the same account.

¶2 A benefit arriving in year 12 does not enter the current period's service flow account. What enters is the change in the asset's net present value arising from the intervention, which reflects the expected future flow. The distinction matters where an intervention is completed and revalued in one period whilst delivering nothing measurable in it.

3.5 Permanence, Reversal and Risk

3.5.1 Loss events

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¶1 Restored and protected ecosystems can be lost. Tropical cyclones, marine heatwaves, disease outbreaks, dieback and encroachment all remove delivered benefit, sometimes in a single event, and the risk is not symmetric across the asset life: a young intervention is more vulnerable than a mature one.

¶2 The scale a compiler should plan for is not marginal. The 2015 dieback along the Gulf of Carpentaria killed of the order of 7,400 hectares of mangrove, some 6 per cent of the Gulf's mangrove extent, synchronously across roughly 2,000 kilometres of coastline, in conditions of extreme temperature, drought and a temporary decline in sea level associated with the 2015 to 2016 El Nino.[19] An event of that kind will exceed the extent of any restoration programme in the same region, which is why reversal is treated here as a recording problem for the ecosystem asset account and not as a project-level contingency.

3.5.2 Recording a reversal

¶1 The recording rule is established and is applied here. Change attributable to human activity is recorded as degradation, whilst change arising from natural processes is recorded in the other changes in volume account.[12] A cyclone destroying a restored mangrove is therefore an unmanaged reduction, and failure of the planting itself is not: the first is a volume change, the second a shortfall in the enhancement that was recorded.

¶2 The attribution carries a practical consequence. An account that records all reversal as degradation will misattribute climate-driven loss to management failure, and an account that records all reversal as an unmanaged volume change will conceal establishment failure. Where the cause cannot be reliably attributed, the total should be recorded without attribution and the limitation documented.

¶3 Catastrophic loss follows the general framework for unforeseen asset value changes in the national accounts.[20] This is the ecosystem-side counterpart of the stranded produced asset treated at TG-6.11 Section 3.5.1, and neither Circular repeats the other's mechanics.

3.5.3 Risk adjustment, and what the account publishes instead

¶1 Buffers are close to universal in NbS crediting, and are correct practice there. Verra's Verified Carbon Standard requires the AFOLU Non-Permanence Risk Tool, and VM0033, the methodology for tidal wetland and seagrass restoration, requires the current version of that tool including for erosion and submergence risk from sea level rise. Withholding percentages are set in the tool and adjusted periodically, and a project whose assessed risk exceeds the highest available percentage is ineligible for crediting.[21] Other standards operate comparable regimes, with some now admitting alternatives such as long-term conservation easements, transfer of reversal liability to a permanence trust, and cancellation of credits of negligible reversal risk.[22]

> ¶2 ⓘ **Why an account does not carry a buffer**
> ¶3 A buffer guarantees delivery to a buyer. An account has no buyer. Withholding a share of recorded enhancement against future reversal would embed a risk position in a statistical aggregate, and a buffer baked into an account cannot be removed by a user who needs the gross figure.

¶4 The ecosystem asset account therefore records the unadjusted value. In place of a buffer, the compiler publishes the parameters a user needs to construct their own adjustment. For each intervention and each service:

1. ¶5 the persistence or survival probability applied, or an explicit statement that none was;
2. ¶6 the maturation profile assumed, and its basis;
3. ¶7 the counterfactual tier under Section 3.3.2, with its uncertainty band;
4. ¶8 reversal events in the period, with the managed against unmanaged attribution at Section 3.5.2;
5. ¶9 the discount rate and the sensitivity range, per TG-1.9 Section 3.1.2;

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6. ¶10 the valuation method and its preference level under TG-2.4 Section 3.10.2, service by service.

¶11 A user holding those six can construct a buffered figure, a risk-adjusted figure or an insurance-priced figure. A user given only a buffered total can construct nothing. One compilation then serves the national accountant, the crediting user and an insurer, without the account taking a position that belongs to none of them.

¶12 The requirement sits inside existing practice, not beside it. **TG-0.7 Quality Assurance Principles** already requires scope, definitions, methods and assumptions to be documented, and supplies quality flags for account tables.[23] Where a risk-adjusted presentation is wanted for policy purposes, it belongs in a complementary presentation, following the treatment of welfare values in TG-1.9.

3.6 Full Lifecycle Cost

3.6.1 Cost over an asset life

¶1 An NbS cost is not its establishment cost. Recurrent maintenance, monitoring and adaptive management continue over decades, and the restoration cost synthesis distinguishes capital costs from operating costs covering maintenance, monitoring, and equipment repair and replacement.[16] Compilers should assemble the cost stream over the intended asset life, and where only capital cost is available should say so, and should not present it as a lifecycle figure.

¶2 Compilation cost is itself material, and constrains how many interventions a jurisdiction can account for and at what frequency. Australia's blue carbon programme committed AUD 30.6 million over 2021 to 2025 across on-ground restoration, project-level environmental-economic accounting and knowledge exchange, and awarded separate measurement and accounting contracts for five restoration sites.[24] Per-site compilation cost is not published, so compilers should budget from their own procurement and should record the cost of compilation alongside the cost of the intervention, since a jurisdiction that cannot afford to account annually will be reporting on a longer cycle than its interventions change.

