

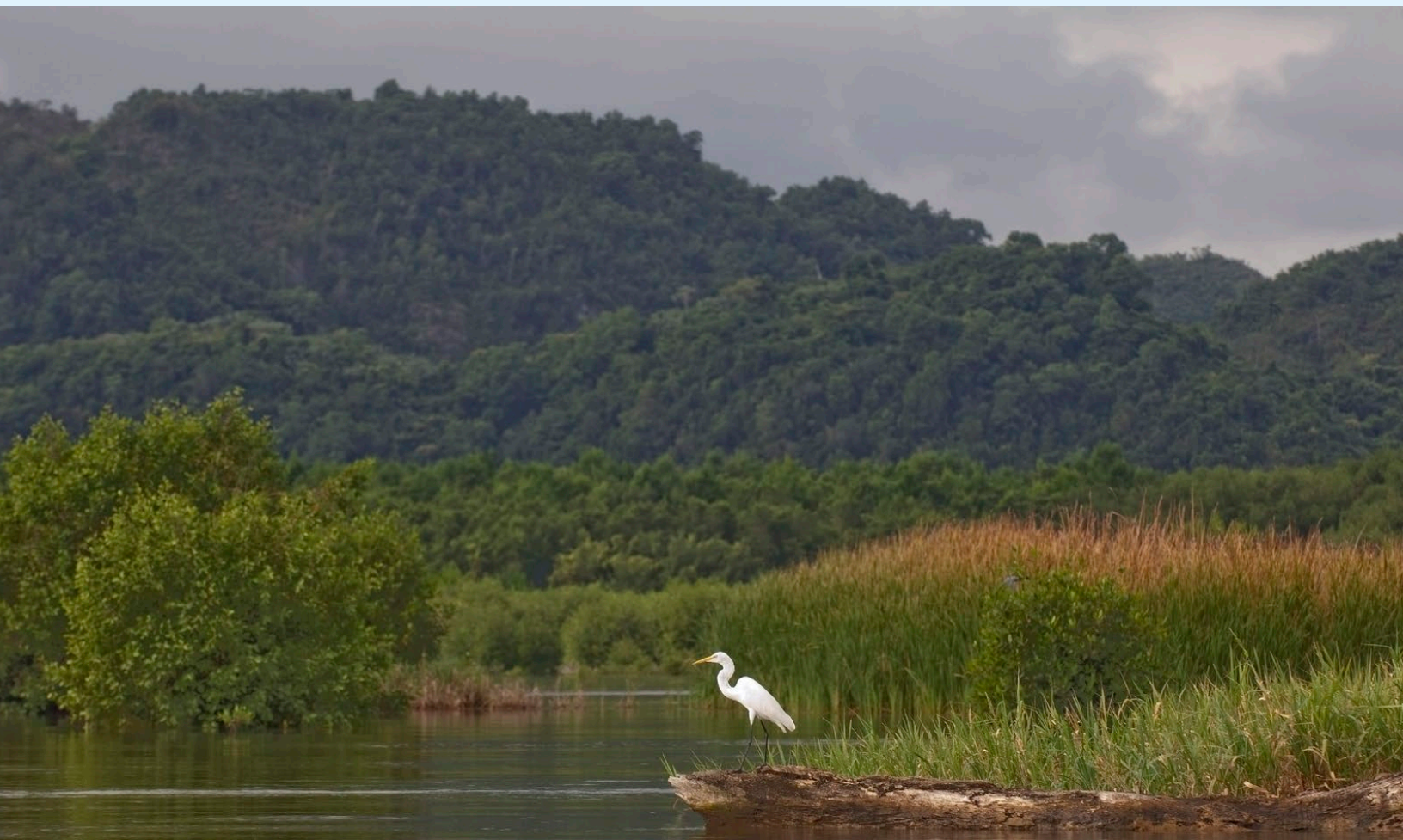


PEMSEA Regional Methodology for Blue Carbon Project Accounting

A Harmonized Guide for Estimating Carbon Stocks, Sequestration, and GHG Reductions in Coastal Ecosystems

Annex C

Salt Marsh Ecosystems – Carbon Stock and Sequestration Assessment Methods



This annex is part of the publication entitled “PEMSEA Regional Methodology for Blue Carbon Project Accounting: A Harmonized Guide for Estimating Carbon Stocks, Sequestration, and GHG Reductions in Coastal Ecosystems. It benefitted from intensive consultations, discussions, and inputs from PEMSEA Country, Non-Country Partners and the PEMSEA Resource Facility supported by Kristina Di Ticman, Blue Carbon consultant. However, the contents of this publication do not necessarily reflect the views or policies of PEMSEA Country and Non-Country Partners and its other participating organizations. The designation employed and the presentation do not imply expression of opinion, whatsoever on the part of PEMSEA concerning the legal status of any country or territory, or its authority or concerning the delimitation of its boundaries.

About Us

Partnerships in Environmental Management for the Seas of East Asia (PEMSEA) is a regional coordinating mechanism for the sustainable coastal and marine development in the East Asian Seas Region.

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C.1 Introduction

Salt marshes, also called tidal salt marshes, are intertidal wetlands that form along sheltered coastlines, estuaries, and embayments where tidal flooding and saline or brackish waters shape their structure. They are dominated by salt-tolerant plants—herbaceous species, grasses, sedges, rushes, and low shrubs—that colonize soft sediments and create distinct zones across tidal gradients. By stabilizing sediments and reducing wave energy, salt marshes play a critical role in coastal protection while supporting highly productive ecological communities.

As blue carbon ecosystems, salt marshes are highly effective in sequestering and storing carbon. Their soils, waterlogged and oxygen-poor, inhibit decomposition, allowing organic matter to accumulate over centuries to millennia. Belowground pools typically account for 65–95% of the total carbon stock in salt marshes, far exceeding the contribution of aboveground vegetation (Howard et. al., 2014). These soil carbon deposits make them among the most persistent and secure natural carbon sinks, while their dense vegetation enhances sediment accretion and nutrient cycling that further promote long-term carbon storage.

Carbon sequestration rates in salt marshes often surpass those of terrestrial forests on an area basis. Global estimates suggest ecosystem carbon stocks ranging between 334 and 593 Mg C ha⁻¹ (Friess et. al., 2020), with roughly 90% stored in sediments (Perera et. al., 2022). Regional studies confirm their importance as carbon hotspots, particularly along the temperate coasts of East Asia, where high sedimentation rates and dense root systems facilitate rapid organic matter burial. Despite their smaller global extent compared to mangroves and seagrasses, salt marshes play a disproportionate role in climate mitigation because of high SOC accumulation rates and long-term burial stability.

In East Asia, extensive salt marshes are found along the eastern seaboard of China (e.g., Yellow River Delta, Yangtze River estuary, and Yancheng coastal wetlands), in South Korea along the West and South Seas, and in Japan on temperate estuarine coasts such as Lake Nakaumi and Osaka Bay (Mason et. al., 2023).

Conservation and restoration programs are recognized as essential to safeguard salt marsh carbon sinks. Restoration approaches such as reintroducing tidal flow, sediment enhancement, and controlling invasive *Spartina alterniflora* are being applied to recover degraded salt marshes and enhance their carbon sequestration capacity. Expanding these efforts across the region is critical to protect remaining marshes, restore lost areas, and fully integrate them into blue carbon strategies.

C.2 Carbon Pools in Salt Marshes

Salt marsh ecosystems store carbon primarily in three major pools: aboveground living biomass (AGB), belowground living biomass (BGB), and soil organic carbon (SOC). While all three contribute to the ecosystem's carbon balance, soils represent the dominant long-term reservoir.

Aboveground Biomass (AGB)

This pool consists of grasses, sedges, rushes, and low shrubs. Although smaller in proportion, aboveground biomass enhances sediment capture and supports ecosystem productivity, with a more prominent role in higher marsh zones.

Belowground Biomass (BGB)

Roots and rhizomes form the majority of the living biomass, often representing 50–95% of total plant production. This pool plays a key role in stabilizing sediments and supplying organic matter that eventually contributes to SOC.

Soil Organic Carbon (SOC)

SOC is the largest and most persistent pool in salt marshes, typically making up 65–95% of total ecosystem carbon stocks and sometimes exceeding 98%. It comprises organic carbon contained within marsh soils, including decomposed plant material, dead roots and rhizomes, and other accumulated organic matter. Living roots and rhizomes quantified under the belowground biomass pool shall be excluded from the SOC estimate to avoid double counting.

Autochthonous and Allochthonous Carbon

Salt marsh carbon originates from both internal and external sources. Autochthonous carbon is produced by marsh plants through photosynthesis and deposited as roots, rhizomes, and decayed vegetation within the marsh. Allochthonous carbon is imported from adjacent terrestrial or marine systems by tides and currents, adding organic matter that becomes trapped in marsh soils. While autochthonous carbon dominates, external inputs can be locally significant, highlighting the dual role of salt marshes as both producers and receivers of organic carbon.

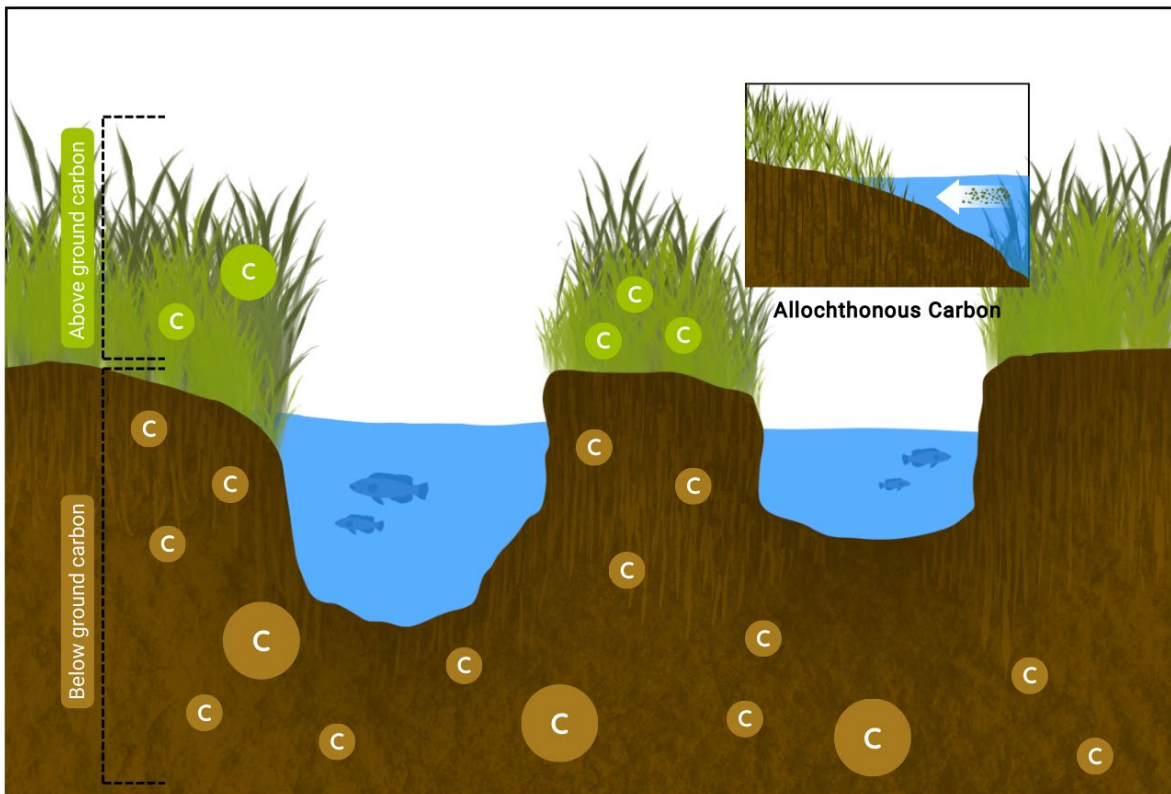


Figure 1: Carbon Pools in Salt Marshes

C.3 Project Design and Sampling Framework

Designing a salt marsh carbon accounting project requires clear definition of project boundaries, appropriate stratification of the marsh area, and a statistically robust sampling design. These steps are essential to ensure that estimates of carbon stocks are representative, accurate, and suitable for long-term monitoring and reporting.

