

Mangrove and Coastal Wetland Accounting

Provides guidance on compiling ecosystem accounts for mangroves and coastal wetlands.

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Status Draft

Stability Applied

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OUTCOME

This Circular provides guidance on compiling ecosystem accounts for mangroves and coastal wetlands. The accounts support four policy applications: blue carbon credit verification for voluntary and compliance carbon markets; coastal protection valuation for infrastructure planning; mangrove restoration prioritisation for climate adaptation; and REDD+ coastal extension for nationally determined contributions under the Paris Agreement.

This Circular connects to [TG-2.8 Climate Change Indicators](#), which draws on blue carbon sequestration rates compiled here; [TG-2.9 Disaster Risk Indicators](#), which uses coastal protection measurements from Section 3.4; and [TG-1.8 OA and Project-Level Finance](#), which applies carbon accounts and service valuations to blue bonds, debt-for-nature swaps, and payments for ecosystem services.

This Circular is one of four thematic ecosystem circulars – alongside [TG-6.1 Coral Reef Accounting](#), [TG-6.3 Seagrass Ecosystem Accounting](#) and [TG-6.4 Kelp Forest and Temperate Reef Accounting](#) – that apply the generic ecosystem asset method in [TG-3.1 Asset Accounts](#), the extent methods in [TG-4.1](#) and the condition methods in [TG-4.8](#) and [TG-4.9](#) to one coastal ecosystem type each. The four are peers: none is a prerequisite for another, and each is compiled independently. Estuarine and deltaic assets influenced by catchment inputs are carried forward in [TG-6.13 Freshwater-Marine Interaction Accounting](#).

Framework Position

This Circular owns the extent, condition, service and asset accounts for IUCN GET MFT1.1 coastal river deltas, MFT1.2 mangroves and MFT1.3 coastal saltmarshes and reedbeds. It also owns the blue carbon pricing rule for the publication (Section 3.6): the SEEA EA two-component model, applied identically across all blue carbon ecosystems.

It cross-refers for the account structure ([TG-3.1](#)), extent and condition measurement ([TG-4.1](#), [TG-4.8](#), [TG-4.9](#)) and valuation principles ([TG-1.9](#)).

Seagrass is [TG-6.3](#), not this Circular, despite the shared blue carbon method. Catchment-borne nutrient and sediment inputs to these systems are [TG-6.13](#). The fisheries production that nursery habitat supports is recorded once, as an intermediate service here and as landed catch in [TG-6.7](#).

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ABOUT THIS CIRCULAR

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DRAFT

1. Outcome

¶1 This Circular provides guidance on compiling ecosystem accounts for mangroves and coastal wetlands. The accounts support four policy applications: **blue carbon credit verification** for voluntary and compliance carbon markets; **coastal protection valuation** for infrastructure planning; **mangrove restoration prioritisation** for climate adaptation; and **REDD+ coastal extension** for nationally determined contributions under the Paris Agreement.

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2. Requirements

- ¶1 **TG-0.1 General Introduction to Ocean Accounts**
- ¶2 **TG-3.1 Asset Accounts** – in particular Section 3.4 on ecosystem asset accounts.
- ¶3 **TG-1.9 Valuation** – foundational valuation concepts are not repeated here.
- ¶4 **TG-4.1 Ecosystem Extent** – general extent accounting, spatial data requirements, and change detection.

¶5 **Readiness and sequencing**. Whether a country is positioned to compile this account at all – mandate, data architecture, capacity and the order in which to build – is assessed under **TG-0.8 Implementation Readiness Assessment**, and is not restated here.

3. Guidance Material

¶1 Mangroves and coastal wetlands occupy the transitional zone between terrestrial and marine environments, classified within the MFT1 Brackish Tidal Systems biome of the IUCN Global Ecosystem Typology (GET)¹. For the GET realm/biome/EFG hierarchy and the national crosswalk obligation, see **TG-4.1** Section 3.2.4.² Key ecosystem functional groups are summarised in Table 3.0.1 below³.

Functional group	Description
MFT1.2 Intertidal forests and shrublands (mangroves)	Characterised by salt-tolerant trees and shrubs with specialised adaptations including pneumatophores, salt excretion glands, and vivipary.
MFT1.3 Coastal saltmarshes and reedbeds	Dominated by salt-tolerant herbaceous plants and grasses in the upper intertidal zone.
MFT1.1 Coastal river deltas	Complex mosaics incorporating mangroves, saltmarshes, and other transitional ecosystem types.

¶2 Sections 3.1–3.6 cover ecosystem extent, condition, blue carbon services, coastal protection, nursery habitat services, and valuation⁴. Compilers should also consult **TG-3.8 Combined Presentations** for the bridge to the SEEA-CF Thematic Carbon Stock Account referenced in Section 3.3. Section 3.7 presents a step-by-step compilation procedure and Section 3.8 provides a worked example.

3.1 Extent Accounting

¶1 Ecosystem extent accounts record mangrove and coastal wetland area within an ecosystem accounting area (EAA), typically in hectares⁵. Extent accounts provide the spatial foundation for all subsequent condition and service accounts. For satellite sensor selection, cloud-cover management, tidal timing, and general accuracy assessment, see **TG-4.1 Ecosystem Extent**. Mangrove-specific considerations are noted below.

Ecosystem type classification

¶1 Mangroves and coastal wetlands should be classified at the ecosystem functional group (EFG) level or finer national classifications⁶:

IUCN GET Code	Ecosystem Functional Group	Description
MFT1.2	Intertidal forests and shrublands	Mangrove forests and related tidal woody vegetation
MFT1.3	Coastal saltmarshes and reedbeds	Herbaceous tidal wetlands including salt marshes
MFT1.1	Coastal river deltas	Complex deltaic mosaics with multiple ecosystem types

¶2 National classifications may disaggregate further by dominant species (e.g., *Rhizophora*-dominated vs. *Avicennia*-dominated) or structural characteristics⁷. Temperate compilers should identify the most appropriate GET functional groups for their national context and document classification decisions transparently.

Remote sensing and accuracy assessment

¶1 Remote sensing provides the primary data source for extent mapping^{8, 9}. Mangrove-specific considerations supplementing **TG-4.1 §3.3** are:

- ¶2 L-band SAR (Sentinel-1, ALOS-2 PALSAR-2) for canopy height retrieval under cloud cover¹⁰
- ¶3 NDVI thresholds for mangrove vs saltmarsh discrimination
- ¶4 Imagery acquired within ± 2 hours of low tide for intertidal fringe mapping

¶5 **Saltmarsh-specific:** Saltmarsh mapping requires high-resolution optical imagery (0.5–2 m) and LiDAR-derived elevation models to separate saltmarsh from adjacent upland vegetation. Multi-temporal classification exploiting phenological contrasts improves discrimination.

¶6 **Global datasets:** Global Mangrove Watch provides annual mangrove extent maps from 1996 at 25-metre resolution¹¹. The Global Tidal Wetland Change Dataset tracks saltmarsh, mangrove, and tidal flat changes globally¹².

¶7 Accuracy documentation must include: accuracy assessment method (area-based probability sampling); reference data source and collection date; overall, producer, and user accuracy by class; confusion matrix; and imagery source, acquisition date, resolution, and cloud cover or tidal stage. For national GHG inventory reporting, minimum overall accuracy of 85% is a widely applied convention (IPCC Good Practice Guidance)¹³. For carbon credit accounting under voluntary standards (e.g., Verra VM0033), methodology-specific requirements apply.

Change detection

¶1 The extent account records changes between opening and closing periods using four categories¹⁴:

Change category	Description
Managed expansions	Increases due to restoration, afforestation, or coastal management.
Unmanaged expansions	Natural colonisation and succession.
Managed reductions	Conversion for aquaculture, agriculture, or urban development.
Unmanaged reductions	Natural losses from erosion, sea-level rise, or catastrophic events.

¶2 Temporary losses from storm damage followed by regeneration should be treated as condition changes rather than extent changes¹⁵.

¶3 **Restored vs. naturally regenerated additions.** Managed expansions should be disaggregated into two sub-categories in account metadata:

- ¶4 *Restored (planted)* – counted as gained extent only after a **survival check at year 3 post-planting** to filter typical 30–60% three-year mortality. The threshold for entry into the extent account is canopy closure or the specified national cover percentage, whichever is reached first.
- ¶5 *Naturally regenerated* – areas colonised by unassisted propagule recruitment, typically reaching the SEEA EA extent threshold at year 10–15.

¶6 Carbon accumulation trajectories differ between sub-categories: planted monocultures accrue above-ground biomass faster initially but commonly reach lower long-term equilibrium carbon stocks than mixed naturally recruited stands. Compilers should document sub-category membership as this distinction is material for downstream carbon accounting and additionality analyses.

Extent account structure

¶1 The extent account structure is set out in **TG-3.1 Asset Accounts** Section 3.5.1 (Tables 2a and 2b) and is not restated here^{16, 17}; Section 3.5.3 of the same circular governs how extent entries flow into the asset balance sheet. Compile one column per ecosystem functional group present – mangroves (MFT1.2), saltmarshes (MFT1.3) and coastal river deltas (MFT1.1) – and a worked account appears at Section 3.8 below.

¶2 Managed expansion arising from a **restoration intervention** carries a second set of entries – counterfactual, survival, permanence and lifecycle cost – recorded in parallel under **TG-6.15 Ocean Accounting for Nature-based Solutions** Section 3.2. The extent entry here and the NbS ledger there describe the same planting from different sides and are not alternatives.

¶3 Two entries need care in wetlands. **Landward migration** under sea-level rise is a reclassification and not an addition: the mangrove belt gains area from terrestrial ecosystem types and loses it seaward, and both legs belong in the reclassification block so the accounting area still balances.