¶3 The produced-asset side of a hybrid intervention is costed under TG-6.11 Sections 3.2.1 and 3.2.2, using the perpetual inventory method and its depreciation treatment.

3.6.2 Opportunity cost of space

¶1 An intervention occupies land or sea space that had, or could have had, another use. Foregone aquaculture production, foregone development value and lost access are costs of the intervention even where no transaction records them. Where tenure is contested the opportunity cost may be borne by parties who are not the implementing entity, which is a distributional question as well as a costing one.

3.6.3 Non-market and unpaid stewardship labour

¶1 Community monitoring, patrolling and locally managed enforcement are frequently the mechanism by which an intervention persists, and are frequently unpaid. The restoration cost synthesis records in-kind volunteer contributions and disaggregates funding across government, non-governmental organisation, private and volunteer sources, which provides a basis for estimating the share of intervention effort that sits outside market transactions.[16]

¶2 Treatment follows **TG-3.5 Social Accounts** for unpaid labour, **TG-2.3 Social and Livelihood Dependencies** for livelihood dependency, and **TG-4.4 Citizen Science and Community-Based Monitoring** for community monitoring as a data source. An account that omits this labour understates the cost of the intervention and, by omitting the contributors, misrepresents who produced the benefit.

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3.6.4 Transaction, safeguard and precondition costs

¶1 Free, prior and informed consent processes, safeguard design and grievance mechanisms carry real cost, treated under **TG-3.6 Traditional Knowledge**. So does the legal and tenure work that determines which interventions are feasible at all: tenure clarity frequently decides which intervention categories can proceed at a given site, and areas of contested tenure are commonly documented and excluded, not modelled. [6]

3.6.5 Why capital-cost comparisons mislead

¶1 Claims that nature-based options are cheaper than engineered ones often compare establishment cost against construction cost. That comparison omits the recurrent and monitoring cost of the nature-based option, the opportunity cost of the space it occupies, the unpaid labour sustaining it, and the survival probability discounting its delivered benefit. It also omits the maintenance cost of the engineered option, which cuts the other way. A lifecycle comparison on equivalent service units, as at Section 3.8, is the only form in which the question can be honestly put.

3.7 Multiple Benefits Without Double Counting

3.7.1 The benefit bundle

¶1 A single intervention typically produces several services. **Table 3.7.1** records the bundle by intervention type and the Circular that owns each service.

¶2 **Table 3.7.1: Benefit bundle and primary recording point**

Service	Mangrove or saltmarsh restoration	Seagrass restoration	Reef restoration	Catchment wetland	Primary recording point
Coastal protection	Yes	Partial	Yes	No	TG-6.2, TG-6.1; interface at TG-6.11 Section 3.3
Carbon retention and sequestration	Yes	Yes	Limited	Partial	TG-2.8 Section 3.2; TG-6.2 Section 3.3
Nursery and habitat	Yes	Yes	Yes	Partial	TG-6.2 Section 3.5; TG-6.3
Recreation and tourism	Partial	Limited	Yes	Partial	**TG-6.14 Marine and Coastal Tourism**
Water quality regulation	Partial	Partial	No	Yes	TG-6.13; **TG-2.7 Pollution and Other Flows**
Biodiversity	Yes	Yes	Yes	Yes	Extent and condition accounts; not a service flow

¶3 The protective service is the largest single item in several published assessments, which is relevant to Section 3.8: mangrove flood protection benefits have been estimated to exceed USD 65 billion annually, with some 15 million more people flooded each year in their absence, and coral reefs have been estimated to avert flood damages of the order of USD 4 billion annually, with expected damages roughly doubling in their absence. [25] These are global estimates produced for advocacy and prioritisation, not account entries, and TG-1.9's preference order governs whether any of them may enter an account.

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3.7.2 The recording protocol

¶1 Per-service rules are established across the thematic Circulars, and are assembled here without restatement. Each service is recorded once, in one place, for a given area.

¶2 TG-6.11 Section 3.3.2 states the rule for coastal protection from a mangrove area: the service should be recorded in one place only, with one Circular serving as the primary recording point and the other carrying a cross-reference. TG-6.2 Section 3.5 treats nursery services as intermediate services that must not be added to the fisheries production they support. TG-6.2 Section 3.3 records that reporting a carbon stock change and additionally applying a sequestration rate per hectare constitutes double counting. TG-6.3 treats sediment organic carbon as an asset attribute rather than a condition variable for the same reason, and sets a default for apportioning seagrass-attributable fisheries contribution. TG-6.1 excludes reef carbon stock from the net present value of annual service flows. TG-6.14 Section 3.4 records that a conservation levy is one transaction with two sides and must not be summed across them.

¶3 The general principle behind these rules is that the supply and use framework records each service flow once, and that intermediate services must not be added to the final services they support.[26] For an intervention spanning several ecosystems, the compiler applies each owning Circular's rule to its own service and records the routing in compilation metadata.