C3.1 Defining Project Area Boundaries

The first step is to delineate the project area, which establishes the scope of assessment and monitoring. Boundaries should reflect the ecological distribution of salt marshes while excluding adjacent ecosystems, such as mangroves, tidal flats, or seagrasses, unless specifically included in the project objectives. Once defined, these boundaries must remain fixed for comparability over time, with any adjustments fully documented.

Boundaries are typically determined using high-resolution satellite or aerial imagery, supported by GIS analysis and existing survey data. In areas where remote sensing data are limited, field surveys and local ecological knowledge provide essential validation. Mapping should clearly identify marsh zones (e.g., low, mid, and high marsh) and capture dominant vegetation and hydrological features such as tidal creeks and channels.

C3.2 Project Area Stratification

Salt marshes are heterogeneous systems influenced by tidal regime, elevation, vegetation, and salinity. Stratification divides the project area into more homogeneous units, reducing sampling error and improving the precision of carbon stock estimates.

Common stratification criteria include:

- Elevation and tidal inundation: Low marsh, mid/high marsh, and higher marsh zones differ in vegetation type, flooding frequency, and carbon storage.
- Vegetation composition and density: Tidal salt marshes consist of grass, shrub, and reed growth forms, which influence above- and below-ground biomass.
- Soil and salinity gradients: Salinity and sediment type influence soil organic carbon stocks and greenhouse gas fluxes.

Stratification should initially be guided by GIS and remote sensing data, then refined and validated through field surveys.

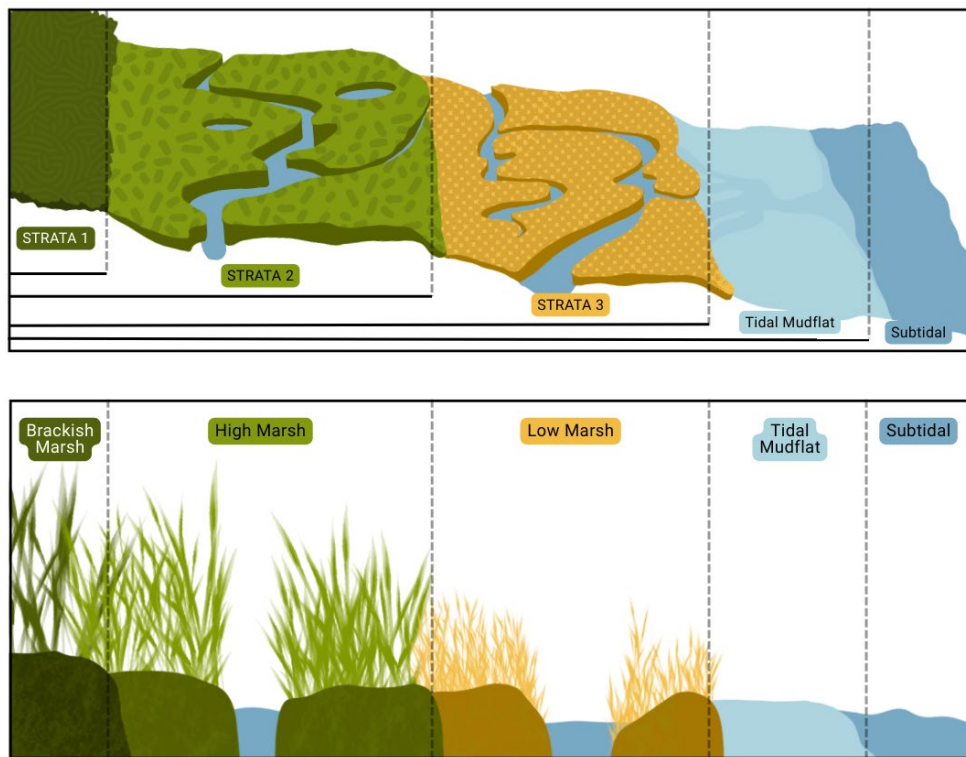


Figure 2: Sample salt marsh stratification

C3.3 Sampling Design

Within each stratum, representative sampling plots are established to capture variability in biomass and soil carbon. Plot placement should follow probability-based approaches (e.g., randomized or systematic grid designs) to avoid bias. Transect-based layouts, oriented perpendicular to tidal channels or shorelines, are often appropriate for salt marshes to capture gradients in elevation, hydrology, and vegetation.

C3.4 Plot Layouts

Plot and subplot dimensions should correspond to the type of carbon pool measured:

- Standard plots: For long-term monitoring, fixed plots of around 20 × 50 m are suitable within each stratum.

- Vegetation subplots: Smaller quadrats (e.g., 0.25×0.25 m or 0.5×0.5 m) are used to sample herbaceous biomass such as grasses, sedges, and succulents. For areas with low shrubs, larger quadrats (e.g., 1 m^2) may be required.
- Nested designs: Nested subplots can be employed to capture both fine-scale herbaceous cover and coarser shrub structures within the same plot.
- Soil and belowground sampling: Soil cores and root samples are collected within plots to represent belowground biomass and SOC, acknowledging that the belowground pool is the dominant component of salt marsh carbon stocks.

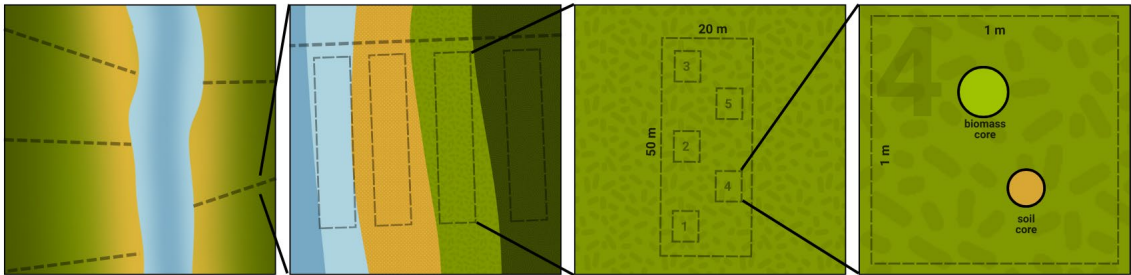


Figure 3: Sample salt marsh plot layouts

C3.5 Number of Plots and Precision Targets

The number of plots must be sufficient to achieve the desired statistical confidence. At least three plots per stratum are recommended, though more may be necessary in heterogeneous systems. For carbon-market sampling design, the target is a 90% confidence interval with a half-width no greater than 10% of the estimated mean carbon stock. Document any additional precision requirements imposed by the applicable certification framework. Preliminary surveys can be used to estimate variance and optimize sample size.

C3.6 Monitoring Schedule and Operational Considerations

Salt marsh biomass and productivity vary seasonally, with patterns differing among species, geographic regions, and environmental conditions. To support comparison across monitoring periods, biomass surveys should be conducted under comparable, site-appropriate seasonal and phenological conditions. Where peak biomass is the intended reference condition, its timing should be established from local observations or relevant ecological information. Sampling dates, tidal conditions, and relevant environmental observations should be documented. Monitoring intervals shall be established according to the carbon pool and monitoring objectives, consistent with Section C10.2.

C.4 Data Collection and Analysis Methods

Accurate quantification of carbon stocks in tidal salt marsh ecosystems requires standardized methods for sampling, processing, and analysis. The primary focus is on aboveground and belowground biomass and on soil organic carbon, as these pools dominate ecosystem carbon storage.

C4.1 Above and Belowground Biomass

Because species-specific allometric equations are largely unavailable for salt marsh vegetation, biomass quantification relies on destructive sampling methods. Aboveground biomass is measured through quadrat-based clipping of vegetation, while belowground biomass is assessed using coring techniques. Both pools are processed through drying and weighing to obtain biomass estimates that can be converted into carbon stocks.

C4.1.1 Equipment for Biomass Collection and Analysis

Accurate biomass assessment involves both field equipment for documentation and sampling and laboratory equipment for processing and carbon analysis.

Field Equipment for Biomass Collection

- Quadrats: Square frames (typically 0.25×0.25 m or 0.5×0.5 m) are used to delineate sampling areas for aboveground vegetation. Larger quadrats (up to 1 m^2) may be used where vegetation is sparse or includes low shrubs.
- Cutting Tools: Scissors, clippers, or small sickles are used to harvest all standing vegetation within the quadrat for aboveground biomass sampling.
- Coring Devices: Soil augers, peat drills, or PVC corers (minimum of 15 cm diameter) are used to collect belowground biomass (roots and rhizomes) together with associated soil material.
- Measuring Tools: Plant height is measured with a tape measure or graduated rod. For shrubs, basal stem diameter may also be recorded.
- Sample Handling: Mesh bags, plastic sample bags, waterproof labels, and permanent markers are used for secure storage and documentation.
- Location and Documentation: Handheld GPS units record precise coordinates for plots. Cameras or smartphones provide visual documentation of site conditions and sample collection.

Laboratory Equipment for Biomass Analysis

- Drying Ovens: Samples are dried at 60–70 °C until constant weight is achieved (commonly 48–72 h).
- Desiccators: Used to cool dried samples without moisture absorption.
- Balances: Analytical balances (± 0.001 g precision) are used to weigh dried biomass.
- Grinding Equipment: Mortar and pestle or automated mills homogenize subsamples for further carbon analysis (e.g., elemental analysis).