Planted restoration is a managed addition only once the stand meets the national classification threshold for the functional group; seedlings planted and not yet established are restoration expenditure with no extent entry, and recording them early is the most common source of overstated mangrove gain.

3.2 Condition Assessment

¶1 Ecosystem condition accounts record ecosystem quality through variables reflecting composition, structure, and function^{18, 19, 20}. For the general ECT framework and condition variable selection, see **TG-4.8 Physical Condition Measurement §3.1** and **TG-4.9 Biological Condition Measurement §3.1**. The variables below are mangrove- and wetland-specific applications of ECT classes, with an indication of whether each is estimable from remote sensing (*RS*) or field sampling (*FS*)²¹.

¶2 **Physical state (A1):** Tidal inundation regime (*FS*); sediment accretion/erosion rate (*FS*); groundwater level (*FS*).

¶3 **Chemical state (A2):** Water salinity (*FS*); nutrient concentrations (*FS*); dissolved oxygen (*FS*).

¶4 **Compositional state (B1):** Species richness (*FS*); community composition (*FS*); presence of key species (*FS*).

¶5 **Structural state (B2):** Canopy cover (*RS*); canopy height (*RS* via LiDAR); above-ground biomass (*RS* via SAR/allometry); tree density (*FS*).

¶6 **Functional state (B3):** Net Primary Productivity (*RS* via MODIS/Sentinel); litterfall rate (*FS*); regeneration success (*FS*).

¶7 **Landscape/seascape (C1):** Hydrological connectivity (*RS+FS*); fragmentation (*RS*); edge effects (*RS*).

Key condition indicators

¶1 **Canopy cover** is a primary structural indicator measurable through remote sensing, and describes forest density and intactness²².

¶2 **Species composition** reflects ecological integrity. Presence of climax species (e.g., *Rhizophora* in many tropical settings) indicates mature, stable ecosystems²³.

¶3 **Hydrological connectivity** governs coastal wetland function, affecting sediment supply, nutrient exchange, and biotic recruitment²⁴. Disruption through road construction, aquaculture bunds, or drainage infrastructure is a major cause of degradation. Assess through tidal range comparison (observed vs. reference), distance to tidal inlet, and presence of flow barriers.

¶4 **Sediment elevation change** indicates whether wetlands are maintaining pace with sea-level rise²⁵. Surface Elevation Tables (SETs) provide direct measurements. Treat as a core indicator where relative sea-level rise exceeds 2 mm/yr, and as optional but recommended elsewhere. This indicator supports climate adaptation planning.

Reference conditions

¶1 Reference conditions are required against which to assess current state, following SEEA EA Section 5.3²⁶:

Reference approach	Description
Historical baselines	Pre-disturbance condition documented through historical records, early imagery, or sediment core analysis.
Minimally disturbed reference sites	Protected or relatively undisturbed examples of the same ecosystem type in the national territory or ecoregion.
Expert-defined targets	Expert assessment where historical data and reference sites are unavailable.

¶2 **Decision rule:** Prefer (i) **minimally disturbed contemporary reference sites** in the same biogeographic region; fall back to (ii) **historical baselines** with documented source and date; fall back to (iii) **expert-defined targets** only where neither alternative exists.

¶3 This ordering is specific to mangrove and differs from the one in **TG-6.1 Coral Reef Ecosystem Accounting** Section 3.2, which prefers a site-specific historical baseline. The difference is a property of the evidence available for each ecosystem, not an inconsistency: minimally disturbed mangrove stands are commonly present within a biogeographic region whilst pre-disturbance mangrove records are commonly not, and for Caribbean reef the reverse holds – there is a strong palaeoecological and historical record and no minimally disturbed contemporary analogue. Compilers should apply the ordering given for the ecosystem they are accounting for, and document which reference condition and estimation method were used (**TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.2).

¶4 Condition variables are normalised using the formula defined in **TG-2.1 Biophysical Indicators for Ocean Accounts** Section 3.4.1. Each variable must be tagged as **standard** or **inverse** direction.

Sampling design for condition assessment

¶1 SEEA EA does not prescribe minimum plot density. Required documentation: number of sampling units; spatial distribution and stratification; plot dimensions; extrapolation method; and data source and collection date²⁷.

¶2 Appropriate stratification variables include: ecosystem type and species composition; hydrological zone and inundation frequency; condition class; geomorphic setting (fringe vs. basin vs. riverine mangrove); and remote sensing-derived indicators (canopy cover, NDVI).

¶3 Tier-appropriate guidance:

- ¶4 **Tier 1:** Single composite estimate from published global or regional defaults; document source, year, and ecological match to accounting area.
- ¶5 **Tier 2:** 2–4 satellite-derived strata, at least 3 field plots per stratum; area-weight stratum means by area.
- ¶6 **Tier 3:** Howard et al. (2014) plot-level protocols with stratified random placement and replicated sediment cores. Minimum quadrat sizes: 7 m x 7 m for mangroves, 0.5 m x 0.5 m for saltmarsh.

¶7 For seagrass condition assessment, see **TG-6.3 Seagrass Ecosystem Accounting**.

Carbon stock estimation – key distinction

¶1 Carbon stocks in the condition account are derived by measuring each pool independently (above-ground biomass, below-ground biomass, soil organic carbon) in tC/ha. The normalised condition indicator (scaled 0–1) is a descriptor for tracking and communication. It is not a multiplier against a reference stock value. A degraded ecosystem with measured SOC of 200 tC/ha against a reference of 471 tC/ha has a condition indicator of approximately 0.42, but the carbon stock entered into the account is 200 tC/ha multiplied by ecosystem area. SOC in particular degrades non-proportionally with above-ground condition: deep sediment SOC may remain largely intact even after surface biomass removal²⁸.

Condition account structure

¶1 The table below follows the SEEA EA condition variable account structure²⁹.

SEEA ECT Class	Variable	Unit	Reference Level	Opening Value	Closing Value	Change
Physical state	Tidal range ratio	% of reference	100%			
Chemical state	Porewater salinity	ppt	Site-specific			

SEEA ECT Class	Variable	Unit	Reference Level	Opening Value	Closing Value	Change
Compositional state	Species richness	count	Pre-disturbance			
Structural state	Canopy cover	%	Reference site			
Structural state	Above-ground biomass	t C/ha	Reference site			
Functional state	Net Primary Productivity	t C/ha/yr	Historical mean			
Landscape	Hydrological connectivity index	0-1	1.0 (fully connected)			

3.3 Blue Carbon Services

¶1 Figure 6.2.1 maps three mangrove carbon pools to SEEA EA accounting destinations: biomass pools enter condition attributes; annual sequestration (Cseq) enters the regulating service account; carbon storage (Cstor) enters a condition attribute with a balance-sheet footnote (not yet standardised).

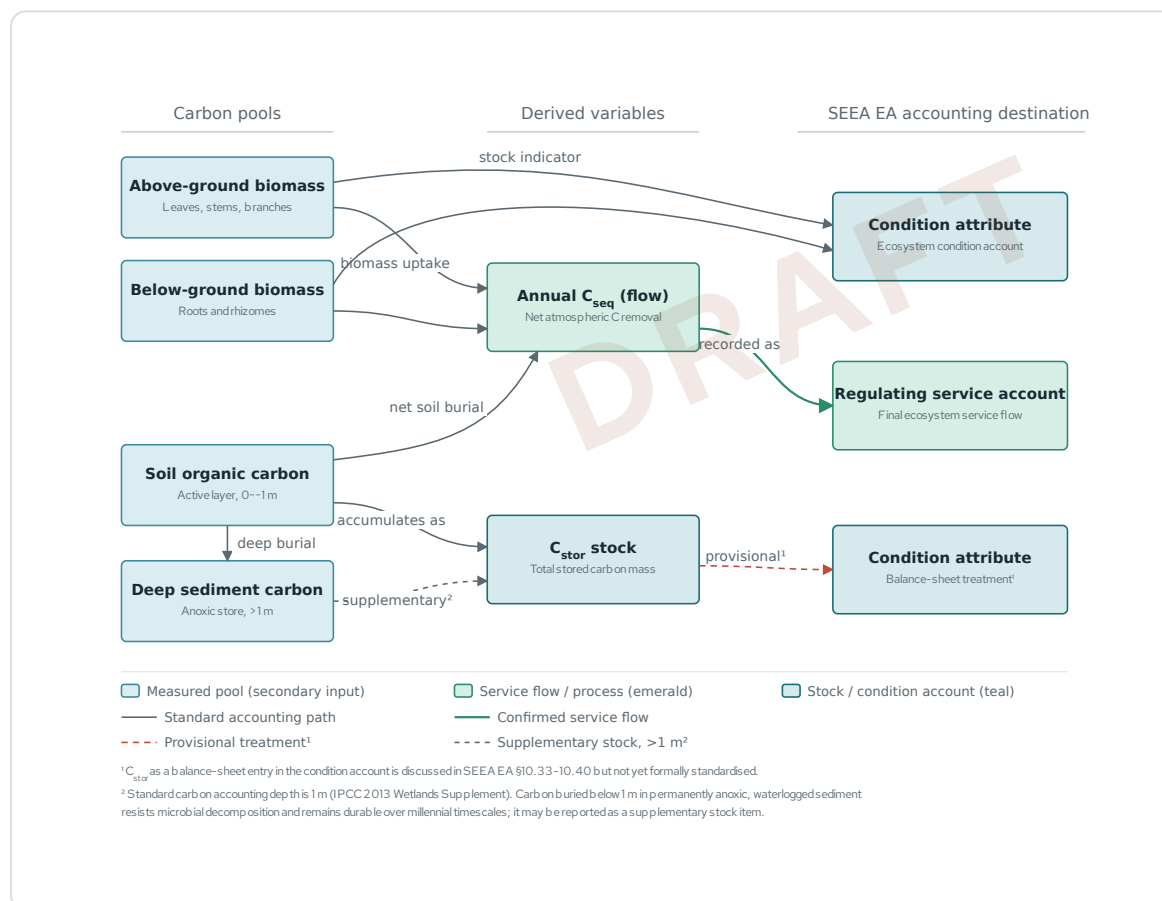


Figure 6.2.1 Blue-carbon pools map to SEEA EA destinations: biomass and soil burial feed Cseq; Cstor is a condition attribute; deep sediment is supplementary. Dashed paths mark non-standardised Cstor-to-condition link and >1 m durable store.