3.7.3 Method compatibility

¶1 Valuation method selection and compatibility are governed by TG-2.4 Section 3.10 and no separate treatment is offered here. Three of its rules bear directly on interventions. Replacement cost sits at preference level 5 in most ocean applications, because the replacement structure is hypothetical.[27] Restoration costs must not be used to value an ecosystem asset.[1] Stated preference estimates of total willingness to pay are not appropriate direct account entries.[28] Values derived from methods with different uncertainty characteristics should not be summed without documentation and sensitivity analysis.

3.7.4 Two cases the existing rules do not reach

¶1 **Benefits recorded in different periods.** Where an intervention's services mature at different rates, the same intervention will be recorded across several Circulars in different accounting periods. The routing metadata should therefore record the period in which each service was first recognised, so that a later compiler does not read the staggered entries as separate interventions.

¶2 **Upstream intervention, downstream benefit.** Where a catchment intervention improves the condition of a downstream marine ecosystem, the intervention and the benefit sit in different ecosystem types whose accounting units do not share a boundary. The service is recorded against the ecosystem that supplies it, which is the downstream unit, whilst the expenditure is recorded against the intervening entity. TG-6.13 governs the attribution, and the metadata must state it explicitly, since the alternative is either a service with no expenditure or an expenditure with no service.

3.7.5 Beneficiary attribution

¶1 Services are attributed to beneficiaries through the supply and use framework, and the distribution matters independently of the total. An intervention whose protective service accrues to a port authority and whose foregone access falls on a fishing community has a different distributional profile from one where both fall on the same population, even at identical net value. TG-3.5 and TG-2.3 govern the treatment.

3.8 Comparing Nature-based, Engineered and Hybrid Options

¶1 TG-6.11 Section 1.1 already identifies the comparison of engineered and nature-based protection options as a decision its asset accounts support. This section supplies the method for making that comparison, and is the point at which the two Circulars meet directly. TG-6.11 supplies the

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produced-asset cost stream, TG-1.9 the valuation methods, and Sections 3.4 to 3.6 above the risk-adjusted nature-based stream.

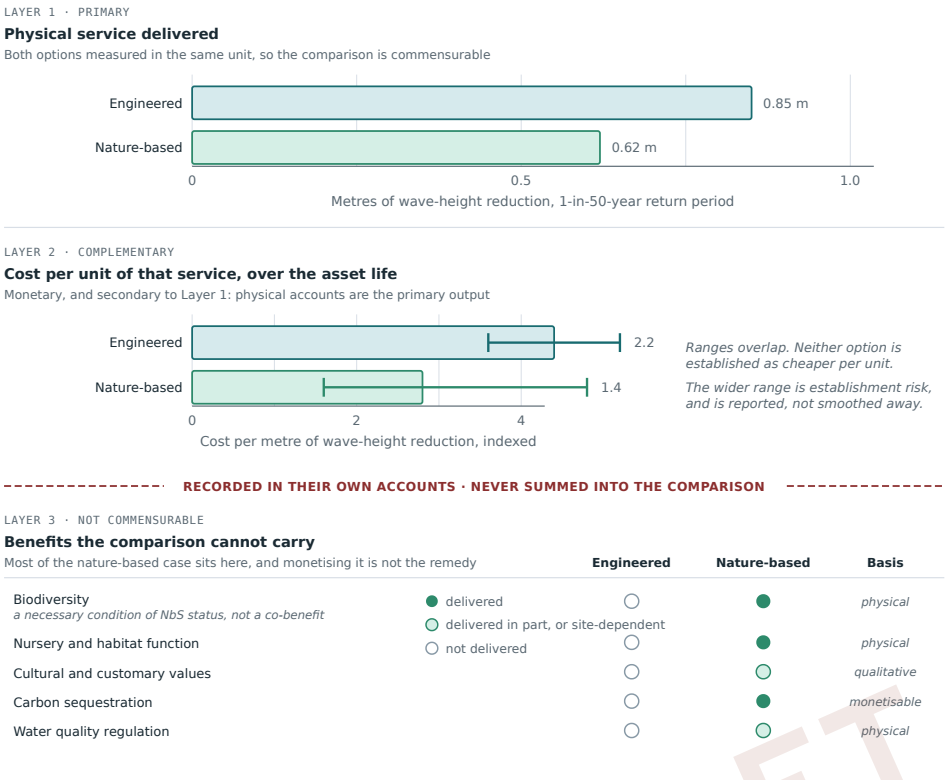


Figure 6.15.4 A three-layer comparison. Physical service delivered is the primary layer and the only commensurable one; cost per unit is complementary; the third layer holds benefits recorded in their own accounts and never summed into the comparison. The commensurable layers favour the engineered option, whilst most of the nature-based case sits in the layer the comparison cannot carry.

Source: TG-1.9, Section 3.2.1 ("Always compile and publish physical accounts. Consider monetary valuation as a complement, not a replacement, for physical measurement") and Section 3.2.3 (monetary values do not capture cultural values, equity, rights, or biodiversity intrinsic value); TG-2.4, Section 3.6 (physical accounts as the primary output); TG-6.11, Sections 3.2.1--3.2.2 (engineered cost stream); Narayan, S. et al. (2016), *PLoS ONE* 11(5), e0154735.