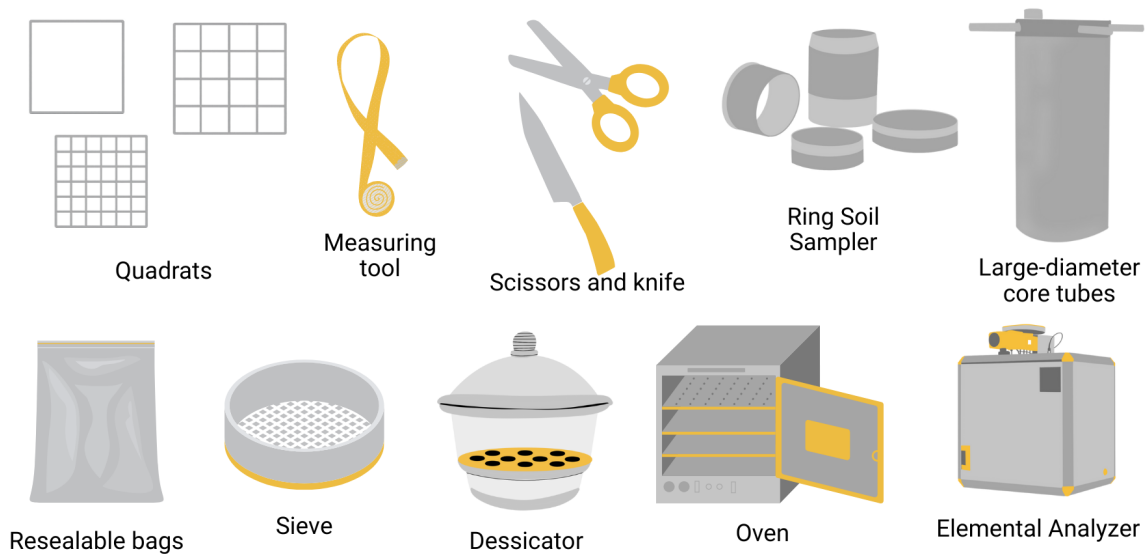


Figure 4: Sample tools and equipment used for salt marsh data collection and analysis

C4.1.2 Visual Assessment

Before collecting biomass samples, a visual assessment of the salt marsh should be conducted within designated quadrats or census points. This step provides baseline information on vegetation structure, density, and site characteristics that support interpretation of carbon stock estimates.

How to assess

1. Select Census Points

Representative quadrats (commonly $0.25\text{--}1\text{ m}^2$) are established within the marsh, positioned to capture variations in vegetation density, species composition, and tidal

elevation. Points may be placed randomly, systematically, or along transects running perpendicular to the shoreline or tidal channels.

2. Record Visual Parameters

Within each quadrat, record:

- *Percent cover*: Estimate the proportion of ground covered by vegetation.
- *Species composition*: Identify dominant grasses, sedges, rushes, or succulents; note mixed stands.
- *Plant height*: Measure average and maximum height of shoots or stems using a ruler or measuring rod.
- *Stem density*: Count the number of stems within the quadrat. For clonal species, record density as shoots or ramets.
- Additional site information: Record substrate type (mud, sandy mud, peat), evidence of disturbance, and salinity or water level if equipment is available.

3. Photographic Documentation

Take vertical photographs of each quadrat to document cover, density, and vegetation structure. These images can support later validation and reduce observer bias.

4. Record Location and Conditions

Log GPS coordinates, date, time, tidal stage, and environmental notes (e.g., water table depth, salinity, temperature).

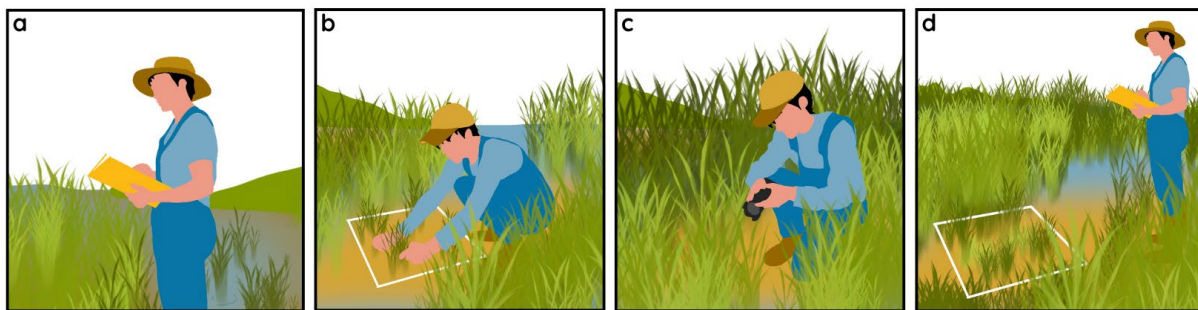


Figure 5: Visual assessment of tidal salt marsh vegetation within quadrats. The observer (a) records site conditions, (b) positions quadrats in representative areas, (c) takes reference photographs for documentation and validation, and (d) notes vegetation cover, height, and density.

C4.1.3 Biomass Sample Collection

Aboveground Biomass (AGB):

1. Place a quadrat (0.25–0.5 m²) on the marsh surface.
2. Clip all living aboveground vegetation (grasses, sedges, rushes, low shrubs) at ground level using scissors or clippers.
3. Collect and store clipped material in labeled mesh or plastic bags.

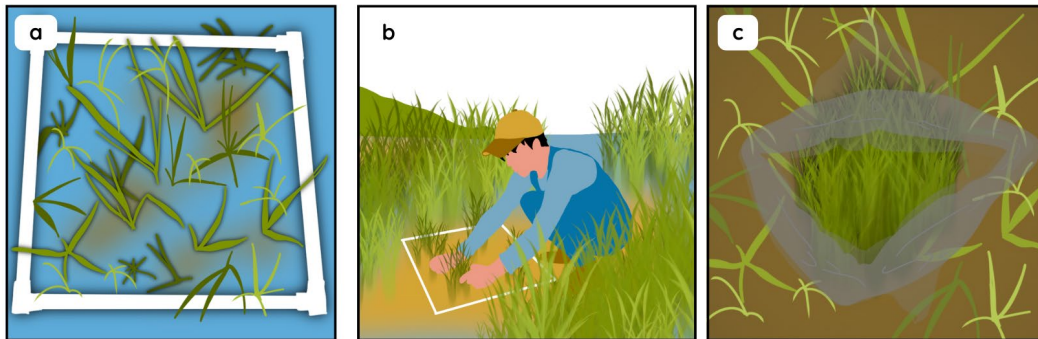


Figure 6: Sampling aboveground biomass in tidal salt marshes: (a) position the quadrat on the marsh surface, (b) clip all live vegetation at ground level, and (c) collect the cut material in labeled mesh bags for drying and analysis.

Belowground Biomass (BGB):

1. Insert a soil core (15 cm or wider diameter) to a depth of ~30 cm, which typically captures the root and rhizome zone of salt marsh plants.
2. Extract the core carefully to retain roots and associated soil.
3. Place the material in mesh bags or sieve for rinsing. Gently wash away sediments until only root and rhizome biomass remains.
4. Store cleaned samples in labeled bags for transport.

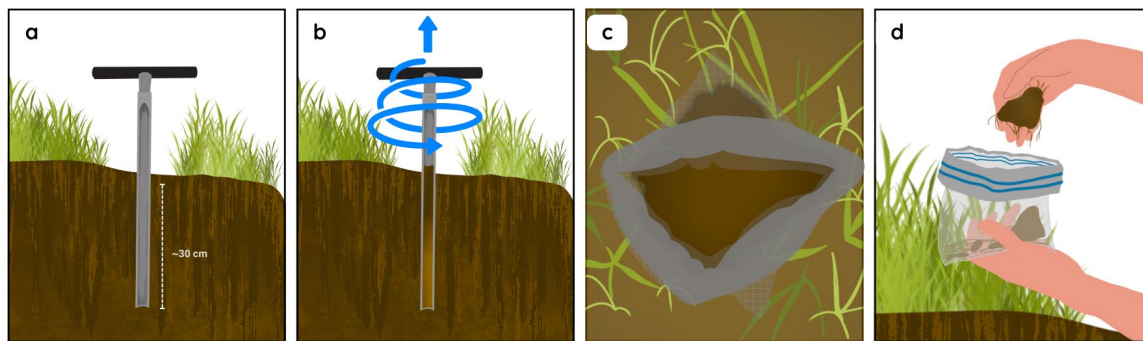


Figure 7: Collection of belowground biomass in salt marshes: (a) insert the corer to ~30 cm depth, (b) extract the core carefully to retain roots and soil, (c) transfer material to a mesh bag for gentle rinsing, and (d) store cleaned root and rhizome samples in labeled containers for analysis.

C4.1.4 Sample Processing

1. Initial Preparation

In the laboratory, rinse residual sediment from belowground samples using clean water; aboveground samples usually require only light cleaning to remove debris.

2. Separation and Sorting

Aboveground and belowground biomass sample sets should be checked, cleaned of foreign material, and, where multiple species occur, sorted by species for species-level accounting if feasible.

C4.1.5 Biomass (Dry Weight) Determination

1. Oven Drying

Separated biomass fractions are dried in an oven at 60 °C until constant weight is reached, usually within 72 hours.

2. Weighing

Once dried, samples are cooled in a desiccator to avoid moisture reabsorption and then weighed using an analytical balance to the nearest 0.001 g. Dry weight values are recorded separately for aboveground biomass and belowground biomass.

3. Data Entry

Recorded dry weights are entered into standardized datasheets. These values are later used in biomass-to-carbon stock calculations by applying area conversions and carbon conversion factors.

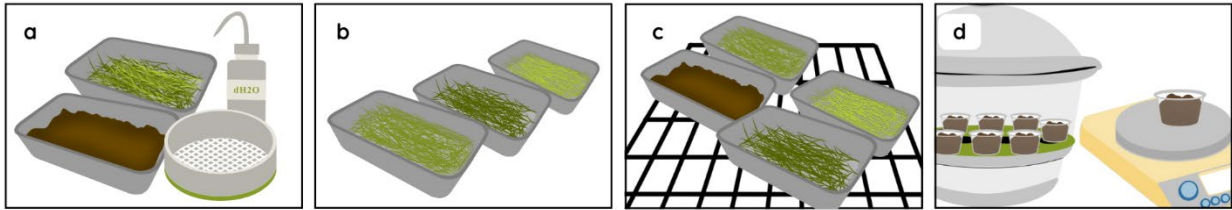


Figure 8: Laboratory processing of salt marsh biomass samples: (a) rinse soil and roots to remove sediment, (b) sort and clean samples by plant part or species, (c) oven-dry samples at 60 °C until constant weight, and (d) cool in a desiccator before weighing to determine dry biomass.

C4.1.6 Total Carbon from vegetative biomass for the core

The total carbon stock from living vegetative biomass in salt marshes is determined by combining aboveground and belowground biomass estimates and applying a carbon conversion factor.