Source: SEEA EA 2024, §§10.20–10.40 (ecosystem condition accounting); TG-6.2 draft, Section 3.3 (Blue Carbon Services) and the net sequestration identity (NECB = biomass increment + net soil burial).

Adapted from: SEEA EA 2024 Figure 10.1 (ecosystem condition account structure), with GOAP extensions for blue carbon pool disaggregation, Cseq/Cstor derivation paths, soil burial routing, and the >1 m durable-store supplementary item.

Conceptual distinction: carbon stocks and carbon flows

¶1 A *carbon stock* is the mass of carbon held in an ecosystem at a point in time (tC or tCO₂e), a state variable in the condition account. A *carbon flow* is the rate of carbon movement between ecosystem and atmosphere over a defined period (tCO₂e/yr), a change variable in the ecosystem services flow account. Conflating stock and flow produces results that cannot be compared across countries or time periods³⁰.

¶2 Physical accounts must be compiled before monetary accounts. The recommended sequence is: (1) extent account; (2) condition account (carbon stocks per pool); (3) services flow account, physical; (4) services flow account, monetary.

IPCC Wetlands Supplement tier framework

¶1 The primary reference for blue carbon accounting is the *2013 Supplement to the 2006 IPCC Guidelines: Wetlands*, Chapter 4. Coverage by ecosystem type: mangroves (full Tier 1 across all carbon pools); tidal marshes and saltmarsh (partial Tier 1; biomass carbon stock changes require Tier 2+; soil carbon estimates carry ±50–90% uncertainty at Tier 1); seagrass (out of scope – see **TG-6.3**); tidal flats (not covered by the Wetlands Supplement)³¹.

¶2 Kelp, sargassum, and other macroalgae are out of scope. Their attribution as carbon sinks remains scientifically unresolved, and no agreed IPCC accounting boundary exists.

¶3 Minimum recommended tiers by use case:

Use case	Minimum tier	Rationale
National GHG inventory (UNFCCC reporting only)	Tier 1 acceptable as starting point	Permitted where coastal wetlands are not a key category
NDC contribution / REDD+ / Warsaw Framework	Tier 2	Country-specific emission factors required
Ocean account for policy planning	Tier 2	Physical precision required for spatial planning
Carbon project accreditation (VCS/Gold Standard)	Tier 3	VM0033 sets this threshold explicitly
Blue carbon credit issuance / financial instruments	Tier 3	Additionality, permanence, and leakage require site-specific baselines
High-precision ecosystem service valuation	Tier 3	Monetary reliability depends on physical account precision

¶4 Countries should not remain at Tier 1 for key categories. Where blue carbon ecosystems make a material contribution to national GHG balances (e.g., Indonesia, Philippines, Madagascar, Australia), Tier 2 should be the minimum for NDC and national communications submissions³².

Scope boundary: aquaculture carbon claims

Note on scope

Bivalve aquaculture (oysters, mussels, clams) is outside scope. Animals are heterotrophs, and bivalve shell calcification ($\text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$) produces CO₂ as a by-product. Net atmospheric effects are contested. Shell formation is a metabolic process, not an ecosystem service delivered by a coastal ecosystem asset.

Seaweed farming is generally outside scope. In most operations, harvested biomass is consumed within months to years without durable long-term sequestration (SEEA EA para. 6.114). Emerging applications (deep-ocean sinking, biochar conversion) should be treated as experimental pending IPCC guidance³³.

Carbon stock accounting

¶1 Mangroves and coastal wetlands store carbon in five pools requiring separate accounting³⁴:

Carbon Pool	Measurement Method	Typical Range	Accounting Treatment
Above-ground biomass	Allometric equations	50-250 tC/ha	Condition account (stock)
Below-ground biomass	Root:shoot ratios or allometry	30-150 tC/ha	Condition account (stock)
Dead wood	Field measurement (volume x density)	1-20 tC/ha (locally significant in disturbed forests)	Condition account (stock)
Litter	Quadrat harvest	0.5-5 tC/ha (minor)	Condition account (stock)
Soil organic carbon (0-1m)	Core sampling	200-1000 tC/ha	Condition account (stock)

¶2 **Above-ground biomass:** Carbon content typically estimated at 45–50% of dry biomass weight³⁵.

¶3 **Below-ground biomass:** Root:shoot ratios of 0.5–1.5 commonly applied. For mangroves with extensive stilt root systems, below-ground biomass may equal or exceed above-ground biomass³⁶.

¶4 **Dead wood and litter:** Minor pools in most intact systems but locally significant in disturbed forests. Enumerate following IPCC Wetlands Supplement Chapter 4 protocols.

¶5 **Sediment organic carbon (SOC):** The largest pool in most coastal wetlands, typically 70–95% of total ecosystem carbon. Representative ranges: mangrove SOC 500–1,500 tCO₂e/ha to 1-metre depth (potentially exceeding 3,000 tCO₂e/ha in Southeast Asian deep peat soils); saltmarsh SOC 200–700 tCO₂e/ha. Methods that neglect soil cores will underestimate total ecosystem carbon.

¶6 The standard accounting depth is 1 metre (IPCC 2013 Wetlands Supplement). For mangrove systems with deep peat soils, compilers may additionally report carbon stocks to bedrock or depth of organic accumulation as a supplementary item, clearly distinguishing these from the 1-metre figures³⁷.

¶7 **Carbon market deeper-deposit requirement:** Verra VM0033 requires sampling to refusal or 3 m (whichever is shallower) for credit issuance. Where the account supports both SEEA reporting and credit issuance, report (a) 0–1 m stock for SEEA/inventory comparability and (b) full-depth stock to refusal or 3 m as a supplementary item.

¶8 **Soil-carbon sampling and laboratory protocol** (Kauffman & Donato 2012, CIFOR WP86 Sections 4–5; Howard et al. 2014 Chapter 4):

- ¶9 *Core count and depth intervals:* minimum 6 cores per plot at 0–15, 15–30, 30–50, and 50–100 cm intervals (plus deeper intervals where the deeper-deposit protocol applies).
- ¶10 *Compaction correction:* record extruded core length against cored interval length; apply ratio as depth-correction factor. Sediment compression of 20–40% during coring is common.
- ¶11 *Laboratory method:* dry combustion using an elemental analyser preferred. Where Walkley-Black wet oxidation is used, apply a recovery factor of 1.30 unless site-specific calibration exists.
- ¶12 *Loss-on-ignition:* requires site- or species-specific calibration against dry combustion before use for accounting purposes.

¶13 The three-tier hierarchy for blue carbon stock measurement maps to the IPCC Wetlands Supplement tier framework (see use-case table above). Murdiyarso et al. (2023) provide a national-scale worked example of the Tier 1 to Tier 2 transition for Indonesian mangroves³⁸.

Allometric equations and uncertainty

¶1 Selection rule – use the most specific equation available, in order:

1. ¶2 **Species-specific local equation** from destructive sampling within the accounting area.
2. ¶3 **Regional species-specific substitute** from the same species in a climatically analogous region. Price et al. (2024) confirmed common allometric equations hold for three transatlantic mangrove species across wide climate gradients.
3. ¶4 **Pantropical equation with measured wood density:** Komiyama et al. (2005): $AGB\ (kg) = 0.251 \times \rho \times D^{2.46}$; $BGB\ (kg) = 0.199 \times \rho^{0.899} \times D^{2.22}$, where ρ is wood density (g/cm^3) and D is DBH (cm).
4. ¶5 **Pantropical default without measured wood density** – lowest confidence; document as a limitation³⁹.

¶6 For saltmarsh, Butler et al. (2025) demonstrated models explaining up to 89.3% of biomass variance for Southeast Australian species. Destructive harvest protocols from Howard et al. (2014) remain the standard fallback: 0.25 m² quadrats and a 0.42–0.45 carbon content factor.

¶7 **Equation applicability ranges:**

Equation	Predictors	Calibrated on	DBH range (cm)	Reported error	Recommended use
Komiyama et al. (2005) pantropical	DBH, wood density	Mixed species (Thailand, Indonesia, Panama)	5–49	RSE approx. 12%	Default; flag extrapolation outside DBH range
Komiyama et al. (2008) species-specific	DBH (species-specific coefficients)	Multiple Rhizophora, Avicennia, Bruguiera, Sonneratia	Varies 2–40	Species-dependent	Preferred where species represented and stand analogous
Kauffman & Donato (2012) / Kauffman et al. (2016)	DBH	Mixed neotropical and Indo-Pacific	2–50	Reported in source	Standard for protocol-level consistency
Butler et al. (2025) saltmarsh	Canopy diameter, height	SE Australian saltmarsh species	n/a	R ² up to 0.893	Saltmarsh AGB where species and structure analogous

¶8 Compilers must: (a) confirm species and DBH range fall within the calibration domain; (b) flag extrapolation as documented uncertainty; and (c) record the equation reference in account metadata.