Note 1: Values are illustrative. The service unit must be stated on the axis, since a comparison that resolves cleanly is a signal the unit has been defined too loosely.

Note 2: Layer 3 is not a residual category to be monetised later. Several of its rows cannot enter an exchange-value account at all, and the method for integrating physical, monetary and qualitative evidence is the subject of TG-3.15, which is not yet available.

3.8.1 Physical service first

¶1 TG-1.9 Section 3.2.1 recommends that physical accounts always be compiled and published, with monetary valuation considered as a complement and not a replacement.[29] TG-2.4 Section 3.6 states the same, requiring physical accounts as the primary output.[30] A comparison expressed only as cost per unit therefore inverts the publication's own ordering, because it makes money the comparator.

¶2 The comparison is accordingly layered.

¶3 **Layer 1, primary.** The physical service each option delivers, both expressed in the same stated unit. For coastal protection this is a measure such as wave-height reduction at a stated return period. Both options are measured in the same unit, so this is the only fully commensurable layer.

¶4 **Layer 2, complementary.** Cost per unit of that physical service over the asset life, drawn from the produced-asset cost stream under TG-6.11 for the engineered option and from Sections 3.4 to 3.6 for the nature-based option, each with an uncertainty range.

¶5 **Layer 3, not commensurable.** Benefits that cannot enter the comparison, treated at Section 3.8.3.

¶6 The service unit must be stated on the face of the comparison. A comparison that resolves cleanly should be treated as a signal that the unit has been defined too loosely, since the published evidence is conditional rather than general: saltmarsh and mangrove defences have been found to be materially cheaper than a submerged breakwater for wave heights up to about half a metre, and to become more cost-effective at greater water depths, which is a result bounded by wave height and depth, not a general ranking. [31]

3.8.2 Building the comparison from account entries

¶1 The comparison uses figures the accounts already contain. From TG-6.11, the engineered option contributes its capital cost, depreciation profile and expected service life. From this Circular, the nature-based option contributes lifecycle cost under Section 3.6, survival-adjusted expected benefit under Section 3.4, and the counterfactual tier under Section 3.3.2, which sets the width of its range.

¶2 The nature-based range will usually be wider, because establishment risk and counterfactual uncertainty compound. That width is a result and should be reported. Where the ranges overlap, the correct statement is that neither option is established as cheaper per unit of service, not that the option with the lower central estimate wins.

3.8.3 What the comparison cannot carry

¶1 Most of the nature-based case sits outside Layers 1 and 2. TG-1.9 Section 3.2.3 records that monetary values from accounts do not capture all relevant considerations for decision-making, naming cultural values, equity, rights and biodiversity intrinsic value. [32] Biodiversity is, under Section 3.1.1, a necessary condition of NbS status, so the single most defining benefit of an NbS is one the commensurable comparison structurally cannot express.

¶2 The remedy is not to monetise it. Several of these benefits cannot enter an exchange-value account at all, and the methods that would force them in are the ones TG-2.4 Section 3.10.5 rules out. Layer 3 is therefore recorded in its own accounts, in physical or qualitative terms, with the measurement basis stated for each benefit, and is never summed into the cost-per-unit comparison. Summing across bases would mix exchange values with physical and qualitative measures and produce a total that means nothing.

> ¶3 ⓘ **For the implementer's consideration**
> ¶4 This Circular recommends against converting Layer 3 into weights, points or a composite index in order to make the layers addable. A composite reintroduces the incommensurability the layering exists to expose, and hides it better, since a single score carries no visible trace of the bases mixed to produce it. The integration of quantitative and qualitative evidence is the subject of TG-3.15, which is not yet available.
> ¶5 The recommendation is not a prohibition, and an implementer may face a decision process that will not accept three unreconciled layers. Multi-criteria decision analysis is an established appraisal technique, and a transparently weighted composite is preferable to an implicit weighting applied in the room. Where a composite is used, three safeguards keep it honest: publish the weights and their provenance, publish the layers unweighted alongside it, and treat the composite as an appraisal output and not an account entry, so it never re-enters the ecosystem asset account. The account itself carries the layers.

3.8.4 Presenting the comparison

¶1 A budget process requires the comparison in the form set out at TG-1.1, and an appraisal in the form set out at TG-1.6. In both cases the presentation should carry all three layers, the service unit,

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and the counterfactual tier. A comparison presented without its tier invites the reader to treat a Tier 1 estimate as a Tier 3 one.

3.9 Financing and Disclosure Interface

3.9.1 What the accounts supply

¶1 The instruments themselves are treated at TG-1.8 and TG-2.6. What a financing or insurance counterparty requires from the accounts is narrower: the physical service measure and its condition basis, the attributable change and its counterfactual tier, the lifecycle cost stream, and the six metadata items at Section 3.5.3. An account that supplies these supports due diligence without the compiler taking a view on the transaction.

3.9.2 Disclosure frameworks ask different questions

¶1 Alignment with the Taskforce on Nature-related Financial Disclosures and with IFRS S1 and S2 is treated at TG-1.11 and TG-6.11.[33] Compilers should note that the wider standards stack around an intervention, including the IUCN Global Standard, the SEEA EA, taxonomy screening criteria and national green finance taxonomies, asks different questions of the same intervention. Meeting one does not constitute meeting another, and an account should not be described as taxonomy-aligned on the strength of SEEA EA compliance.