- a. Calculate Biomass per Core Area (g/cm^2):

Aboveground Biomass (AGB):

Biomass per unit area is calculated as the dry mass of clipped aboveground vegetation divided by the quadrat area.

$$AGB_{\text{quadrat}}(\text{g}/\text{cm}^2) = \frac{\text{dry mass of aboveground tissues (g)}}{\text{Area of quadrat (cm}^2\text{)}} \quad \text{Equation 1}$$

Belowground Biomass (BGB):

Biomass per unit area is calculated as the dry mass of roots and rhizomes divided by the cross-sectional area of the corer.

$$BGB_{\text{core}}(\text{g}/\text{cm}^2) = \frac{\text{dry mass of roots + rhizomes from core (g)}}{\text{Area of core (cm}^2\text{)}} \quad \text{Equation 2}$$

Where:

$$Area\ of\ core\ (cm^2) = \pi \times \left(\frac{diameter}{2}\right)^2 \quad \text{Equation 3}$$

- b. Standardize to Megagrams per Hectare (Mg/ha)

Biomass values expressed in g/cm² are scaled up to a Mg dry biomass per hectare basis using the conversion factor 100.

$$AGB(Mg/ha) = AGB_{quadrat}(g/cm^2) \times 100 \quad \text{Equation 4}$$

$$BGB(Mg/ha) = BGB_{core}(g/cm^2) \times 100 \quad \text{Equation 5}$$

- c. Apply Carbon Conversion Factors

Biomass is converted to carbon stock by multiplying by an appropriate carbon fraction (Howard et. al., 2014):

- Marsh grasses and herbs: use 0.45 (45% carbon concentration).
- Roots and rhizomes: site-specific analysis is preferred, but a default of 0.34 (34% carbon concentration) may be used.

$$C_{AGB}(Mg\ C/ha) = AGB_{quadrat}(Mg\ dry\ biomass/ha) \times Carbon\ fraction \quad \text{Equation 6}$$

$$C_{BGB}(Mg\ C/ha) = BGB_{core}(Mg\ dry\ biomass/ha) \times Carbon\ fraction \quad \text{Equation 7}$$

- d. Compute Total Vegetative Carbon

The total vegetative carbon stock is the sum of aboveground and belowground pools.

$$C_{Total\ vegetation}\ (Mg\ C/ha) = C_{AGB} + C_{BGB} \quad \text{Equation 8}$$

C4.2 Soil Organic Carbon (SOC)

Soil organic carbon (SOC) represents the largest and most stable carbon pool in salt marsh ecosystems. Because biomass sampling requires clipping and coring of plant material, SOC assessment must be conducted as a distinct procedure to ensure that sediments remain intact and to avoid double counting carbon already allocated to aboveground and belowground biomass

pools. In practice, aboveground and belowground biomass are harvested separately for vegetation estimates, while dedicated soil cores are collected, sectioned, and analyzed independently for SOC determination.

C4.2.1 Field Equipment for Soil and Sediment Sampling and Analysis

Accurate measurement of soil organic carbon (SOC) in salt marsh ecosystems requires specialized field equipment to collect intact cores and laboratory tools to analyze bulk density and organic carbon content. Equipment should minimize disturbance, preserve soil structure, and ensure reliable subsampling for both carbon stock and carbon burial assessments.

Soil Sample Collection Equipment

- Coring Devices:
 - PVC Core Tubes: Thin-walled PVC pipe (300–500 mm length, ~50 mm inner diameter, 4 mm wall thickness) for soft, fine-grained sediments.
 - Thick-walled PVC or Metal Corers: For coarser sediments or peaty soils commonly found in high marsh zones.
- Driving Tools: Sledgehammer or post-pounder for inserting corers into compacted sediments.
- Extraction Tools: Tripod with pulley, winch, or manual crank system for retrieving cores from sticky or waterlogged soils.
- Core Sealing Materials: Rubber caps, stoppers, and duct tape to seal both ends of the core, maintaining suction and preventing mixing or loss of pore water.
- Sample Containers: Labeled plastic bags or rigid containers for storing core sections; labels should include site, core ID, depth, device, and date.
- Cool Box / Ice Box: For transporting soil cores and subsamples while maintaining low temperatures to reduce microbial alteration.
- GPS Device: Handheld GPS or GPS-enabled smartphone for precise geolocation of sampling sites.
- Measuring Tools: Measuring tape, ruler, or graduated rod for soil depth, core length, and subsampling intervals.
- Depth Probing Tools: Wooden stakes, metal rods, or marked sticks to estimate sediment depth before coring.
- Field Documentation Tools: Waterproof notebooks, pencils, pre-prepared datasheets, and tally sheets for recording sampling information.
- Photographic Documentation: Camera or smartphone for recording site conditions, quadrat placement, core appearance, and processing steps.

- Auxiliary Instruments (Optional): pH meter, conductivity/salinity meter, and thermometer for associated water and porewater sampling.

Laboratory Equipment for SOC Analysis

- Drying Ovens: For drying soil samples at 60 °C to constant weight (typically 48–72 h).
- Grinding Tools: Mortar and pestle or mechanical grinder for homogenizing dried soils into fine powder.
- Sieves: 1 mm mesh for removing roots, shells, and coarse debris; finer mesh ($\leq 180 \mu\text{m}$) for detailed subsampling.
- Desiccators: For cooling dried samples while preventing moisture reabsorption.
- Precision Balances / Microbalances: For weighing dried soils and subsamples to $\pm 0.001 \text{ g}$ accuracy.
- Elemental Analyzer (CHN Analyzer): For determining total carbon, nitrogen, and hydrogen through dry combustion.
- Sample Holders: Silver capsules and tin foil for containing subsamples during combustion analysis.
- Acidification Materials: Hydrochloric acid (1 M HCl) for removing inorganic carbon (carbonates) prior to organic carbon analysis.
- Hotplate: For controlled drying of acid-treated samples.
- Muffle Furnace: For Loss on Ignition (LOI) analysis, combusting samples at 450–550 °C to estimate organic matter.
- Glass Crucibles / Ceramic Boats: Containers for LOI procedures.
- Carbonate Analyzer (Optional): For direct measurement of carbonate fractions in sediments.

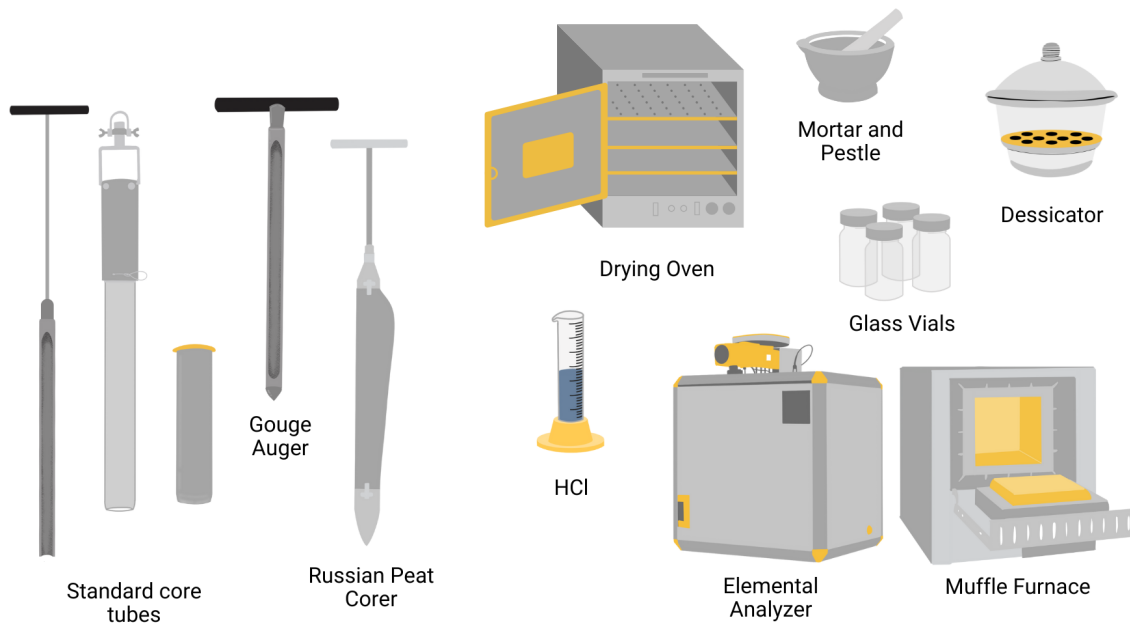


Figure 9: Tools and equipment for sediment collection and analysis

C4.2.2 Soil Sample Collection and Laboratory Analysis

1. Core Collection

Before coring, remove loose litter, surface detritus, or standing vegetation from the soil surface. Insert the coring device vertically at a steady pace to minimize compaction. In coarse or compacted sediments, a sledgehammer or post-pounder may be used to drive the corer. Once the target depth is reached, twist the corer to cut through fine roots and seal the top with a stopper or duct tape to create suction and prevent loss of material. Withdraw the corer while maintaining the seal, and cap the bottom immediately. Cores should be transported upright to preserve stratigraphy.

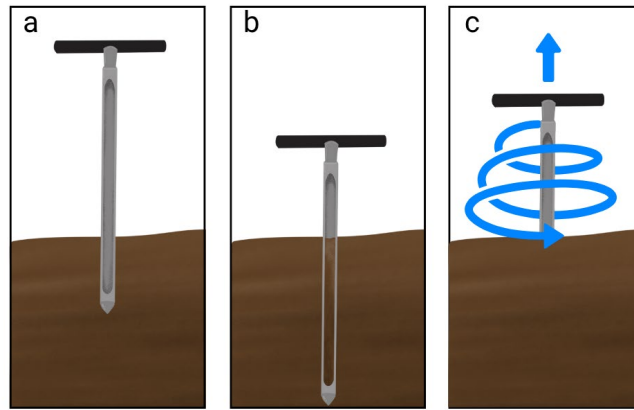


Figure 10: Soil core collection in salt marsh sediments: (a) insert the corer vertically into the soil after clearing surface debris, (b) drive the corer steadily to the target depth to minimize compaction, and (c) twist and withdraw the core carefully while maintaining suction to retain material and preserve stratigraphy.

Correction for Core Compression (Soil Compaction)

Core compression, or core shortening, can occur when coring devices are driven into saturated salt marsh sediments, resulting in a recovered core that is shorter than the penetration depth. Because SOC calculations depend on accurate depth and volume measurements, compaction must be minimized and corrected when present.

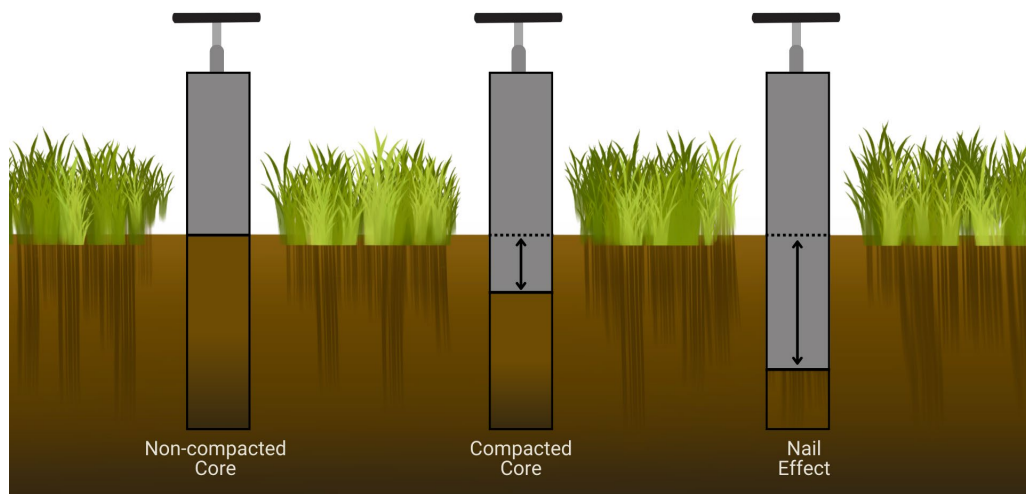


Figure 11: Core compression during coring, where recovered core length is shorter than penetration depth due to sediment compaction.