¶9 **DBH measurement conventions (Kauffman & Donato 2012 Section 3.2; Howard et al. 2014 Chapter 3):**

- ¶10 *Rhizophora* spp. – 1.3 m above the highest prop root.
- ¶11 *Avicennia* spp. – 1.3 m above substrate; pneumatophores not measured as stems.
- ¶12 *Sonneratia* spp. – 1.3 m above substrate; multi-stemmed individuals reported as sum of basal area.
- ¶13 *Bruguiera* spp. – 1.3 m above substrate.
- ¶14 *Excoecaria agallocha*, *Heritiera* spp. – measure immediately above buttress where buttresses exceed 1.3 m.
- ¶15 Coppicing/multi-stemmed – record each stem >5 cm DBH separately; sum basal area for biomass.

¶16 **Uncertainty quantification:** Allometric equation uncertainty typically constitutes 30–75% of total biomass estimation uncertainty⁴⁰. Where Monte Carlo simulation is feasible, sample from

each parameter's error distribution across 1,000+ iterations and report mean and 95% confidence interval. Where not feasible, report known confidence intervals from the equation's published validation. Uncertainty is documented in the technical annex, not embedded in account tables.

Carbon sequestration measurement

¶1 Carbon sequestration is the ongoing removal of CO₂ from the atmosphere, distinct from carbon storage⁴¹. For mangroves and coastal wetlands, it occurs through biomass accumulation (net growth of vegetation) and sediment burial (organic matter incorporation into accreting sediments)⁴².

¶2 Global average sequestration rates: mangroves approximately 1.5–2.5 tC/ha/yr; saltmarshes approximately 0.5–2.0 tC/ha/yr^{43, 44}.

¶3 **Net sequestration identity (operational rule for the flow account):**

$$\text{Net carbon sequestration (period } t) = \text{Gross biomass increment} + \text{Net soil C accumulation} - \text{Mortality and respiration losses} - \text{Conversion and degradation emissions}$$

¶4 The retention (stock) service is recorded in the condition account⁴⁵. The sequestration (flow) service is recorded in the services flow account using the net identity above⁴⁶. Reporting stock change and additionally applying a sequestration rate per hectare constitutes double counting.

Approach	Description
Biomass change methods	Repeated measurements of vegetation structure with allometric equations applied to compute net biomass increment between censuses.
Sediment carbon burial rate	Radioisotope dating (210Pb CRS, optionally cross-validated with 137Cs) to establish sediment accumulation rates.
Eddy covariance	Direct measurement of net ecosystem CO ₂ exchange (NEE) for intensive sites. NEE captures gas-phase flux only; do not substitute NEE for burial or vice versa. NEE and burial together approximate Net Ecosystem Carbon Balance (NECB) when combined with lateral flux and harvest terms (Chapin et al. 2006).

Sediment carbon burial rate measurement

¶1 The sediment carbon burial rate, also termed the organic carbon accumulation rate (CAR), measures carbon passing below the zone of active decomposition into stable, anoxic long-term storage. It is distinct from standing stock and from short-term surface accumulation.

¶2 **Lead-210 (210Pb) CRS model – primary method:** The Constant Rate of Supply (CRS) model is recommended for vegetated coastal sediments, as it allows sedimentation rates to vary, which is appropriate for blue carbon systems. The carbon accumulation rate is:

¶3 **CAR (g C/cm²/yr) = SAR x DBD x %OC**

¶4 where SAR is sediment accumulation rate (cm/yr); DBD is dry bulk density (g/cm³); %OC is organic carbon content. To convert: 1 g C/cm²/yr = 100 tC/ha/yr.

¶5 Published global mean rates (Arias-Ortiz et al. 2018): mangroves approximately 1.74 tC/ha/yr (range 0.08–4.26); saltmarshes approximately 2.10 tC/ha/yr⁴⁷.

¶6 **Methodological note – mixed layer correction:** Calculate CAR from accumulation rates below the surface mixed layer. Using near-surface values inflates the estimate because carbon in the mixed layer is not yet durably stored (Piñeiro-Juncal et al. 2023).

¶7 **Marker horizon method (feldspar plots) – operational alternative:** Feldspar clay spread across 50 x 50 cm plots captures recent accretion over months to years. Operationally simple but

systematically overestimates long-term burial rates. Use only to characterise recent accretion dynamics. Do not extrapolate to centennial burial rates without correction (Cahoon et al. 1995)⁴⁸.

¶8 Report the method used and time window. For 210Pb CRS, report as centennial mean and, where temporal variation is evident, as a 10- or 25-year recent average. For marker horizons, report as an explicit short-term estimate.

Human disturbance and the accounting treatment of emissions

¶1 When a blue carbon ecosystem is disturbed or converted, the account captures consequences through three mechanisms⁴⁹:

1. ¶2 The **extent account** records area reduction (ha), disaggregated by conversion type (Section 3.1).
2. ¶3 The **condition account** records carbon stock decline across all pools.
3. ¶4 The **services flow account** records change in service supply: where NECB falls to zero or below following disturbance, the carbon sequestration service entry is set to zero (SEEA EA para. 6.114). Emission pulses are not recorded as negative service flows.

¶5 The physical measure for the carbon sequestration service is the Net Ecosystem Carbon Balance (NECB), preferred over Net Ecosystem Productivity because NECB additionally captures disturbance losses, harvest, and lateral fluxes.

¶6 Emission pulses from conversion are directed to the SEEA-CF Air Emission Accounts and to the SEEA-CF Thematic Carbon Stock Account (SEEA-CF 2028 Guidance Note D1, November 2025). Apply IPCC 2013 Wetlands Supplement Chapter 4 emission factors⁵⁰:

Pool	Conversion driver	Default emission factor (IPCC 2013 WS)	Time profile
Above-ground biomass	Clear-cut (any driver)	(1 – harvested wood C retention fraction) x AGB stock	Year of conversion
Soil organic carbon (0–1 m)	Drainage for aquaculture, agriculture, settlements	7.9 tC/ha/yr (~29 tCO ₂ /ha/yr) – tropical default for drained mangrove soils (Table 4.13, Section 4.2.2)	20 years post-drainage
Soil organic carbon (0–1 m)	Erosion exposing buried C	Site-specific (no Tier 1 default)	Year of exposure
Below-ground biomass	Conversion	Released with AGB unless retained as residue	Year of conversion

¶7 The 7.9 tC/ha/yr factor is expressed in tonnes of carbon. Multiply by 44/12 for tCO₂e. Cross-reference **TG-2.8 Climate Change Indicators** for NDC reporting.

Permanence and reversibility – accounting treatment

¶1 Physical carbon stocks are recorded at their measured face value. Risk adjustment belongs to the monetary valuation layer, not the physical account (SEEA EA para. 6.115)⁵¹.

¶2 SEEA EA para. 6.114: “Where net carbon sequestration is zero or negative, the level of service supplied by an ecosystem is zero.” A “permanence buffer” is a voluntary carbon market mechanism (e.g., Verra VM0033) and must not be applied to SEEA EA physical accounts.

¶3 Where blue carbon ecosystems are identified as “at risk”: (a) prioritise high-quality measurement of the retention component (opening stock in tCO₂e); and (b) update stock measurements more frequently, annually if feasible⁵².

Non-CO₂ greenhouse gases (CH₄ and N₂O)

¶1 CH₄ (methane) contains one carbon atom per molecule and can be included in the carbon account expressed in tonnes of carbon. N₂O contains no carbon and is out of scope for the

carbon account⁵³.

¶2 **Methane:** Include as an additional row in the carbon service account expressed in tC. A bridge table linking the carbon account (tC) to a GHG account (tCO₂e) is recommended as a supplementary output. Where CH₄ flux measurements are unavailable, apply IPCC Tier 1 defaults and document the omission.

¶3 Peer-reviewed evidence (Rosentreter et al. 2021, 2022) confirms CH₄ emissions from tropical coastal wetlands can substantially offset CO₂ sequestration benefits when expressed in CO₂e.

¶4 **Supplementary GHG budget table:** Where a complete climate assessment is required, compile a supplementary table: CO₂, CH₄ (x GWP100 = 28), N₂O (x GWP100 = 265), expressed as tCO₂e/yr. This is supplementary and does not modify the core carbon account structure.

Tidal export and lateral carbon fluxes – scope note

¶1 Lateral carbon fluxes (DOC, POC, macroalgae from coastal ecosystems to the open ocean) are out of scope. No agreed accounting methodology exists, and attribution and permanence cannot be reliably established under any adopted framework⁵⁴. Excluding lateral export introduces a conservative bias. Mangroves export an estimated 11–56 tC/ha/yr as POC and DOC (Bouillon et al. 2008). Future iterations will incorporate lateral export guidance as the evidence base matures.

Linking blue carbon accounts to national GHG inventories

¶1 Blue carbon ecosystem accounts are ecosystem accounts under the SEEA EA spatial perspective. National GHG inventories use the IPCC sector-based LULUCF framework. The two are complementary but not directly interchangeable⁵⁵.

¶2 The carbon sequestration service flow (NECB > 0, tCO₂e/yr) corresponds directly to the sink function reported in LULUCF 4.C.1 (Coastal Wetlands). The extent account provides IPCC activity data. The retention service (opening stock, tCO₂e) has no direct UNFCCC inventory equivalent.

¶3 **IPCC reporting category and unit conversion:** Blue carbon ecosystems are reported under LULUCF subcategory **4.C.1 – Coastal Wetlands**. Multiply NECB in tC/yr by **3.664** to obtain tCO₂/yr, and multiply carbon stocks in tC by 3.664 for tCO₂e comparison.