3.9.3 Credit stacking and the account

¶1 TG-1.8 Section 3.4 raises the stacking of carbon credits with payments for other services.[15] The accounting risk is narrower and should be stated plainly: where a service is recorded as enhancement in a national ecosystem asset account and simultaneously sold as a credit, the same benefit supports two claims. The account should record the existence and coverage of any credit issuance over the accounting area, so that a user can identify the overlap. This is a metadata requirement, not a netting rule: the account does not deduct sold credits from recorded enhancement.

3.9.4 What the accounts cannot supply

¶1 Accounts establish the quantum. Whether it can be transacted is determined by legal and institutional preconditions that sit outside them, among them the definition of carbon rights, the legal enablement of payments for ecosystem services, operational protocols for free, prior and informed consent, and tenure clarity.[6] A Circular presenting accounts as sufficient for financing would mislead, and compilers asked whether an intervention is bankable should answer that the accounts inform the question without settling it.

3.10 Compilation Procedure

¶1 **Step 1: Build the intervention register.** Record site, area, date of completion, technique, implementing entity, funding sources, and land or sea tenure status. One row per intervention, with a stable identifier that later periods reuse.

¶2 **Step 2: Screen eligibility and classify.** Apply the instrumental test at Section 3.1.4 and record the determination with its reasoning. Classify by IUCN category and by intensity type (Section 3.1.3), and record the benefit bundle expected (Section 3.7.1). Record the IUCN Global Standard assessment, where one exists, as quality metadata.

¶3 **Step 3: Establish the baseline and select the counterfactual tier.** Compile the pre-intervention state. Select the highest tier the data support under Section 3.3.2 and record it, together with the control or model used. Where Tier 1 is the ceiling, record that attributable change is not established.

¶4 **Step 4: Assemble lifecycle cost.** Capital, recurrent, monitoring and adaptive management over the intended asset life; opportunity cost of space; non-market and unpaid stewardship labour;

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transaction, safeguard and precondition costs (Section 3.6).

¶5 **Step 5: Measure attributable extent and condition change.** Compile extent and condition following the owning thematic Circular's methods, and difference against the counterfactual, not against the baseline alone. Attribute managed and unmanaged change under Section 3.2.3. A compiler holding a two-period extent account, plot-based condition data and a protection-status stratification has what this step requires.

¶6 **Step 6: Apply survival and maturation, then value.** Adjust design capacity to expected delivered benefit under Section 3.4.2, documenting the survival source and the maturation assumption. Value service flows under TG-2.4 Section 3.10, recording the method and preference level for each.

¶7 **Step 7: Route the entries and run the double-counting check.** Post to each applicable entry point in Table 3.2.1. Confirm against Section 3.7.2 that each service is recorded once, and record the routing, including any staggered or upstream-downstream attribution under Section 3.7.4.

¶8 **Step 8: Assemble the combined presentation.** Bring the expenditure, produced asset, ecosystem asset, service flow and social entries into a single presentation following **TG-3.8 Combined Presentations**, with the account-tier boundary preserved.

¶9 **Step 9: Quality assurance and documentation.** Publish the six metadata items at Section 3.5.3. Apply the quality flags and uncertainty categories at TG-0.7, noting that ecosystem dynamics uncertainty and valuation uncertainty will usually dominate.

3.11 Illustrative Compilation

¶1 The illustration that follows is stylised. Figures are constructed to exercise the distinctions this Circular draws and are not drawn from any jurisdiction. Empirical application belongs in the Section 5 country case studies.

¶2 Three interventions in a single coastal accounting area, over a five-year accounting period.

¶3 **Intervention A, Type 2 restoration.** 400 ha of mangrove replanting for coastal protection, carbon and nursery habitat. Baseline and matched control sites available, so Tier 2.

¶4 **Intervention B, Type 1 protection.** 1,200 ha of existing mangrove brought under area-based protection, producing avoided loss against a modelled counterfactual of continued conversion. Tier 2, model-based.

¶5 **Intervention C, Type 3 creation.** A constructed wetland in the catchment, with engineered inlet works, reducing sediment load to a downstream seagrass meadow.

¶6 **Table 3.11.1: Intervention register extract**

	A: restoration	B: protection	C: creation
IUCN category	Ecosystem restoration	Ecosystem protection	Infrastructure-related
Intensity type	Type 2	Type 1	Type 3
Area	400 ha	1,200 ha	45 ha
Instrumental test	Pass	Pass	Pass
Counterfactual tier	Tier 2, matched controls	Tier 2, modelled	Tier 2, regional trend
Benefit form	Empirical net gain	Avoided loss	Empirical net gain, downstream
Produced-asset component	None	None	Inlet works, AN1122
Survival applied	72%, Table 3.4.1	Not applicable	Engineered; ecosystem component 75%

¶7 Three features of the routing are worth drawing out.