Minimizing compression: Use devices designed to preserve sediment structure (e.g., gouge augers, piston corers), insert them slowly, avoid obstructions such as thick roots or debris, and keep cores upright after extraction. Cores with severe compaction or obvious slumping should be rejected and re-collected.

Quantifying compression: When moderate compaction is unavoidable, a compaction correction factor (CCF) must be applied. It is calculated as:

$$CCF = \frac{L_{recovered}}{L_{inserted}} \quad \text{Equation 9}$$

where $L_{recovered}$ is the length of the extracted core and $L_{inserted}$ is the penetration depth.

To determine the in-situ thickness represented by an interval measured in the recovered core, divide the recovered interval thickness by the core compression factor:

$$L_{in\ situ, interval} = \frac{L_{recovered, interval}}{CCF} \quad \text{Equation 10}$$

Where:

$L_{in\ situ, interval}$ is the estimated original thickness of the sampled interval before compression (cm)

$L_{recovered, interval}$ is the thickness of that interval measured in the recovered core (cm)

For example, where $CCF = 0.86$, an 8.6-cm recovered interval represents an estimated 10-cm in-situ interval. Conversely, to sample an interval representing 10 cm in situ, select $10 \times 0.86 = 8.6$ cm of recovered material.

This correction assumes uniform compression along the core and shall be applied only where the shorter recovered length is attributable to compression rather than sediment loss. Document the assumption and use a consistent corrected interval-volume basis for bulk density and SOC calculations, so that compression is not corrected twice.

2. Subsampling and Storage

Cores are sectioned into depth intervals (e.g., 0–15 cm, 15–30 cm, 30–50 cm, 50–100 cm) to capture vertical variation in organic matter. Subsamples are placed into labeled containers noting site, core ID, depth, and date. Samples should be stored on ice during transport and frozen if laboratory processing is delayed.

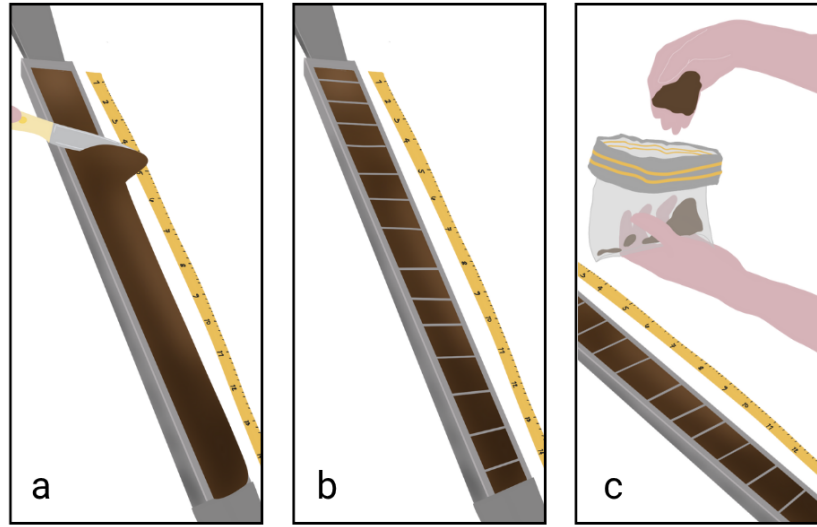


Figure 12: Core subsampling and storage: (a) “Flatten” soil samples using a knife, (b) dividing the core into defined depth intervals to capture vertical variation, and (c) transferring labeled subsamples into containers for storage and transport on ice or freezing prior to laboratory analysis.

3. Laboratory Processing

During preparation, remove identifiable living roots and rhizomes assigned to the belowground biomass pool, including identifiable living fine roots. Retain dead root material where it falls within the defined SOC pool. Document the separation procedure and any residual root material that cannot reliably be classified.

Samples are dried at 60 °C until constant weight to determine dry bulk density, calculated as:

$$DBD (g/cm^3) = \frac{\text{Dry soil mass (g)}}{\text{Volume sampled (cm}^3\text{)}} \quad \text{Equation 11}$$

Calculate bulk density using the dry sediment mass remaining after living-root and rhizome removal and the original sampled volume. Determine organic carbon concentration on a representative aliquot of the same sediment fraction. Document any subsequent sieving or material removal and maintain a consistent mass basis.

Samples are then homogenized using a mortar and pestle or grinder and passed through a sieve to remove coarse debris.

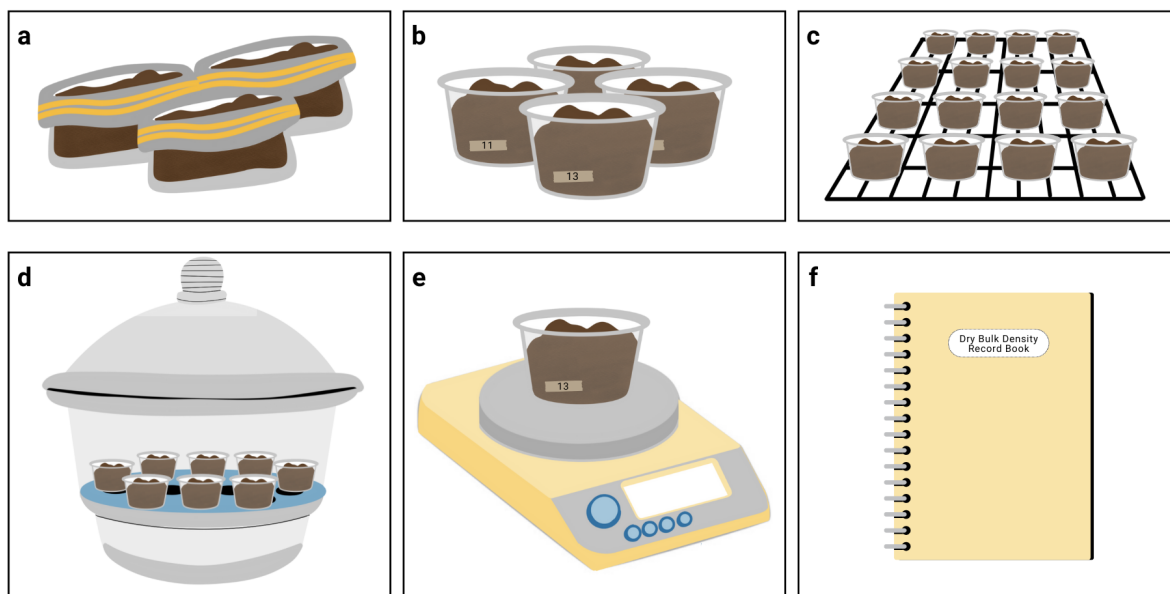


Figure 13: Workflow for determining dry bulk density of soil samples. (a) Samples are first air-dried for 3–7 days before processing. (b) Air-dried material is transferred into labeled, microwave-safe cups and weighed. (c) The samples are then oven-dried at 60 °C overnight, followed by (d) cooling in a desiccator to prevent moisture reabsorption. (e) Each cup is weighed with the dried soil sample, and the drying–cooling–weighing steps are repeated until a constant weight is achieved (defined as $\leq 4\%$ difference from the previous measurement). (f) Results are recorded in a dedicated dry bulk density logbook.

4. Testing for Carbonates

Before LOI analysis, take a small portion of the homogenized sample and apply a few drops of 1N HCl. Effervescence indicates the presence of inorganic carbon (carbonates), requiring acidification before combustion. If no effervescence occurs, the sample may proceed directly to LOI after drying.

5. Inorganic Carbon Removal by Gentle Acidification

When carbonates are present, inorganic carbon (IC) must be removed to avoid overestimating organic carbon during LOI. A slow acidification procedure is recommended to minimize loss of organic carbon.

Procedure:

a. Subsample preparation

Weigh approximately 5 g of dried, homogenized soil into a glass beaker or 50-mL conical tube.

b. Initial acid test and treatment

Add enough 1N HCl to fully submerge the sample. Agitate gently (manual shaking or ultrasonic bath) for 15 minutes to break up clumps and allow uniform reaction.

c. Overnight soaking and verification

Allow the sample to sit 18–24 hours until effervescence subsides. Add additional 1N HCl and repeat agitation. If no bubbles appear, carbonate removal is complete.

d. Rinsing

Once soil settles (or after centrifugation), decant the acid (or remove the liquid with a pipette). Rinse with distilled water, allow settling or centrifuge again, and decant. Repeat three times.

e. Drying

Dry the acid-treated sample at 60 °C overnight, cool in a desiccator, and reweigh. Determine organic carbon on an aliquot using a validated carbonate-correction or removal procedure. Express organic carbon relative to the original dry-sediment mass basis used in the stock calculation, documenting mass changes, recovery and applicable corrections. Determine bulk density on a separate untreated aliquot of known volume. Do not assume that acid-treatment mass loss consists entirely of carbonate or use that loss as a direct SOC measurement.

After drying, the decalcified sample is ready for LOI combustion.

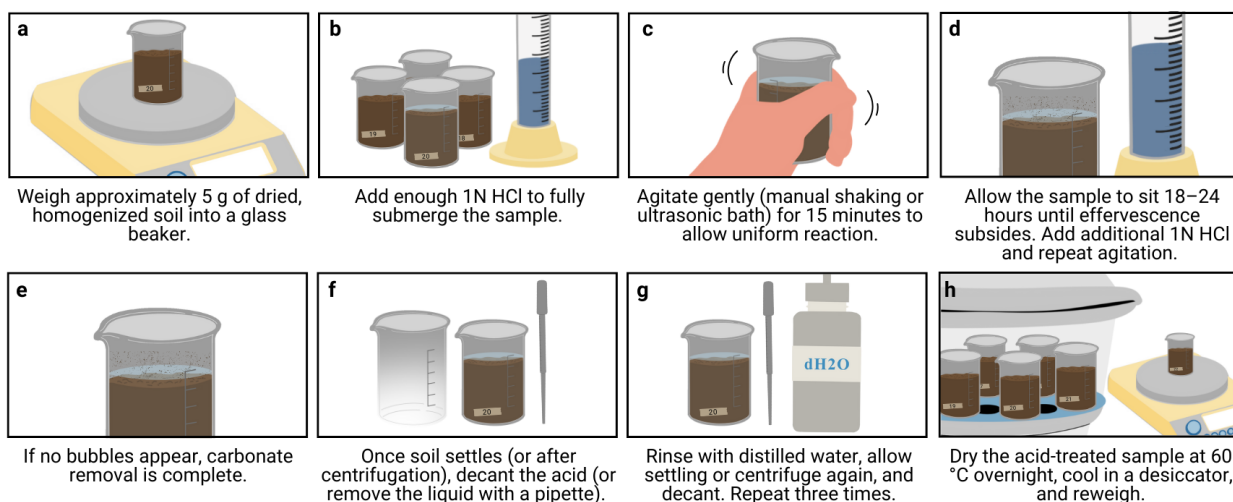


Figure 14: Acidification steps

C4.2.3 Estimating Organic Carbon Content (%C_{org}) using Loss on Ignition

The LOI method estimates organic matter by determining the mass lost during high-temperature combustion.