¶4 **Crosswalk – SEEA extent account to IPCC activity data:**

- ¶5 Managed reductions (aquaculture conversion) → IPCC “Land converted to Settlements” or “Land converted to Cropland”
- ¶6 Unmanaged reductions (erosion/SLR) → IPCC “Wetlands remaining Wetlands” with degradation flag
- ¶7 Managed expansions (restoration) → IPCC “Land converted to Wetlands (revegetation)”

¶8 **Large coastal wetland countries and peat-specific guidance:** For countries where coastal wetlands are a key category (Indonesia, Philippines, Malaysia, Madagascar, Australia, Brazil, Mexico), Tier 2 is the minimum for NDC and national communications. For countries with substantial coastal peatland (particularly Indonesia and Malaysia), apply IPCC Wetlands Supplement Chapter 4 Section 4.3 peat decomposition emission factors in addition to standard biomass and surface soil estimates.

¶9 **Recommended integration pathway:** Compile SEEA extent and condition accounts at the highest feasible tier; derive NECB via stock-difference method; classify data quality against IPCC tier framework; report to national GHG inventory compiler as Tier 2 or Tier 3 LULUCF input; document reconciliation between SEEA account boundaries and IPCC reporting categories. The SEEA-CF 2028 Guidance Note D1 (Carbon Stock Account, November 2025) describes the bridge table mechanism.

Carbon condition account (stock variables)

Carbon Pool	Unit	Opening Stock (tC/ha)	Opening Total (tCO ₂ e)	Closing Stock (tC/ha)	Closing Total (tCO ₂ e)	Change (tCO ₂ e)
Above-ground biomass	tC/ha					
Below-ground biomass	tC/ha					
Dead wood	tC/ha					
Litter	tC/ha					
Soil organic carbon (0-1m)	tC/ha					
Total carbon stock	tC/ha					

Carbon services flow account (flow variables)

Service Component	Physical Measure	Unit	Value
Carbon Retention			
Opening stock (reference for retention service)	tCO ₂ e	tCO ₂ e	
Carbon Sequestration (NECB)			
Net biomass carbon accumulation	tCO ₂ e/yr	tCO ₂ e/yr	
Net sediment carbon burial rate	tCO ₂ e/yr	tCO ₂ e/yr	
CH ₄ emissions (if measured)	tC/yr	tC/yr	
Total net sequestration (NECB)	tCO ₂ e/yr	tCO ₂ e/yr	

3.4 Coastal Protection Services

¶1 Coastal protection services are the ecosystem contributions of mangroves, saltmarshes, and other coastal wetlands in protecting shorelines from erosion, wave damage, and storm surge⁵⁶, ⁵⁷. The measurement approaches here are consistent with **TG-6.1 Coral Reef Accounting** Section 3.3, which supports cross-ecosystem aggregation. For general valuation methodology, see **TG-1.9 Valuation**.

¶2 ⓘ Recording rule – coastal protection service

¶3 This Circular is the recording point for the coastal protection service supplied by mangroves, saltmarshes and other coastal wetlands. **TG-6.11 Coastal Infrastructure Accounting** Section 3.3.2 records the produced-asset side – the capital cost and depreciation of engineered and hybrid works – and cross-refers here for the service; it does not estimate a second protection value for the same area. **TG-6.15** Section 3.8 supplies the method for comparing the two.

Wave attenuation and storm surge reduction

¶1 Mangroves and saltmarshes reduce wave energy through friction with vegetation⁵⁸. Wave height reductions of 13–66% per 100 metres of mangrove forest have been demonstrated, with higher attenuation in denser vegetation and lower water depths⁵⁹. Saltmarshes attenuate approximately 78–95% over 100-metre widths⁶⁰.

¶2 Coastal wetlands also reduce storm surge heights by 4–50 cm per km of forest width depending on storm intensity and forest characteristics⁶¹, ⁶². Key factors determining supply:

- ¶3 Forest width and density
- ¶4 Species composition (different root structures provide varying resistance)
- ¶5 Bathymetry and coastal slope
- ¶6 Storm characteristics

¶7 **Reference values for benefit transfer and simplified spatial models:**

- ¶8 *Minimum mangrove width threshold*: 100 m for sheltered coastlines; 500 m for open-ocean exposed coasts (ABS 2022).
- ¶9 *Wave-height attenuation*: 30–70% per 100 m of vegetated width (McIvor et al. 2012); apply lower end to sparse/fragmented stands, upper end to dense mature stands.
- ¶10 *Global benefit transfer*: Menendez et al. (2020) report approximately USD 65 billion/yr avoided flood damages across 14 Mha globally; order-of-magnitude USD 4,600/ha/yr global average, adjusted by PPP and coastline exposure before local application.

¶11 Compilers with hydrodynamic modelling capacity should follow the World Bank expected damage function approach (World Bank 2016)⁶³. Cross-reference **TG-2.8 Climate Change Indicators** for the linkage to climate-vulnerability indicators.

Physical measurement

¶1 Recommended metrics⁶⁴:

- ¶2 **Wave attenuation rate** (% reduction per 100m width)
- ¶3 **Storm surge reduction** (cm reduction per km width)
- ¶4 **Shoreline erosion prevention** (m/yr erosion avoided)
- ¶5 **Protected coastline length** (km fronted by wetlands)

¶6 Beneficiary identification is essential: residential and commercial property owners; infrastructure; agricultural land; coastal communities.

Coastal protection service account

Metric	Unit	Value
Mangrove fringe width	m	
Wave attenuation rate	% per 100m	
Coastline protected	km	
Population protected	persons	
Property value protected	\$	
Average annual protection service	\$ avoided damages/yr	

3.5 Nursery Habitat Services

¶1 Mangroves and coastal wetlands provide nursery habitat through structural complexity (roots and stems providing refuge), food resources (detritus and invertebrate prey), environmental moderation (reduced wave energy and thermal buffering), and connectivity to offshore adult habitats⁶⁵, ⁶⁶. The nursery function supports commercial and subsistence fisheries by providing juvenile habitat.

Ecological basis and intermediate service accounting

¶1 Nursery services are classified as intermediate ecosystem services in SEEA EA (para 6.15): they contribute to the final biomass provisioning services recorded in fisheries accounts⁶⁷. To avoid double counting, nursery service values should not be added to the fisheries production they support. Record separately as an intermediate input using the supply-use framework in SEEA EA Chapter 7. If a fisheries accounting circular is compiled (e.g., TG-6.7), document the linkage explicitly⁶⁸.

Species-habitat relationships

¶1 Key evidence linking mangrove/wetland habitat to fisheries productivity⁶⁹, ⁷⁰:

- ¶2 Juvenile density surveys quantifying fish and invertebrate use of wetland habitats

- ¶3 Tagging and genetic studies tracing adult fish to nursery origins
- ¶4 Correlations between wetland extent and fisheries catch at regional scales

¶5 Published syntheses document positive relationships between mangrove area and catches of penaeid shrimp, mud crabs, barramundi, and snappers⁷¹. Anneboina & Kumar (2017) estimated the marginal effect at 1.86 t/ha fringe mangrove per year (~USD 1,900/ha/yr), derived from a stochastic production frontier model and not applicable as a universal transfer value without local calibration⁷².

Fish recruitment metrics

Metric	Description
Juvenile fish density	Individuals per unit area or volume of habitat.
Species composition	Diversity and proportion of commercially important species.
Growth rates	Productivity of the nursery habitat.
Survival rates	Proportion of juveniles surviving to recruit to adult populations.
Recruitment contribution	Proportion of adult population derived from wetland nurseries.

¶1 Where field data are limited, wetland area with demonstrated fish use (based on published studies for the biogeographic region) provides a Tier 1 proxy.

¶2 **Allocation rule for intermediate vs final service value.** Record the intermediate nursery service at its marginal contribution to the final catch: production-function elasticity of catch with respect to nursery habitat multiplied by catch value. The final fisheries provisioning entry is reported net of this intermediate value. Published estimates indicate 30–50% of penaeid shrimp catch in tropical mangrove countries is traceable to mangrove nursery use (Hutchison et al. 2014). Cross-reference **TG-4.10 Fisheries Statistics and EBM** for the fisheries-account interface.

Nursery service account structure

Metric	Unit	Value
Wetland nursery habitat area	ha	
Juvenile fish density	individuals/ha	
Commercially important species	count	
Annual recruitment to fisheries	tonnes	
Proportion from wetland nurseries	%	
Contribution to fisheries production	tonnes/yr	

Provisioning services – partition with fisheries account

- ¶1 *Plant-derived NTFPs*: timber poles, fuelwood, honey, tannin, palm fronds, medicinal plants, dyes, and resins – recorded in this circular’s provisioning section.
- ¶2 *Mangrove-substrate fauna harvest*: mud crab, cockle, wild shrimp post-larvae, mudskipper – route through the fisheries account (**TG-4.10**) where catch statistics exist. Where unavailable, record here as provisional pending fisheries account integration. The intermediate nursery allocation rule applies to wild post-larvae collection.

3.6 Valuation Methods

¶1 Monetary valuation applies the general framework from **TG-1.9 Valuation** to mangrove- and wetland-specific contexts⁷³.

Carbon pricing

¶1 For blue carbon services⁷⁴:

¶2 **Social cost of carbon (SCC):** Appropriate for the carbon retention component, applied as: (opening stock in tCO₂e) x (SCC per tCO₂e) x (rate of return). The SEEA Valuation gives a range of USD 14.9–80.5/t CO₂ in 2020⁷⁵, though subsequent analyses have revised that range substantially upward. Applying SCC to retention (standing stock) remains an area of active methodological debate, and the SEEA EA 2021 adopts the two-component model (Keith et al. 2019).