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¶8 **Intervention B posts nothing to entry point 3 as a gain.** Its extent is unchanged and its condition may be unchanged. What is recorded is the difference between observed extent and the modelled counterfactual, entered as avoided degradation with the model documented. An account that recorded zero would report a successful intervention as having achieved nothing.

¶9 **Intervention C splits across the account-tier boundary.** The inlet works are a produced asset under TG-6.11, at cost less depreciation. The wetland's ecosystem entries are recorded under this Circular. The two are never summed. The service, sediment reduction benefiting the seagrass meadow, is recorded against the downstream seagrass unit under TG-6.13, whilst the expenditure is recorded against the intervening entity, per Section 3.7.4.

¶10 **Intervention A's benefit is not fully delivered in the period.** With a five-year period and a mangrove maturation profile extending beyond it, the account records the change in asset net present value arising from the intervention, with the maturation assumption documented, and does not record design capacity as delivered service.

¶11 **Table 3.11.2: Reversal in year 4**

¶12 A cyclone in year 4 removes an estimated 30 per cent of Intervention A's replanted area.

Entry	Treatment
Extent account	Unmanaged reduction, recorded in other changes in volume, not as degradation
Condition account	Condition of the remaining area reassessed
Monetary asset account	Asset revalued on the reduced expected flow
Metadata	Event, date, attribution basis and the evidence for attributing to natural process
What is not done	No buffer is released or drawn, because none was withheld (Section 3.5.3)

¶13 Had the loss instead arisen from planting in unsuitable substrate, the reduction would be a shortfall in the enhancement previously recorded, not an unmanaged volume change, and the earlier enhancement entry would be revised.

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3.12 Summary and Cross-References

¶1 Five principles carry this Circular.

1. ¶2
   Eligibility turns on mechanism. An ecosystem process must be the primary functional mechanism addressing the challenge. Activities that fail this test have expenditure but no attributable enhancement.
2. ¶3
   One intervention, six entry points, recorded in parallel. Expenditure is recorded because it was incurred and enhancement because condition changed. They are different quantities and no relationship between their magnitudes should be assumed.
3. ¶4
   The attributable change is the quantity of interest. It requires a counterfactual, its credibility is set by the tier, and a Tier 1 account should not report it as a point estimate.
4. ¶5
   Record expected benefit, not design capacity. Survival and maturation both reduce delivered benefit, and an account that ignores them overstates the asset.
5. ¶6
   Publish parameters, not adjusted totals. The account records the unadjusted value and supplies the six metadata items that let any user construct the adjustment they need.

¶7 **Cross-Reference Summary**

Related Circular	Relevance to TG-6.15
TG-0.1 General Introduction	Prerequisite — foundational concepts
TG-3.1 Asset Accounts	Prerequisite — asset classification, and the managed against un-managed attribution of extent change
TG-2.4 Ecosystem Goods and Services	Prerequisite — service framework, and physical accounts as the primary output
TG-6.11 Coastal Infrastructure Accounting	Companion Circular. Produced assets, the grey, green and blue vocabulary, hybrid attribution, stranded assets and adaptation investment tracking
TG-2.4 Environmental (including Ecosystem) Goods and Services	The prohibition this Circular operationalises (Section 3.10.5); all valuation methods and preference levels (Section 3.10)
TG-1.9 Safe Usage of Monetary Valuation	Whether and when to value at all; discount rate guidance; how monetary figures are communicated and caveated
TG-1.3 Marine Spatial Management	Counterfactual designs, and the attribution of condition change
TG-0.7 Quality Assurance Principles	Tiered implementation, documentation requirements and quality flags
TG-6.2 Mangrove and Coastal Wetland Accounting	Extent, condition and service accounting for the ecosystems most interventions act on
TG-2.8 Climate Change Indicators	Blue carbon measurement for carbon-focused interventions
TG-2.9 Disaster Risk Indicators	Ecosystem-based protection indicators, and hazard and exposure assessment
TG-1.8 Project-Level Finance	Crediting instruments, and crediting additionality as distinct from accounting additionality
TG-6.13 Freshwater-Marine Interaction	Upstream intervention with downstream benefit
TG-1.6 Environmental Impact Assessment	Interventions as offsets or compensation, and appraisal presentation

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4. Acknowledgements

¶1 **Authors:** [To be confirmed]

¶2 **Reviewers:** [To be confirmed]

5. References

1. ¶1 TG-2.4 Environmental (including Ecosystem) Goods and Services, Section 3.10.5, which distinguishes replacement costs, appropriate for individual services, from restoration costs, and states that restoration costs should not be used to value ecosystem assets.
2. ¶2 United Nations Environment Assembly (2022), resolution 5/5, "Nature-based solutions for supporting sustainable development", UNEP/EA.5/Res.5.
3. ¶3 IUCN (2020), *Global Standard for Nature-based Solutions: a user-friendly framework for the verification, design and scaling up of NbS*, first edition, Gland: IUCN, operationalising IUCN Resolution WCC-2016-Res-069. The Standard comprises eight criteria and 28 indicators and is a design and quality standard rather than a statistical instrument.
4. ¶4 UNSW Centre for Sustainable Development Reform (2026), *Project Development and Access to Finance for Nature-Based Solutions: Inception Report*, for Expertise France under the EU Green Recovery Facility, Section 1.2.4, which reconciles the IUCN, UNEA, World Bank and OECD definitions.
5. ¶5 Cohen-Shacham, E., Walters, G., Janzen, C. and Maginnis, S. (eds.) (2016), *Nature-based Solutions to address global societal challenges*, Gland: IUCN, Table 4, page 10, "Categories and examples of NbS approaches", with the same list in narrative form at page 5. DOI 10.2305/IUCN.CH.2016.13.en. Note that Table 4 gives natural infrastructure and green infrastructure as the examples under infrastructure-related approaches; the grey, green and blue distinction used elsewhere in this Circular is taken from TG-6.11 Section 1 and is not IUCN's.