Sample preparation:

- For samples without carbonates, weigh ~5 g of dried, homogenized soil into a pre-weighed crucible.
- For samples with carbonates, use the acid-treated and redried subsample.

Combustion:

1. Place crucibles into a muffle furnace and combust at 450 °C for 4–8 hours,
Or 550 °C for ≥3 hours depending on laboratory protocol.
2. Allow crucibles to cool inside a desiccator to prevent moisture uptake.
3. Reweigh crucibles to obtain post-combustion mass.

Calculation:

4. The percentage mass loss is calculated as:

$$\%LOI = \frac{W_{pre} - W_{post}}{W_{pre}} \times 100 \quad \text{Equation 12}$$

5. Convert %LOI to %C_{org} using a conversion factor (commonly 0.46 for salt marsh, or site-specific empirical equations when available).

$$\%C_{org} = \%LOI \times CF \quad \text{Equation 13}$$

Because LOI can also burn off non-organic components in the sediment, it may overestimate organic carbon. For this reason, calibration with CHN elemental analysis is strongly recommended whenever possible.

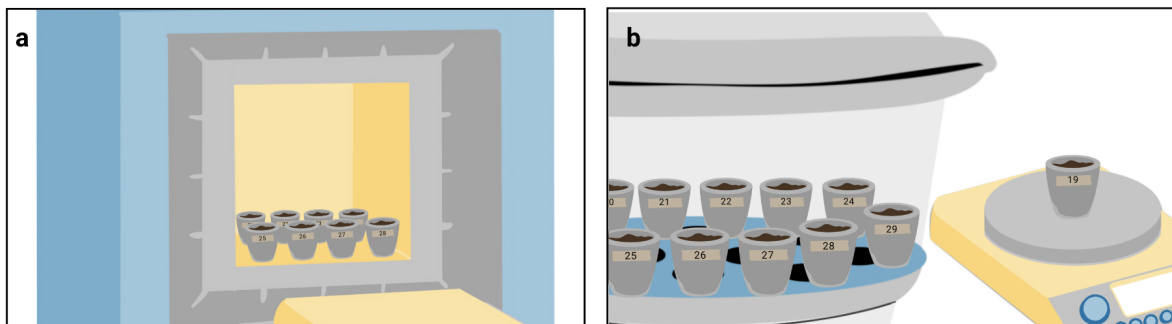


Figure 15: Subsample processing for Loss on Ignition (LOI): (a) Soil subsamples are placed inside a muffle furnace and combusted at 450°C for 4–8 hours to oxidize organic matter. (b) After combustion, samples are allowed to cool to room temperature inside a desiccator to prevent moisture reabsorption. Each crucible is then weighed to determine post-combustion mass for organic matter and carbon content calculations.

C4.2.4 Estimating Organic Carbon Content (%C_{org}) using Elemental Analysis

Elemental analysis via a CHN analyzer is considered a more accurate method for determining soil organic carbon.

Procedure:

1. Dried, homogenized subsamples (2–200 mg depending on sediment type) are weighed into pre-combusted silver capsules.
2. Samples containing carbonate are acidified (in-situ HCl addition) and dried before combustion.
3. Capsules are wrapped in tin foil and analyzed in an elemental analyzer, which combusts samples at high temperature and quantifies C, H, and N by gas chromatography or infrared spectroscopy.
4. The resulting percentage of carbon by dry weight represents the organic carbon content.

$$\%C_{org} = \text{Measured \%C from CHN}$$

Equation 14

C4.2.5 Total SOC for the core

a. Determine SOC per Soil Layer

For each layer, the SOC content is calculated by combining bulk density, organic carbon concentration, and layer depth.

$$SOC_{layer} (Mg\ C/ha) = Depth\ (cm) \times DBD\ (g/cm^3) \times \frac{\%C_{org}}{100} \times 100 \quad \text{Equation 15}$$

The factor 100 converts from g C/cm² to Mg C/ha.

b. Sum Across Soil Depths

The SOC stock for an entire core is calculated by summing the SOC values from all depth intervals. This produces an estimate of the soil organic carbon pool per unit area.

$$SOC_{core} (Mg\ C/ha) = \sum (SOC_{layer\ 1} + SOC_{layer\ 2} + SOC_{layer\ 3} + \dots) \quad \text{Equation 16}$$

Where $SOC_{layer\ 1}$, $SOC_{layer\ 2}$, $SOC_{layer\ 3}$... are the SOC for each layer/depth.

c. SOC Reporting Depth

SOC stocks are normally reported for the upper 1 m of soil. Where sampling extends beyond 1 m, calculate and report the standardized stock using only the measured intervals within 0–100 cm; deeper stocks may be reported separately. Where sampling reaches less than 1 m, report the stock for the actual sampled depth and state that depth explicitly. Do not extrapolate a shallower measured stock to 1 m using a simple depth ratio. Comparisons between monitoring periods shall use a consistent depth basis.

C4.2.6 Sediment Accretion Monitoring Using RSET and Marker Horizon

Sediment accretion is the accumulation of material above the marsh surface. Carbon accumulation associated with accretion is estimated by combining the measured accretion rate with dry bulk density and organic carbon concentration.

The Rod Surface Elevation Table–Marker Horizon (RSET–MH) system provides complementary measurements. The RSET measures surface elevation change relative to its benchmark, while the marker horizon measures accretion above the marker. These measurements are not interchangeable: surface elevation change also reflects processes below the marker horizon, including compaction, subsidence and expansion. Use marker-horizon accretion measurements with sediment carbon density to estimate carbon accumulation. Distinguish this estimate from long-term net burial after losses, and avoid subtracting losses already represented in a net burial estimate.

Components

1. Benchmark Pole (Fixed Stake): A stainless steel rod driven into consolidated substrate, serving as a permanent reference point.
2. RSET Arm: A detachable mechanical leveling device mounted on the benchmark during measurements; adjustable pins measure soil surface elevation relative to the fixed datum.
3. Marker Horizon (MH): A thin, inert layer (e.g., feldspar, kaolin, or clean sand) spread over the marsh surface in marked plots to record new sediment deposition above the baseline.

Deployment and Monitoring Protocol:

1. Site Selection and Setup:
Choose representative salt marsh zones (e.g., low marsh dominated by grasses, high marsh with shrubs). Record GPS coordinates and mark stations for relocation.
2. Benchmark Installation:
Drive a stainless steel rod to refusal (bedrock or consolidated substrate). Ensure stability for long-term monitoring.
3. Marker Horizon Application:
Adjacent to the RSET station, spread an approximately 1 cm layer of feldspar or clean sand within a $\sim 0.25 \text{ m}^2$ quadrat. The inert material must form a continuous, uniform layer so that later measurements of deposited thickness are reliable. Clearly mark quadrat boundaries for consistent resampling.

4. Baseline Measurement (T_1):

Attach the RSET arm to the benchmark and lower pins until they gently contact the marsh surface. Record initial surface elevation and the marker horizon as depth zero.

5. Repeat Monitoring ($T_2, T_3, \dots$):

At seasonal or annual intervals, repeat RSET measurements to track surface elevation change. Extract small sediment plugs (5–10 cm diameter) from the MH quadrat to measure thickness of new sediment.

Monitor accretion and surface elevation in accordance with the minimum frequency specified in C10.2, using consistent seasonal timing and additional measurements where needed to represent variability.

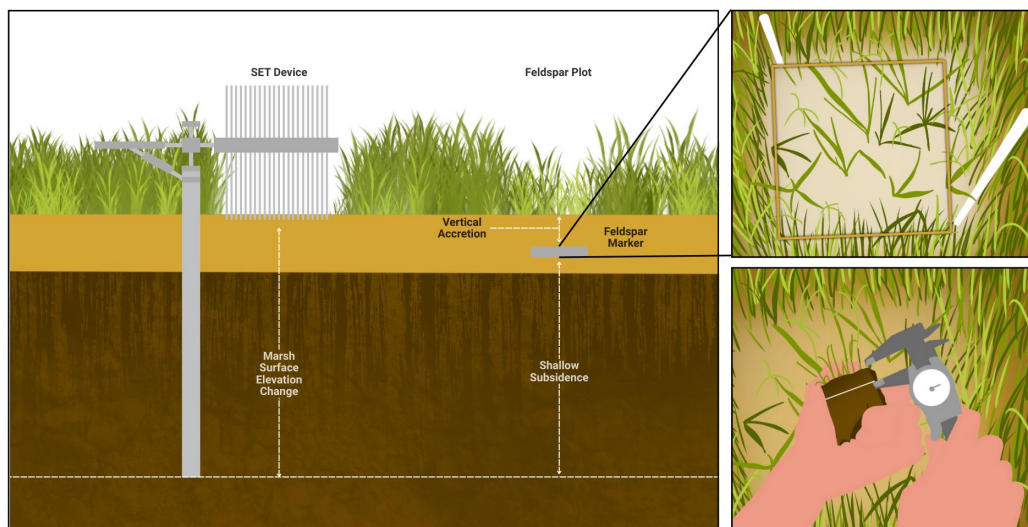


Figure 16: Sample RSET and elevation marker set up

C4.2.7 Isotope Sampling for Burial Rates

Isotope dating, particularly using Lead-210 (^{210}Pb), is a widely applied technique for reconstructing long-term sediment accumulation in tidal salt marshes. While SOC cores provide present-day carbon stock estimates, isotope profiles extend the temporal scale of analysis, enabling reconstruction of carbon burial over decades to centuries. By combining isotope-derived sedimentation rates with bulk density and organic carbon content ($\%C_{\text{org}}$), the ^{210}Pb method yields carbon accumulation rates that complement RSET–MH monitoring.

Lead-210 is a naturally occurring radionuclide supplied to marsh surfaces by atmospheric deposition and water inflow. Its radioactive decay allows estimation of sediment age with depth. Profiles of unsupported (excess) ^{210}Pb within a core provide accumulation rates, which can then be converted into carbon burial rates.

Components

1. Coring Device: A gouge auger, Russian peat corer, or vibracorer capable of extracting intact sediment cores at least 1 m in depth.
2. Core Transport and Storage: Upright transport in sealed tubes to preserve stratigraphy and prevent mixing.
3. Laboratory Facilities: Equipment for bulk density measurement, organic carbon analysis (CHN analyzer or LOI with calibration), and radioisotope detection (alpha spectrometry, gamma spectrometry, or equivalent).

Field Procedure (Sediment Core Collection and Subsampling):

1. Site Selection

Select representative salt marsh zones (low marsh grasses, high marsh shrubs). Record GPS coordinates and environmental conditions.