¶3 **Compliance market prices:** Appropriate for the carbon sequestration component⁷⁶. Specify price source, date, and any adjustments applied. VCM prices are not recommended for SEEA-EA-aligned monetary accounts: VCM prices historically underestimate exchange values⁷⁷. Obtain current prices from the World Bank State and Trends of Carbon Pricing report or national carbon pricing instruments.

Avoided damage valuation

¶1 Coastal protection services are valued using avoided damage cost methods⁷⁸. The expected damage function (EDF) approach requires:

Element	Description
Hazard modelling	Probability distribution of storm events and surge heights/wave energy.
Exposure assessment	Identification and valuation of assets at risk.
Vulnerability functions	Relationship between hazard intensity and damage extent.
Counterfactual analysis	Comparison of damages with and without wetland protection.

¶2 Menendez et al. (2020) estimated global mangrove flood protection benefits exceed USD 65 billion annually^{79, 80}.

¶3 **Replacement cost methods** provide a Tier 2 alternative; for seawall unit cost benchmarks and annualisation procedure, see **TG-3.2 Flows from Environment to Economy** Section 3.5⁸¹.

¶4 **Benefit transfer:** Where primary EDF analysis is not feasible, draw on published global and regional valuations (Menendez et al. 2020; InVEST Coastal Vulnerability model), adjusting for coastline exposure, asset density, and PPP.

Productivity change methods

¶1 Nursery habitat services are valued using productivity change methods⁸²:

Step	Description
Production function estimation	Statistical relationship between wetland area/condition and fisheries catch.
Marginal productivity calculation	Additional catch attributable to marginal wetland area.
Market value application	Multiplication by appropriate fish prices.

¶2 Anneboina & Kumar (2017) estimated gross value at ~USD 1,900/ha/yr using a production frontier model for Indian mangroves^{83, 84}.

Aggregation and double counting

¶1 Carbon and coastal protection services are largely independent and additive. Nursery services are intermediate inputs and must not be summed with fisheries production values (see Section 3.5 allocation rule). The SEEA EA supply-use framework ensures each service flow is recorded once^{85, 86}.

Valuation summary table

Service	Valuation Method	Tier	Key Parameters
Carbon retention	Social cost of carbon	1–3	Carbon price, discount rate
Carbon sequestration	Compliance market price	2–3	Compliance market prices (VCM prices not SEEA-aligned)
Coastal protection	Avoided damage cost	2–3	Storm probabilities, asset values
Coastal protection	Replacement cost	2	Engineering cost estimates
Coastal protection	Benefit transfer	1	Published global estimates, PPP adjustment
Nursery habitat	Productivity change	2–3	Production function, fish prices
Nursery habitat	Habitat extent proxy	1	Area of suitable habitat, regional unit values

3.7 Compilation Procedure

¶1 Step 1: Data Collection

¶2 Compile: (1) spatial data (Landsat, Sentinel-2, SAR, national vegetation maps, protected area boundaries); (2) extent data (remote sensing, national wetland inventories, Global Mangrove Watch); (3) condition data (field surveys, remote sensing variables); (4) carbon data (biomass measurements, sediment cores, allometric equations, literature values); (5) service data (wave attenuation studies, storm assessments, fisheries statistics, juvenile fish surveys); (6) valuation data (carbon prices, coastal property values, fish prices, engineering cost estimates). Coordinate across environmental ministries, statistical offices, meteorological agencies, and fisheries authorities.

¶3 Step 2: Classification and Mapping

¶4 Map national classifications to IUCN GET functional groups (MFT1.1, MFT1.2, MFT1.3). Define EAA boundaries. Classify ecosystems by remote sensing. Validate using ground-truth surveys.

¶5 Step 3: Extent Account Compilation

¶6 Generate baseline extent map; detect changes using multi-date imagery; classify as managed/unmanaged expansions or reductions; populate extent account. Validate: Closing extent = Opening extent + Additions – Reductions.

¶7 Step 4: Condition Assessment

¶8 Confirm minimum tier (IPCC Wetlands Supplement Tier Framework, Section 3.3) and record in account metadata. Select condition variables from all six ECT classes; measure using field surveys and remote sensing; establish reference conditions; normalise into indicators; compile condition account.

¶9 Step 5: Ecosystem Service Quantification

¶10 *Blue carbon*: Measure carbon stocks by pool; enter NECB into services flow account; document disturbance events and direct emission pulses to SEEA-CF accounts. Compile carbon condition account (stocks) and carbon services flow account (flows) as two separate tables.

¶11 *Coastal protection*: Map mangrove/wetland fringe and forest width; identify protected coastline and beneficiary populations; estimate wave attenuation; quantify storm surge reduction.

¶12 *Nursery habitat*: Delineate nursery habitat; measure juvenile fish density and species composition; estimate recruitment contribution; link extent/condition to fisheries production using production functions.

¶13 Step 6: Monetary Valuation

¶14 Apply carbon pricing (SCC for retention, compliance market price for sequestration; VCM prices are not SEEA-aligned). Calculate avoided damages or replacement costs for coastal protection. Estimate productivity contributions for nursery habitat. Document assumptions, price

sources, and uncertainty. For finance instrument applications, refer to **TG-1.8 OA and Project-Level Finance**⁸⁷.

¶15 **Step 7: Account Integration and Balancing**

¶16 Reconcile accounts for mutual consistency. Check stock-flow balancing identities. Link to national ocean accounts, climate accounts, and fisheries accounts. Prepare metadata. Compile time series.

Note on additionality, leakage, and baseline analyses

Where account outputs are intended to support carbon market instruments or results-based payments, additionality assessment, counterfactual baseline construction, and leakage analysis are applied on top of the account by the relevant market methodology (e.g., Verra VM0033).

Document pre-intervention carbon stock values in the condition account to facilitate subsequent additionality assessment.

3.8 Worked Example

¶1 This worked example demonstrates the full accounting sequence for a hypothetical coastal zone in a Southeast Asian setting. All data are synthetic and illustrative.

¶2 **Setting:** 8,000 ha of mangrove forest (MFT1.2) and 3,000 ha of salt marsh (MFT1.3), totalling 11,000 ha dominated by *Rhizophora* and *Avicennia* species.

¶3 **Step 1: Extent account (year t to t+1)**

Entry	Mangroves (MFT1.2)	Saltmarshes (MFT1.3)	Total
Opening extent (ha)	8,000	3,000	11,000
Additions to extent			
– Managed expansions (restoration planting)	120	25	145
– Unmanaged expansions (natural colonisation)	45	15	60
<i>Total additions</i>	165	40	205
Reductions in extent			
– Managed reductions (aquaculture conversion)	200	10	210
– Unmanaged reductions (erosion, storm damage)	65	30	95
<i>Total reductions</i>	265	40	305
Net change in extent	-100	0	-100
Closing extent (ha)	7,900	3,000	10,900

¶4 **Interpretation:** Net loss of 100 ha of mangroves driven by aquaculture conversion exceeding restoration. Saltmarshes showed no net change.

¶5 **Step 2: Condition account**

¶6 Condition indicators derived from field survey and remote sensing, using minimally disturbed reference sites:

Condition variable	Observed value	VH (reference)	VL (degraded)	Indicator score
Canopy cover	72%	90%	20%	0.74
Seedling density	3,200 stems/ha	5,000	500	0.60
Sediment accretion rate	4.5 mm/yr	6.0	1.0	0.70
Water quality (dissolved oxygen)	5.8 mg/L	7.0	3.0	0.70

¶7 Composite condition index (equal weights): $(0.74 + 0.60 + 0.70 + 0.70) / 4 = 0.69$

¶8 Indicator score calculated using the normalisation formula in **TG-2.1** Section 3.4.1. Example: canopy cover indicator = $(72 - 20) / (90 - 20) = 52 / 70 = 0.74$.

¶9 **Important:** The condition index of 0.69 is a tracker, not a carbon stock multiplier. Each pool is measured independently and entered at its measured value.

¶10 Step 2b: Carbon condition account (mangroves, MFT1.2)

Carbon pool	Method	Opening (tC/ha)	Closing (tC/ha)	Opening total (tC)	Closing total (tC)
Above-ground biomass	Komiyama et al. (2005) allometric	120	116	960,000	916,400
Below-ground biomass	Root:shoot ratio 0.70	84	81	672,000	640,000
Dead wood	Field inventory	5	5	40,000	39,500
Litter	Litterfall traps	2	2	16,000	15,800
SOC (0–1 m)	Sediment coring, bulk density	450	447	3,600,000	3,531,300
Total		661	651	5,288,000	5,143,000

¶11 Opening: 8,000 ha. Closing: 7,900 ha (net loss of 100 ha; 200 ha converted to aquaculture). Carbon fraction: a single illustrative 45% of dry biomass is applied to AGB and BGB; compilers apply the pool-specific fractions in footnote 34 (0.47 AGB, 0.39 BGB). SOC expressed directly in tC.

¶12 Net change: $5,143,000 - 5,288,000 = -145,000$ tC (about 66,100 tC from the net loss of 100 ha at the opening density of 661 tC/ha, and about 79,000 tC from the decline of 10 tC/ha across the remaining 7,900 ha).