6. ¶6 UNSW Centre for Sustainable Development Reform (2026), as above, Section 1.2.5 for the intensity classification, and Sections 5 and 6 for tenure as a determinant of feasibility and for the legal preconditions to financing pathway activation.
7. ¶7 UNSW Centre for Sustainable Development Reform (2026), as above, Section 1.2.4, which states the analytical test and distinguishes instrumental NbS from co-benefit activities.
8. ¶8 The eligibility screen adopted here is a GOAP position and not a requirement of the SEEA EA or of the UNEA definition, neither of which supplies an operational test. It follows the instrumental-versus-co-benefit distinction in UNSW Centre for Sustainable Development Reform (2026), as above, Section 1.2.4.
9. ¶9 SEEA EA (2021), Chapter 10, paragraph 10.15. The same definition is quoted at TG-6.11 Section 3.4.2 and TG-1.3 Section 3.4.1.
0. ¶10 SEEA EA (2021), Chapter 10, on the measurement of enhancement through change in net present value rather than through expenditure incurred.
1. ¶11 TG-3.1 Asset Accounts, Section 3.5.1, on the attribution of every addition and reduction in the extent account by cause, distinguishing managed change from direct human activity from unmanaged change from natural processes.
2. ¶12 TG-1.3 Marine Spatial Management, Section 3.4.1, including the instruction that where causality cannot be reliably attributed compilers should not disaggregate between degradation and other volume changes, but should record the total change without attribution and document the limitation in account metadata; SEEA EA (2021), paragraph 10.21.
3. ¶13 TG-1.3 Marine Spatial Management, Section 3.4.3, on counterfactual analysis, control-site selection and the three principal designs, and on the treatment where no design is feasible.
4. ¶14 TG-0.7 Quality Assurance Principles, Section 3.8, on tiered implementation frameworks: tier designations are Circular-specific, and Tier 1 represents the minimum viable approach.
5. ¶15 TG-1.8 Project-Level Finance, Section 3.4, on account-based carbon quantification, verification requirements, and the differences between crediting standards in baseline setting, additionality demonstration, permanence buffers and leakage assessment, together with the treatment of credit stacking.
6. ¶16 Bayraktarov, E., Saunders, M.I., Abdullah, S., Mills, M., Beher, J., Possingham, H.P., Mumby, P.J. and Lovelock, C.E. (2016), "The cost and feasibility of marine coastal restoration", *Ecological Applications* 26(4), DOI 10.1890/15-1077. Table 3.4.1 reports median values of the *Average survival (%)* field computed from the study's published dataset (Dryad, DOI 10.5061/dryad.rc0jn), which comprises 955 observations across five ecosystem workbooks. Coral reef figures are taken from the *Average survival (%)* field; the same source separately reports transplant and post-transplant survival, which measure different stages and are not pooled here.
7. ¶17 Boström-Einarsson, L., Babcock, R.C., Bayraktarov, E., Ceccarelli, D., Cook, N., Ferse, S.C.A. et al. (2020), "Coral restoration – a systematic review of current methods, successes, failures and future directions", *PLoS ONE* 15(1): e0226631, DOI 10.1371/journal.pone.0226631; van Katwijk, M.M., Thorhaug, A., Marbà, N., Orth, R.J., Duarte, C.M., Kendrick, G.A. et al. (2016), "Global analysis of seagrass restoration: the importance of large-scale planting", *Journal of Applied Ecology* 53, 567–578, DOI 10.1111/1365-2664.12562, and its 2019 corrigendum, DOI 10.1111/1365-2664.13428; Primavera, J.H. and Esteban, J.M.A. (2008), "A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects", *Wetlands Ecology and Management* 16(3), 173–253, DOI 10.1007/s11273-008-9101-y.
8. ¶18 TG-1.9 Safe Usage of Monetary Valuation, Section 3.1.2, on discount rate selection, the treatment where no published social discount rate exists, and the requirement for sensitivity analysis; SEEA EA (2021), paragraphs 10.76–10.81.
9. ¶19 Duke, N.C. et al. and subsequent analyses of the event, including Harris, T. et al. (2021), "Influence of the 2015–2016 El Nino on the record-breaking mangrove dieback along northern Australia coast", *Scientific Reports* 11, DOI 10.1038/s41598-021-99313-w. Reported dieback extent is of the order of 7,400 to 7,650 hectares, approximately 6 per cent of Gulf of Carpentaria mangrove extent, distributed synchronously across approximately 2,000 kilometres of coastline. Compilers citing this event should check the extent figure against the specific study used, since estimates differ with the mapping method applied.
0. ¶20 2025 SNA, Chapter 12, on other changes in the volume of assets, which provides the general framework for recording unforeseen asset value changes including catastrophic losses.
1. ¶21 Verra, *VCS Standard* and the *AFOLU Non-Permanence Risk Tool*, under which risk analysis criteria and buffer withholding percentages are set and periodically adjusted, and a project whose assessed non-permanence risk exceeds the highest available withholding percentage for its project type is ineligible; Verra, *VM0033 Methodology for Tidal Wetland and Seagrass Restoration*, v2.1, which requires the latest version of the tool including for the risk of erosion and submergence of carbon stocks due to sea level rise.
2. ¶22 Gold Standard mandates a pooled buffer for forestry activities. The American Carbon Registry and the Climate Action Reserve operate comparable reversal-risk regimes, and the Reserve's revised permanence approach (2026) admits alternatives to a buffer including long-term conservation easements, transfer of reversal-monitoring liability to an eligible entity such as a permanence trust, and cancellation of credits of negligible reversal risk. Compilers should verify current requirements against the operative programme documents, since this area is under active revision.
3. ¶23 TG-0.7 Quality Assurance Principles, Sections 3.4 (categories of uncertainty, including ecosystem dynamics uncertainty and valuation uncertainty), 3.5 (documentation requirements) and 3.6 (quality flags for accounts tables).
4. ¶24 Australian Government, Department of Climate Change, Energy, the Environment and Water, Blue Carbon Conservation, Restoration and Accounting Program, which committed AUD 30.6 million over 2021 to 2025 across on-ground restoration and conservation activity, the application of project-level environmental-economic accounting, and collaboration and knowledge exchange, and which awarded five contracts in June 2023 to measure restoration