2. Core Extraction

Insert the corer vertically to minimize compression. Extract to ≥ 1 m depth or until refusal. Mark top and bottom ends clearly and log metadata (site, core ID, date).

3. Core Description

Document stratigraphy in situ or in the laboratory, noting color, texture, layering, and root presence. Photograph cores with scale.

4. Subsampling

Section cores at fine resolution near the surface (e.g., 0–2 cm intervals for the upper 10–20 cm) and at coarser intervals (e.g., 5 cm) deeper down. This captures recent versus historical deposition.

5. Preservation

Store subsamples in sealed, labeled containers. Keep refrigerated (4 °C) or frozen if immediate analysis is not possible.

Laboratory Analysis:

6. Bulk Density (BD)

Dry subsamples at 60 °C to constant weight. Calculate as dry mass divided by sample volume.

7. Organic Carbon Content (% C_{org})

Determine %C_{org} using a CHN elemental analyzer, with acid pretreatment to remove inorganic carbon. Where unavailable, LOI may be used with calibration.

8. Isotope Analysis

Measure the total ²¹⁰Pb activity using alpha spectrometry with PIPS detectors. Derive excess ²¹⁰Pb (²¹⁰Pb_{xs}) by subtracting supported ²¹⁰Pb from the total. Construct age–depth models using Constant Rate of Supply (CRS) or Constant Initial Concentration (CIC) models.

9. Carbon Burial Rate

Calculate sediment accumulation rate (cm/yr) from isotope profiles, then multiply by bulk density and %C_{org} to estimate carbon burial:

$$CAR = \text{Sedimentation Rate} \times \text{Bulk Density} \times C_{org} \times 100 \quad \text{Equation 17}$$

Results are typically expressed as Mg C /ha/yr.

SOC inventory alone does not establish sediment-volume gain or durable carbon sequestration. Interpret the relationship among organic carbon mass, sediment volume and long-term burial using site evidence and uncertainty. No universal correction factor for organic matter that contributes little to sediment volume is prescribed here.

C.5 Carbon Stock Estimation for Salt Marsh Project Area

The total carbon stock within a salt marsh project area is estimated by systematically aggregating carbon stocks from individual plots, then scaling up to strata, and finally to the entire project area. This hierarchical approach ensures accuracy across different spatial levels and provides results both as carbon stock density (Mg C/ha) and as total carbon stock (Mg C).

C5.1 Compute Total Carbon Stock per Plot (Mg/ha)

For each plot, calculate the carbon stock for each measured pool: aboveground biomass (AGB), belowground biomass (BGB), and soil organic carbon (SOC). The methods for each pool are described in the corresponding sections.

- a. Measure Carbon Stock for Each Pool:

$C_{AGB}(MgC/ha)$: Aboveground biomass carbon stock per hectare.

$C_{BGB}(MgC/ha)$: Belowground biomass carbon stock per hectare.

$C_{SOC}(MgC/ha)$: Soil organic carbon stock per hectare.

- b. Sum Carbon from All Pools:

$$C_{Plot}(Mg\ C/ha) = C_{AGB} + C_{BGB} + C_{SOC} \quad \text{Equation 18}$$

C5.2 Aggregate Carbon Stock to Stratum Level

For stratified salt marsh project areas, carbon stock values are aggregated by stratum to account for spatial variability in elevation, vegetation type, or hydrologic regime (e.g., low marsh dominated by grasses vs. high marsh with shrubs).

- a. Calculate Average Carbon Stock per Stratum:

Average carbon stock for all plots within a stratum:

$$C_{Stratum}(Mg\ C/ha) = \frac{\sum C_{Plot\ (MgC/ha)}}{\text{Number of Plots in the Stratum}} \quad \text{Equation 19}$$

- b. Calculate Total Carbon Stock for the Stratum:

Multiply the average carbon stock by the total area of the stratum:

$$C_{Stratum}(Mg\ C) = C_{Stratum}(Mg\ C/ha) \times \text{Stratum Area (ha)} \quad \text{Equation 20}$$

C5.3 Compute Total Carbon Stock for the Project Area

- a. Sum Carbon Stocks Across All Strata:

Total carbon stock for the project area is the sum of carbon stocks across all strata:

$$C_{Project\ Area}(Mg\ C) = \sum C_{Stratum}(Mg\ C) \quad \text{Equation 21}$$

- b. Calculate Average Carbon Stock for the Project Area:

The average carbon stock for the project area (reported in Mg C/ha) is calculated as the weighted average:

$$C_{Project\ Area}(Mg\ C/ha) = \frac{\sum [C_{Stratum}(Mg\ C/ha) \times Stratum\ Area\ (ha)]}{Total\ Project\ Area\ (ha)} \quad \text{Equation 22}$$

C5.4 Uncertainty in Carbon Stock Estimation

Accurate reporting of carbon stock estimates in tidal salt marsh projects requires not only the measurement of each carbon pool but also the quantification of uncertainty associated with those measurements. Uncertainty arises from variability in field sampling, laboratory analysis, and spatial extrapolation.

C5.4.1 Error Propagation

- a. Estimate Carbon Stock and Uncertainty for Each Carbon Pool

For each plot or core, calculate carbon stock for vegetative biomass (aboveground biomass and belowground biomass) and soil organic carbon (SOC). Each pool should be expressed as:

$$Carbon\ Stock_{Pool} = Mean \pm Standard\ Error \quad \text{Equation 23}$$

where SE (standard error) is computed from replicate plots or samples within the stratum.

- AGB, BGB: Estimated from destructive biomass samples collected using quadrats (AGB) or soil cores (BGB), dried to constant weight, and converted to carbon using species-specific or default carbon conversion factors.

- SOC: Derived from dry bulk density, organic carbon concentration (%C_{org}), and sampled soil depth.

b. Combine Uncertainty from All Carbon Pools (Error Propagation)

Once uncertainties are calculated for each pool, combine them using the root-sum-square (RSS) method:

$$SE_{Total\ Pools} = \sqrt{(SE_{AGB})^2 + (SE_{BGB})^2 + (SE_{SOC})^2} \quad \text{Equation 24}$$

This provides the stand-level or plot-level total carbon stock uncertainty, typically expressed in Mg C/ha.

c. Account for Uncertainty in Area Estimates

Salt marsh extent is typically mapped using remote sensing, GIS analysis, and field validation. These area estimates also carry uncertainty, which should be reported as:

$$Area_{pool} = Mean\ Area \pm Standard\ Error_{Area} \quad \text{Equation 25}$$

d. Propagating Stock and Area Uncertainty

To calculate total uncertainty for the project area, propagate both stock and area uncertainty as:

$$SE_{total} = Total\ Carbon\ Stock \times \sqrt{\left(\frac{SE_{Stock}}{Carbon\ Stock}\right)^2 + \left(\frac{SE_{Area}}{Area}\right)^2} \quad \text{Equation 26}$$

e. Report Total Carbon Stock with Uncertainty

The final result is presented as:

$$Total\ Carbon\ Stock = Mean \pm SE_{total} \quad \text{Equation 27}$$

Values should be presented with clear units (e.g., Mg C/ha), and where applicable, converted to Mg CO₂ using a 3.67 molar mass factor.

Root-sum-square propagation assumes independent errors. Where estimates share a model, carbon fraction, laboratory calibration or area estimate, account for that dependence. When combining strata, apply the corresponding area weights and include area uncertainty where material, following main Chapter 6.

C5.4.2 Monte Carlo Simulation (Optional Advanced Method)

Monte Carlo simulation is an advanced statistical approach for propagating uncertainty by repeatedly simulating possible outcomes based on input variability. For salt marsh projects, it is especially useful when multiple parameters (e.g., biomass, bulk density, %C_{org}, soil depth, and marsh extent) contribute uncertainty simultaneously.

Monte Carlo Simulation Steps Summarized:

a. Define Uncertain Inputs

Identify key variables with measurement or sampling uncertainty, such as aboveground biomass, belowground biomass, soil bulk density, %C_{org}, sediment depth, and salt marsh area. Assign appropriate probability distributions (e.g., normal, lognormal) to each parameter based on field data, literature, or expert judgment.

b. Run Random Simulations

Conduct thousands of iterations (typically 5,000–10,000). For each iteration, randomly sample from the distributions of each input variable and compute total carbon stock using the equations outlined in previous sections.

c. Analyze Output

Summarize the distribution of simulation results by calculating the mean, variance, standard deviation, and confidence intervals of total salt marsh carbon stock.

d. Report Results

Report the estimated mean and its confidence interval at the confidence level used to assess the adopted sampling precision target in C3.5. Label any additional reporting interval at another confidence level separately. Distinguish standard deviation, standard error and confidence-interval half-width. Report per-hectare densities in Mg C/ha and project totals in Mg C.

- e. Visualize

Graphical representations such as histograms or probability density plots can be used to illustrate the uncertainty range, the most likely values, and the overall distribution of carbon stock estimates.

C.6 Carbon Sink (Sequestration Rate) Estimation in Salt Marsh Ecosystems

Estimating carbon sequestration in salt marsh ecosystems requires quantifying the net annual increase in stored carbon across major pools—aboveground biomass (AGB), belowground biomass (BGB), and soil organic carbon (SOC). Depending on data availability, monitoring design, and project objectives, two principal methods are applied: the Stock-Difference Method and the Gain–Loss Method.

The **Stock-Difference Method** involves measuring carbon stocks in each relevant pool at two time points and calculating the net change over time. This approach is particularly useful for restoration or conservation projects where long-term, plot-based monitoring is feasible. It is well-suited to biomass and soil pools, as these exhibit measurable changes over multi-year periods. When baseline and subsequent stock measurements are obtained using standardized protocols, the method provides transparent and verifiable estimates of sequestration.

The **Gain–Loss Method** estimates annual fluxes by tracking gains (e.g., primary production, sediment accretion, and carbon burial) and subtracting losses from decomposition, erosion, or disturbance. In salt marshes, this method is often applied to the soil pool. Accretion measurements combined with sediment carbon density estimate carbon accumulation over the monitoring interval, while isotope dating supports estimates of historical carbon burial over the dated period. This method is particularly valuable in environments with high rates of sedimentation or erosion.

In practice, both methods are often combined—using the Stock-Difference Method for biomass carbon pools and the Gain–Loss Method for sediment carbon. The choice of method depends on project scope, monitoring capacity, and the pools of interest.

C6.1 Stock-Difference Method for Salt Marsh

The stock-difference approach requires field-based measurements from the same sampling plots at two points in time (t_1 and t_2). These values are then annualized and scaled to the project area.

Field-derived carbon stock values used here must come from consistent plot locations, methodologies, and stratification categories, as defined in the field data collection and stock estimation chapters (C.4 and C.5). Where relevant, the mean carbon density (e.g., Mg C/ha) per pool per stratum is used and scaled by the area represented by the sample plots.

C6.1.1 Carbon Stock Change in Aboveground Biomass

Aboveground biomass in salt marshes consists mainly of herbaceous vegetation such as grasses, sedges, and rushes, with shrubs present in some systems. To calculate stock change, biomass is clipped within quadrats at t_1 and t_2 , dried to constant weight, converted to carbon using a default factor and expressed in Mg C/ha.