¶13 Step 3a: Carbon services flow account (annual flows)

Service flow component	Physical measure	Unit	Annual value
Change in biomass carbon pools (AGB, BGB, dead wood, litter)	Stock difference, Step 2b (–76,300 tC)	tCO ₂ e/yr	–279,600
Change in soil organic carbon (0–1 m)	Stock difference, Step 2b (–68,700 tC)	tCO ₂ e/yr	–251,700
Net ecosystem carbon balance (NECB)	Stock difference, –145,000 tC x 3.664	tCO ₂ e/yr	–531,300
Net carbon sequestration service supply	NECB (floored at zero where negative)	tCO₂e/yr	0

¶14 NECB is derived by the stock-difference method (Section 3.3): $-145,000$ tC x 3.664 = –531,300 tCO₂e/yr. Because NECB is negative, the carbon sequestration service entry is set to zero (SEEA EA para. 6.114). A per-hectare burial or accumulation rate is not added on top of the measured stock change, which would double count. The loss is directed to SEEA-CF Air Emission Accounts (aquaculture sector) and the Thematic Carbon Stock Account. Carbon retention service ($5,288,000$ tC = 19,375,000 tCO₂e opening stock) is recorded in the condition account above.

¶15 Corrected 24 September 2026

¶16 This flow account previously showed net sequestration of +20,500 tCO₂e/yr, built from per-hectare rates, while the measured stocks in Step 2b fell by 145,000 tC; on this circular's own stock-difference rule NECB is negative, so the sequestration service is now zero and the asset value falls from USD 201.3 million to USD 175.7 million.

¶17 Step 3b: Ecosystem service monetary valuation summary

Service	Physical quantity	Monetary value (USD)
Carbon sequestration	0 tCO ₂ e/yr (NECB negative)	0 (at USD 80/t CO ₂ e)
Coastal protection	85 km coastline protected	6,400,000 (avoided damage)
Fisheries nursery habitat	2,100 tonnes recruitment	3,900,000 (productivity change)
Timber and NTFPs	1,500 m ³ timber; assorted NTFPs	950,000 (market price)
Total valued services		11,250,000

¶18 *Carbon sequestration*: $0 \times \text{USD } 80 = \text{USD } 0$. The price applies in a period where NECB is positive.

¶19 *Coastal protection*: Expected damage function approach; avoided damages across storm probability distribution = USD 6.4 million/yr.

¶20 *Nursery habitat*: Marginal contribution: 0.25 t catch/ha/yr. Nursery area: 8,400 ha (8,000 ha mangrove fringe + 400 ha salt marsh adjacent to tidal creeks; 2,600 ha inland salt marsh excluded as lacking direct fish access). Contribution: $8,400 \times 0.25 = 2,100$ t/yr. At average fish price USD 1,857/t: USD 3,900,000. Note: If fisheries provisioning is separately valued in national accounts (TG-6.7), exclude the nursery value from the total to avoid double counting. Presented here for illustrative purposes.

¶21 **Step 4: Asset valuation**

Asset value = Annual service value $\times$ PV annuity factor (4%, 25 years) *Asset value = $11,250,000 \times 15.62 = \text{USD } 175,700,000$*

¶22 PV annuity factor: $[1 - (1 + 0.04)^{-25}] / 0.04 = 15.62$.

¶23 **Step 5: Upward connections to policy circulars**

¶24 **TG-2.8**: The net carbon stock change of -145,000 tC (-531,300 tCO₂e, a net loss) and above-ground carbon stocks feed into NDC blue carbon reporting and SDG 13 monitoring.

¶25 **TG-2.9**: Coastal protection value of USD 6.4 million/yr and 85 km protected coastline feed into vulnerability assessments for disaster risk reduction.

¶26 **TG-1.8**: Asset value of USD 175.7 million and annual service flows provide the measurement foundation for blue bonds, debt-for-nature swaps, or payments for ecosystem services.

¶27 All values are illustrative. The carbon price of USD 80/t CO₂e should be replaced with the prevailing compliance market price or social cost of carbon applicable in the compiler's jurisdiction.

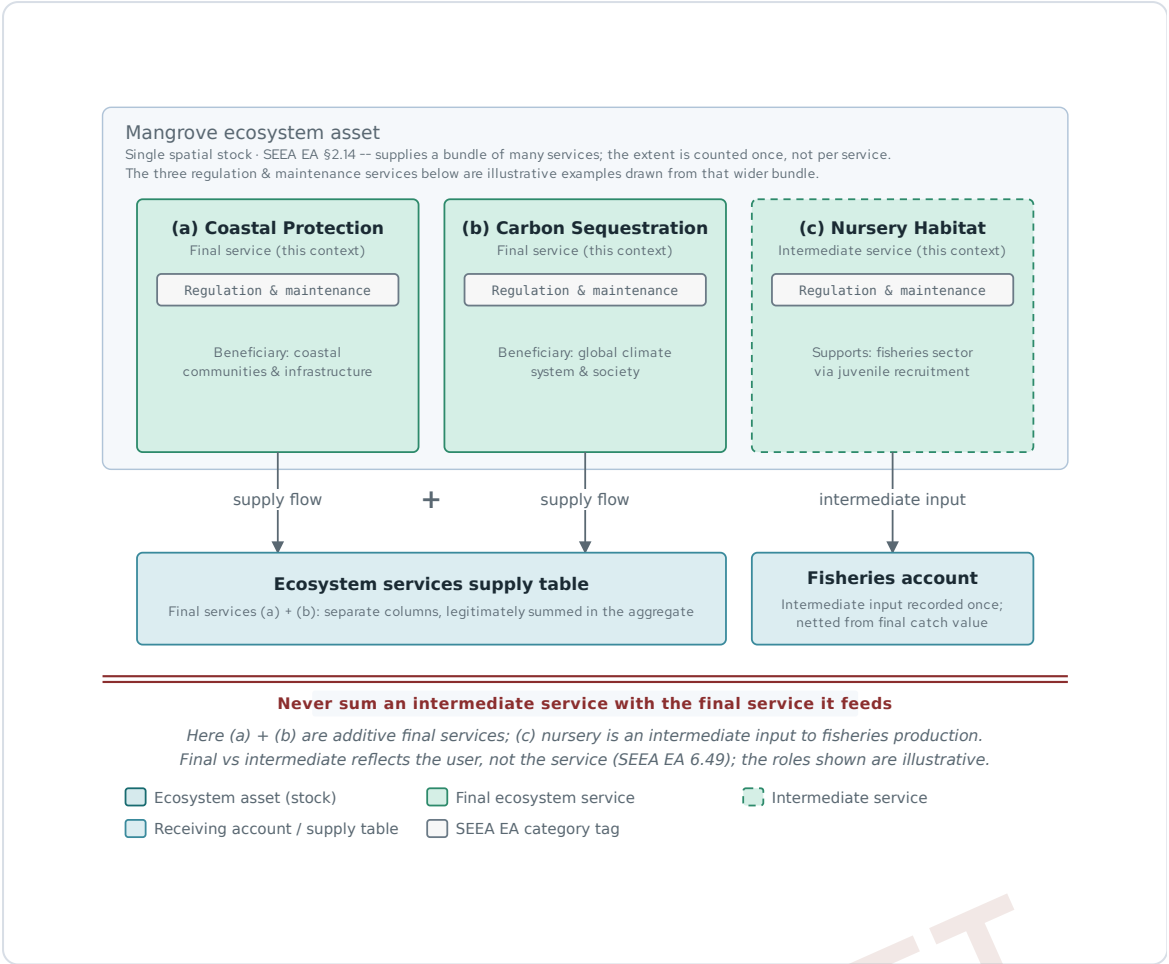


Figure 6.2.2 One mangrove ecosystem asset supplies a service bundle: two final services may be summed; nursery is intermediate; extent is counted once. Final/intermediate role is user-context dependent (SEEA EA para. 6.49).

Source: TG-6.2, Sections 3.3--3.6 (mangrove service bundle worked example); final/intermediate distinction per SEEA EA 2024, paras. 6.24 and 6.49; nursery treatment per para 6.15.

Adapted from: SEEA EA 2024 ecosystem service concepts (Chapter 6), with GOAP extensions (final/intermediate routing, single-extent caution, beneficiary sub-labels, illustrative-subset framing).

4. Acknowledgements

- ¶1 **Authors:** [To be confirmed]
- ¶2 **Reviewers:** [To be confirmed]

5. References and Further Reading

¶1 **SEEA framework and ecosystem accounting:**

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¶56 Nursery habitat services:

