

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

¶5 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;²

¶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.

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**.
- ¶4

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

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.

- ¶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

¶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 $TVU = \sqrt{(0.5^2 + (0.013 \times 20)^2)} = \sqrt{(0.25 + 0.0676)} = \sqrt{0.3176} \approx \mathbf{0.56\ m}$. 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/> ([\(https://dataspace.copernicus.eu/\)](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

¶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.

DRAFT

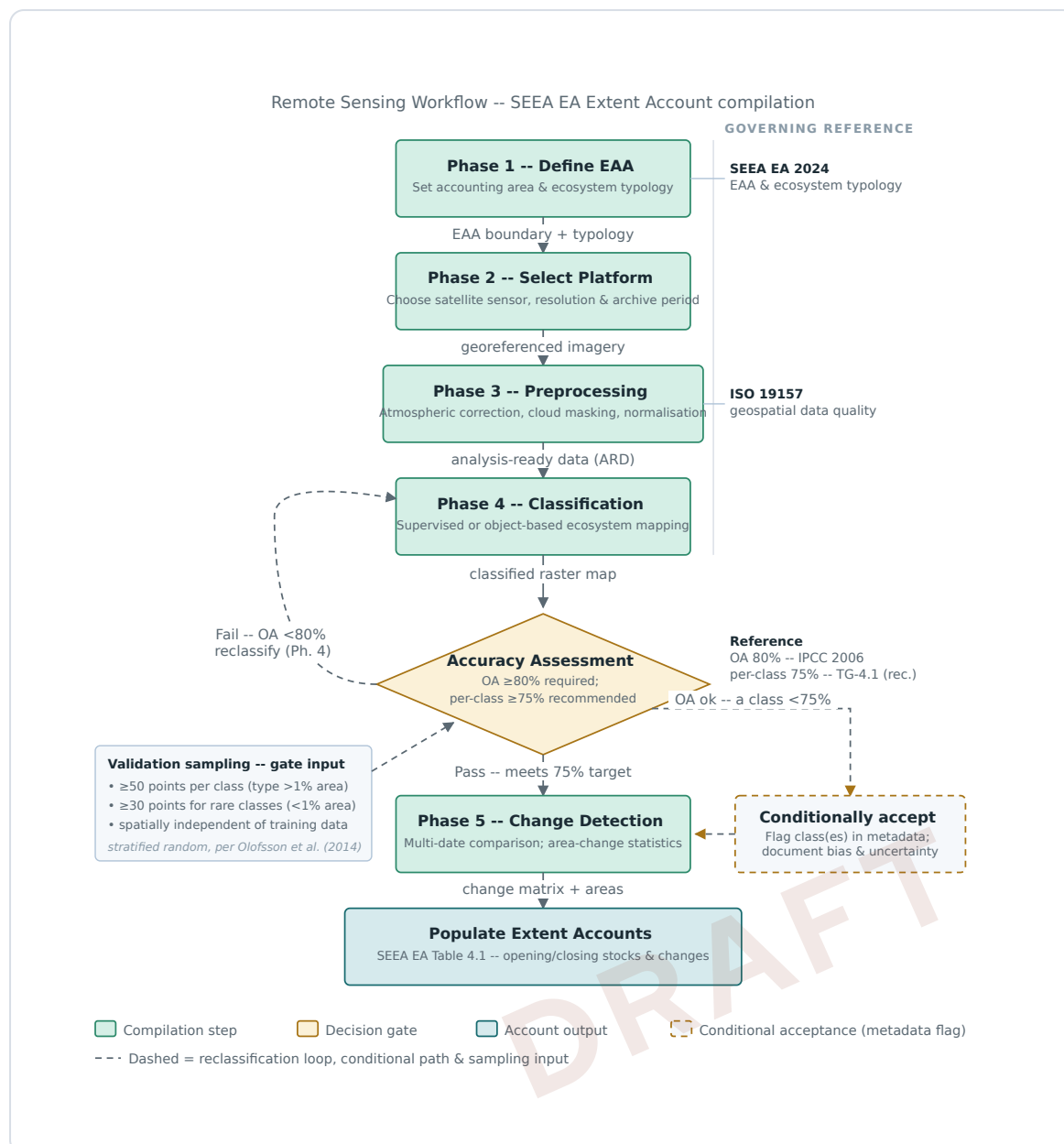


Figure 4.1.1 Five-phase remote-sensing workflow produces SEEA EA extent accounts, gated by overall and per-class accuracy tests. Products at ≥80% overall proceed; below per-class may be flagged; failing overall loops back.

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 salt-marshes 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:

- ¶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

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**.

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.

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.

¶8 **Co-occurring ecosystem types.** In shallow tropical systems, seagrass meadows frequently grow beneath sparse coral framework, kelp canopies overlies 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 meta-data 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:

- ¶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 meta-data accompanying ocean accounts.⁵⁹

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*

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:

¶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, salt-marshes, 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

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)

¶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**

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.

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]

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.globalmangrovetwatch.org/>) (<https://www.globalmangrovetwatch.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.
10. ¶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.
11. ¶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.
12. ¶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).

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) (<https://doi.org/10.2305/IUCN.CH.2020.13.en>). Accessible at [iucnget.org](https://www.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 $TVU \approx 0.56$ 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/>).

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.
10. ¶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 meta-data 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.
10. ¶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

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.
10. ¶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.
11. ¶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.
12. ¶62 Millennium Ecosystem Assessment (2005), *Ecosystems and Human Well-being: Current State and Trends*, Volume I, Chapter 19. The 100km/50m definition was adopted as an operational boundary for the assessment’s coastal chapter, not as a universal standard.
13. ¶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.
14. ¶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.
15. ¶65 TG-0.7 Quality Assurance Principles provides the overarching quality framework for ocean accounts.
16. ¶66 Guidelines on Biophysical Modelling, Table 8, provides definitions of confusion matrix accuracy metrics.
17. ¶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.
18. ¶68 IHO S-104 (Water Level Information for Surface Navigation) provides the framework for tidal water level data products referenced in tidal correction workflows.
19. ¶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.

DRAFT