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benefits and develop accounts for five sites selected under the Blue Carbon Ecosystem Restoration Grants. Per-site compilation cost is not published; the figures above bound the programme, not the unit cost.

5. ¶25 Menendez, P., Losada, I.J., Torres-Ortega, S., Narayan, S. and Beck, M.W. (2020), "The global flood protection benefits of mangroves", *Scientific Reports* 10, 4404, DOI 10.1038/s41598-020-61136-6, which estimates annual flood protection benefits exceeding USD 65 billion and 15 million additional people flooded annually in the absence of mangroves; Beck, M.W., Losada, I.J., Menendez, P., Reguero, B.G., Diaz-Simal, P. and Fernandez, F. (2018), "The global flood protection savings provided by coral reefs", *Nature Communications* 9, DOI 10.1038/s41467-018-04568-z, which estimates annual averted flood damages of the order of USD 4 billion and finds expected annual damages roughly doubling without reefs. Both are global modelled estimates and neither is an exchange value; TG-2.4 Section 3.10.2 governs whether any figure derived from them may enter an account.
6. ¶26 SEEA EA (2021), Section 7.3, on avoiding double counting in ecosystem service accounting, and paragraph 6.15 on the intermediate-service classification that underlies the nursery-services rule at TG-6.2 Section 3.5.
7. ¶27 TG-2.4 Environmental (including Ecosystem) Goods and Services, Section 3.10.2, Table 1 and the accompanying note on replacement cost, which places it at preference level 5 in the large majority of ocean accounting applications because the replacement structure is hypothetical.
8. ¶28 TG-2.4 Environmental (including Ecosystem) Goods and Services, Section 3.10.5, on consumer surplus measures and stated preference methods.
9. ¶29 TG-1.9 Safe Usage of Monetary Valuation, Section 3.2.1: "Always compile and publish physical accounts. Consider monetary valuation as a complement, not a replacement, for physical measurement." The same section records legitimate concerns about the commodification of marine ecosystems as a reason physical accounts may be preferred.
0. ¶30 TG-2.4 Environmental (including Ecosystem) Goods and Services, Section 3.6, on physical against monetary indicators, and Section 3.6.2 on presenting physical and monetary indicators together.
1. ¶31 Narayan, S., Beck, M.W., Reguero, B.G., Losada, I.J., van Wesenbeeck, B., Pontee, N., Sanchirico, J.N., Ingram, J.C., Lange, G.-M. and Burks-Copes, K.A. (2016), "The effectiveness, costs and coastal protection benefits of natural and nature-based defences", *PLoS ONE* 11(5): e0154735, DOI 10.1371/journal.pone.0154735, which synthesises 69 field measurements of wave-height reduction across mangroves, salt marshes, coral reefs and seagrass or kelp beds, and the costs and coastal protection benefits of 52 nature-based defence projects.
2. ¶32 TG-1.9 Safe Usage of Monetary Valuation, Section 3.2.3, on the risk of misinterpretation, which records that monetary values from accounts do not capture all relevant considerations for decision-making, including cultural values, equity, rights and biodiversity intrinsic value.
3. ¶33 TNFD (2023), *Recommendations of the Taskforce on Nature-related Financial Disclosures*; IFRS S1 and IFRS S2. See also TG-6.11 footnote 70 and TG-1.11 Ocean Accounts and Private Sector Decision-Making.

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