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FOOTNOTES

- ¶1 IUCN GET describes the MFT1 Brackish Tidal Systems biome as "associated with prograding depositional shore-lines at the interface of terrestrial, freshwater, and marine realms."
- ¶2 IUCN GET, Biome MFT1 description; SEEA EA, Appendix A3.2 presents the IUCN GET reference classification.
- ¶3 SEEA EA, para 4.11-4.12 on ecosystem type classification and the relationship between national classifications and the international reference classification.
- ¶4 SEEA EA, para 1.1, noting that "ecosystem accounting provides a basis for compiling coherent and systematic data on the biophysical characteristics of ecosystems and their contribution to the economy and society"; see also World Bank (2016) on mangrove values.
- ¶5 SEEA EA, para 4.1: "Ecosystem extent is the size of an ecosystem asset. It is usually measured in terms of spatial area."
- ¶6 SEEA EA, para 4.11-4.12 on ecosystem type classification.
- ¶7 National classification systems may distinguish mangrove types based on dominant species or structural classes; see FAO mangrove classification systems.
- ¶8 SEEA EEA Technical Recommendations, Chapter 3 on spatial data organization.
- ¶9 SEEA EEA Technical Recommendations, para 3.79.
- ¶10 SAR applications for mangrove mapping are well-established; see references in Global Mangrove Watch methodology.
- ¶11 Global Mangrove Watch provides globally consistent annual mangrove extent maps; available at www.globalmangrovetwatch.org (<http://www.globalmangrovetwatch.org>).
- ¶12 Murray et al. (2019) on global tidal wetland change mapping.
- ¶13 SEEA EA, para 4.14-4.16 on accounting entries for extent changes.
- ¶14 IPCC (2006/2019 Refinement), Volume 4, Chapter 3 on consistent representation of lands. See also Bunting et al. (2018) on Global Mangrove Watch accuracy assessment procedures.
- ¶15 SEEA EA, para 4.16.
- ¶16 SEEA EA, para 4.8.
- ¶17 SEEA EA, Table 4.1 provides the ecosystem extent account structure.
- ¶18 SEEA EA, para 5.1: "Ecosystem condition accounts provide a structured approach to recording and aggregating data describing the characteristics of ecosystem assets and how they have changed."
- ¶19 SEEA EA, para 5.2.
- ¶20 SEEA EA, Section 5.2.4 on ecosystem condition variables and their selection.
- ¶21 SEEA EA, Table 5.1 presents the SEEA Ecosystem Condition Typology with six classes.
- ¶22 SEEA EA, para 5.36.
- ¶23 SEEA EA, para 5.35.
- ¶24 Hydrological connectivity is fundamental to tidal wetland function; disruption is a major driver of degradation globally.
- ¶25 SEEA EA, para 5.11 notes ecosystem resilience considerations; sediment elevation monitoring is critical for sea-level rise adaptation.
- ¶26 SEEA EA, Section 5.3 on reference conditions for ecosystem condition assessment.
- ¶27 UNSD (2023), Method of the Ecosystem Condition Account; Howard et al. (2014) on minimum plot specifications for blue carbon surveys; GFOI (2025) on sampling requirements for national inventory submissions.
- ¶28 SEEA EA, paras 6.110-6.115; UNSD (2023), Method of the Ecosystem Condition Account. SOC non-proportional degradation is well-established: deep sediment SOC may persist for centuries even after surface biomass removal because anaerobic conditions limit decomposition.
- ¶29 SEEA EA, Table 5.2 provides the ecosystem condition variable account structure.
- ¶30 United Nations (2022), Monetary Valuation Technical Report v1.5, Section 4.2.9; Keith et al. (2019), London Group paper on accounting for carbon stocks and flows.
- ¶31 IPCC (2013), Wetlands Supplement, Chapter 4; IPCC (2019) Refinement, Volume 4, Chapter 7. Tidal flat accounting gaps acknowledged in GFOI (2025).

2. ¶32 IPCC (2013), Wetlands Supplement, Chapter 4 escalation guidance; High Level Panel for a Sustainable Ocean Economy (2023), Blue Carbon Handbook.
3. ¶33 SEEA EA, para 6.114; Lim et al. (2025) on macroalgal ecosystem inclusion in IPCC inventories.
4. ¶34 IPCC 2013 Wetlands Supplement provides methodology for blue carbon stock accounting across five standard pools.
5. ¶35 Above-ground biomass carbon fraction of 0.47 is sourced from IPCC 2006 Guidelines Volume 4 Chapter 4 Table 4.3 (forest biomass carbon fraction). Below-ground biomass carbon fraction of 0.39 is the mangrove-specific value derived from Kauffman et al. (2011) measurements and tabulated in Howard et al. (2014) Table 3.1; this should not be attributed solely to Kauffman & Donato (2012).
6. ¶36 Komiyama et al. (2008) on mangrove root:shoot ratios and allometry.
7. ¶37 IPCC 2013 Wetlands Supplement recommends 1-metre depth for sediment carbon reporting as the standard minimum. Howard et al. (2014) provide coring protocols for depths beyond 1 metre in high-carbon systems.
8. ¶38 IPCC (2013), Wetlands Supplement, Chapter 4; Murdiyarso et al. (2023) on national-scale Tier 2 methodology in Indonesia; Howard et al. (2014) on Tier 3 field protocols.
9. ¶39 Komiyama et al. (2005) pantropical equations; Price et al. (2024) on transatlantic species validation; Butler et al. (2025) on saltmarsh allometry; Howard et al. (2014) on destructive harvest protocols.
0. ¶40 Berger et al. (2020) on allometric uncertainty quantification; SEEA EA conventions on uncertainty reporting in metadata rather than account tables.
1. ¶41 The distinction between carbon storage (stock) and sequestration (flow) is fundamental to carbon accounting; see SEEA Valuation Section 4.2.9.
2. ¶42 SEEA Valuation, Section 4.2.9 on carbon sequestration measurement.
3. ¶43 Duarte et al. (2005); Mcleod et al. (2011) on mangrove carbon sequestration rates.
4. ¶44 Chmura et al. (2003) on saltmarsh carbon sequestration.
5. ¶45 SEEA Valuation, Section 4.2.9 on carbon retention scope.
6. ¶46 SEEA EA and SEEA Valuation recommend distinguishing carbon retention and sequestration components; Keith et al. (2019).
7. ¶47 Arias-Ortiz et al. (2018) global synthesis of ²¹⁰Pb-derived carbon accumulation rates.
8. ¶48 Cahoon et al. (1995) on the feldspar marker horizon technique; Piñeiro-Juncal et al. (2023) on mixed layer corrections and burial rate quantification.
9. ¶49 SEEA EA, paras 6.110-6.115 on disturbance treatment in ecosystem accounts; IPCC 2013 Wetlands Supplement, Chapter 4.
0. ¶50 UNSD/SEEA Technical Committee (2025), Draft Guidance Note D1 – Carbon Stock Account; UNSD/SEEA Technical Committee (2025), Draft Guidance Note B3; IPCC (2013), Wetlands Supplement, Chapter 4 emission factors for conversion events.
1. ¶51 SEEA EA, paras 6.110-6.115.
2. ¶52 SEEA EA, para 6.114; Verra (2018), VM0033; Bertram et al. (2021) on blue carbon wealth of nations and risk assessment.
3. ¶53 Rosentreter et al. (2021, 2022); UNSD/SEEA Technical Committee (2025), Draft Guidance Note D1.
4. ¶54 Bouillon et al. (2008) on mangrove carbon export; High Level Panel for a Sustainable Ocean Economy (2023), Blue Carbon Handbook; Howard et al. (2014).
5. ¶55 GFOI (2025), Blue Carbon Guidance for National GHG Inventories; UNSD/SEEA Technical Committee (2025), Draft Guidance Note D1; IPCC (2013), Wetlands Supplement, Chapter 4; Blue Carbon Partnership (2021).
6. ¶56 SEEA EA, Section 6.3 on ecosystem service reference list includes coastal protection.
7. ¶57 SEEA Valuation, Section 4.2.13 on coastal protection definition.
8. ¶58 Wave attenuation by mangroves has been extensively studied; see McIvor et al. (2012) review.
9. ¶59 Wave attenuation rates vary widely; ranges from synthesis studies.
0. ¶60 Saltmarsh wave attenuation from Moller et al. (2014) and related studies.
1. ¶61 Storm surge attenuation mechanisms differ from wave attenuation; both contribute to coastal protection.
2. ¶62 Storm surge reduction estimates from Krauss et al. (2009) and related studies.
3. ¶63 SEEA Valuation, Section 4.2.13 references World Bank (2016).
4. ¶64 World Bank (2016) provides detailed methodology for coastal protection measurement.
5. ¶65 Blue carbon terminology established by Nellemann et al. (2009); widely adopted in IPCC and UNFCCC contexts. For seagrass-specific guidance, see TG-6.3 Seagrass Ecosystem Accounting.
6. ¶66 Ecological mechanisms of mangrove nursery function; see Nagelkerken et al. (2008).
7. ¶67 SEEA EA reference list definition of nursery population and habitat maintenance services; SEEA Valuation, Section 4.2.14.
8. ¶68 SEEA EA, para 6.15.
9. ¶69 Quantifying nursery-fisheries linkages is essential but methodologically challenging.
0. ¶70 Nursery function metrics following Beck et al. (2001) framework.
1. ¶71 Multiple studies document mangrove-fisheries correlations; see Hutchison et al. (2014) meta-analysis.
2. ¶72 SEEA Valuation, Section 4.2.14 citing Anneboina and Kumar (2017).
3. ¶73 SEEA EA, Chapter 10 on ecosystem asset valuation; SEEA Valuation provides comprehensive guidance.

4. ¶74 SEEA Valuation, Section 4.2.9 on carbon pricing approaches.
5. ¶75 SEEA Valuation, Section 4.2.9 on social cost of carbon estimates.
6. ¶76 SEEA Valuation, Section 4.2.9 on compliance market prices.
7. ¶77 United Nations (2022), Monetary Valuation Technical Report v1.5, Section 4.2.9; Edens et al. (2019); Keith et al. (2019).
8. ¶78 SEEA Valuation, Section 4.2.13 on coastal protection valuation methods.
9. ¶79 SEEA Valuation, Section 4.2.13.
10. ¶80 SEEA Valuation, Section 4.2.13 citing Menendez et al. (2020).
1. ¶81 SEEA Valuation, Section 4.2.13 notes replacement cost as Tier 2 method.
2. ¶82 SEEA Valuation, Section 4.2.14 on productivity change methods for nursery services.
3. ¶83 SEEA Valuation, Section 4.2.14.
4. ¶84 SEEA Valuation, Section 4.2.14 citing Anneboina and Kumar (2017).
5. ¶85 SEEA EA, Section 7.3 on avoiding double counting in ecosystem service accounting.
6. ¶86 SEEA EA supply-use framework ensures consistent recording of service flows.
7. ¶87 Verra (2018), VM0033 Methodology for Tidal Wetland and Seagrass Restoration.

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