Formula:

$$\Delta C_{AGB} = \frac{(C_{t2,AGB} - C_{t1,AGB}) \times A}{t_2 - t_1} \quad \text{Equation 28}$$

Where:

- ΔC_{AGB} = Annual change in AGB carbon (Mg C/yr)
- $C_{t1,AGB}, C_{t2,AGB}$ = Mean AGB carbon stock at t_1 and t_2 (Mg C/ha)
- A = Area of ecosystem represented (ha)
- $t_2 - t_1$ = Time interval between measurements (years)

C6.1.2 Carbon Stock Change in Belowground Biomass

Belowground biomass includes roots and rhizomes, which typically account for the majority of vegetative biomass in salt marshes. Core samples collected at consistent depths (e.g., 30 cm) at t_1 and t_2 are dried, weighed, converted to carbon and expressed in Mg C/ha.

Formula:

$$\Delta C_{BGB} = \frac{(C_{t2,BGB} - C_{t1,BGB}) \times A}{t_2 - t_1} \quad \text{Equation 29}$$

C6.1.3 Carbon Stock Change in Soil/Sediment

Soil organic carbon (SOC) is the largest and most stable carbon pool in salt marsh ecosystems. SOC is estimated from soil cores collected to standardized depths (e.g., 1 m). For each sampling interval, carbon stock is calculated from bulk density, organic carbon concentration

(%C_{org}), and layer thickness. SOC change is then calculated as the difference between t₁ and t₂ values.

Formula:

$$\Delta C_{SOC} = \frac{(C_{t2,SOC} - C_{t1,SOC}) \times A}{t_2 - t_1} \quad \text{Equation 30}$$

C6.1.4 Estimating Total and Annual Sequestration from Stock Change

The total net annual sequestration rate for a salt marsh project area is the sum of the changes in all measured carbon pools:

$$\Delta C_{total} = \Delta C_{AGB} + \Delta C_{BGB} + \Delta C_{SOC} \quad \text{Equation 31}$$

This estimate is expressed in Mg C/yr. To convert to CO₂-equivalent:

$$\Delta CO_2e = \Delta C_{total} \times 3.67 \quad \text{Equation 32}$$

Where 3.67 is the molecular weight ratio of CO₂ to C. This conversion expresses the carbon-stock change as a CO₂ quantity. A stock increase represents a removal, while a stock decrease represents an emission. Apply the emissions-positive/removals-negative convention when entering the result into the GHG balance. Calculate project net GHG benefits relative to the baseline, including applicable project emissions and leakage, in accordance with main Section 9.6. The converted stock change alone does not establish an issuable credit quantity, and any gain or loss already represented in the stock change shall not be counted again.

The accuracy of this estimate is contingent on plot representativeness, measurement consistency, and the interval between measurements. Annualization shall only be applied where the interval between measurements is at least one year. The selected interval should be appropriate to the carbon pool, expected rate of change, and monitoring objectives, and should be consistent with the pool-specific monitoring frequencies in Section C10.2. Multi-year intervals may be used where necessary to improve the reliability of detected stock changes.

C6.2 Gain–Loss Method for Salt Marsh

The Gain–Loss Method estimates net annual carbon sequestration in salt marshes by balancing measured carbon gains, such as sediment carbon burial, against carbon losses, including decomposition, disturbance, and greenhouse gas emissions. This approach is particularly useful when repeated long-term stock measurements (stock-difference method) are not feasible, or when sediment burial data are available from accretion monitoring or isotope dating.

The general formula applied is:

$$\Delta C = \Delta C_{Gain} - \Delta C_{Loss} \quad \text{Equation 33}$$

Inputs are derived from the field measurements and laboratory analyses described in Section C.4.

Calculate gains and losses separately for each stratum. Express every term in Mg C/yr, multiplying any per-hectare rate by the corresponding stratum area once. Sum the stratum totals to obtain the project total.

C6.2.1 Estimating Carbon Gains

a. Soil Carbon Accumulation via Sediment Accretion

Salt marsh soils accumulate carbon via vertical accretion of organic and mineral material. Accretion rates can be measured using marker horizons, SET–MH systems, or sediment plates.

$$\Delta C_{SOC}(\text{Mg C/yr}) = BD \times Z \times C_{org} \times 100 \times A \quad \text{Equation 34}$$

Where:

- BD = Bulk density (g/cm³)
- Z = Accretion rate (cm/yr)
- C_{org} = Organic carbon mass fraction (g C/g dry sediment), expressed as a decimal; e.g., 0.02 for 2%
- A = Area (ha)

The factor 100 converts g C/cm² to Mg C/ha.

b. Radiometric Dating for Burial Rates

Radiometric dating (^{210}Pb) provides long-term estimates of sedimentation and carbon burial in salt marsh soils. The Carbon Accumulation Rate for each depth interval k is calculated as:

$$CAR_k = BD_k \times C_{org,k} \times Z_k \quad \text{Equation 35}$$

Where:

- CAR_k = Carbon accumulation rate in interval k (g C/cm²/yr)
- BD_k = Bulk density of interval k (g/cm³)
- $C_{org,k}$ = Organic carbon fraction in interval k (g C per g dry mass)
- Z_k = Sedimentation rate for interval k (cm/yr)

Convert to Mg C/ha/yr:

$$CAR_{ha} = CAR_k \times 100 \quad \text{Equation 36}$$

$$\Delta C_{SOC}(\text{Mg C/yr}) = CAR_{ha} \times A \quad \text{Equation 37}$$

C6.2.2 Estimating Carbon Losses

Carbon losses must be subtracted from gains to reflect net sequestration. Major categories include:

a. Decomposition and Respiration

Losses from litter decomposition or root turnover can be estimated as:

$$C_{loss,resp} = M_{decomp} \times CF \times A \quad \text{Equation 38}$$

Where:

- $C_{loss,resp}$ = Annual carbon loss for the stratum (Mg C/yr)
- M_{decomp} = Annual dry biomass or litter mass decomposed per hectare (Mg dry biomass/ha/yr)
- CF = Carbon mass fraction, expressed as a decimal
- A = Stratum area (ha)

Decomposition rates may be sourced from site studies or literature.

Count decomposition as an ecosystem carbon loss only to the extent that carbon leaves the included accounting pools. Transfers from biomass or litter into an included soil carbon

pool shall not be counted as ecosystem losses. Do not subtract a loss separately where it is already reflected in the stock-change or net burial estimate.

b. Disturbance and Physical Damage

Losses from storms, flooding, reclamation, dredging, or land-use change can be expressed as area or biomass lost and scaled by event frequency.

c. Soil Disturbance and Oxidation

Disturbance that exposes anoxic soils to oxygen (e.g., excavation, drainage) can rapidly oxidize stored carbon. Default emission factors from IPCC (2014) may be used if site-specific data are unavailable.

d. Methane (CH₄) and Nitrous Oxide (N₂O) Emissions

Salt marshes generally emit low levels of CH₄ due to saline, sulfate-rich conditions. Where emissions occur (e.g., in brackish or eutrophic sites), they can be estimated using IPCC default emission factors or measured directly.

Account for CH₄ and N₂O separately from the Mg C gain–loss subtotal. Convert these emissions to CO₂-equivalents using the applicable GWP values and include them in the GHG balance under main Section 9.6.

C6.2.3 Calculating and Reporting Sequestration Rate

Calculate project net annual carbon gain by summing the differences between annual carbon gains and losses across all strata:

$$C_{net,project} = \sum_{i=1}^n (\Delta C_{Gain,i} - \Delta C_{Loss,i}) \quad \text{Equation 39}$$

Where:

- $C_{net,project}$ = Project net annual carbon gain (Mg C/yr)
- $\Delta C_{Gain,i}$ = Sum of annual carbon gains across included pools in stratum i (Mg C/yr)
- $\Delta C_{Loss,i}$ = Sum of annual carbon losses from included accounting pools in stratum i (Mg C/yr)

a. Conversion to CO₂-equivalent

To express results in terms of CO₂-equivalent for reporting and crediting purposes:

$$\Delta CO_2e_{net} = C_{net,project} \times 3.67 \quad \text{Equation 40}$$

Where 3.67 is the molecular weight ratio of CO₂ to C.

This conversion expresses net carbon gain as a CO₂ removal quantity; it does not by itself establish project net GHG benefits or an issuable credit quantity. Calculate project net GHG benefits relative to the baseline, including applicable project emissions and leakage, under main Section 9.6. Apply the emissions-positive/removals-negative convention when entering the removal into the GHG balance, and avoid counting any gain or loss twice.

b. Temporal Averaging and Reporting Period

Results should be annualized over multi-year monitoring intervals (minimum 1 year, preferably 2–5 years). All reported values must be clearly linked to the field and laboratory methods (C.4), specify whether data are direct or literature-based, and present uncertainty estimates consistent with Section C.8.

c. Integration with Stock-Difference Estimates

If both methods are applied (e.g., stock-difference for biomass and gain–loss for soil burial), results should be combined at the pool level, avoiding double counting and following uncertainty combination procedures.

C.7 Measurement of Direct Carbon Emissions (CO₂ FLUX)

Direct CO₂ flux measurements quantify soil and ecosystem respiration in salt marshes. Although most carbon dynamics in salt marsh projects are addressed through biomass and soil carbon stock assessments, direct flux measurements may be required when project activities involve hydrological modification, vegetation removal, drainage, or other disturbances that could increase soil CO₂ emissions.

C7.1 Measurement Approaches

Salt marsh CO₂ fluxes arise primarily from:

1. Soil respiration, including microbial mineralization of organic matter and live root respiration.
2. Net ecosystem exchange (NEE), representing the balance between salt marsh photosynthesis and respiration.

Most blue carbon project needs relate to soil CO₂ efflux, which can be reliably measured using chamber techniques deployed directly on the sediment surface. NEE methods such as eddy covariance require specialized infrastructure and are generally limited to long-term research.

C7.1.1 Static Chamber Method (Soil CO₂ Efflux)

The static chamber method is the most practical approach for quantifying soil CO₂ efflux in salt marshes. Its portability and simple setup make it well-suited to tidal environments, where frequent inundation limits the use of more complex flux systems. The technique measures the rate of CO₂ accumulation within an enclosed headspace placed over the marsh surface.

Chamber Design and Installation

Select the chamber configuration according to the process being measured. A transparent chamber enclosing vegetation under light measures net CO₂ exchange within its footprint, including photosynthesis and respiration. An opaque chamber enclosing vegetation measures ecosystem respiration under the measurement conditions. For soil or sediment CO₂ efflux, define and document the vegetation treatment so that the measured flux is clearly identified. These measurements shall not be used interchangeably.

Fit the chamber to a collar with a gas-tight seal, minimizing sediment disturbance. Provide sufficient clearance for enclosed vegetation and a suitable pressure-equilibration vent. Record chamber volume, footprint, vegetation treatment, light conditions, temperature, water level and tidal state.

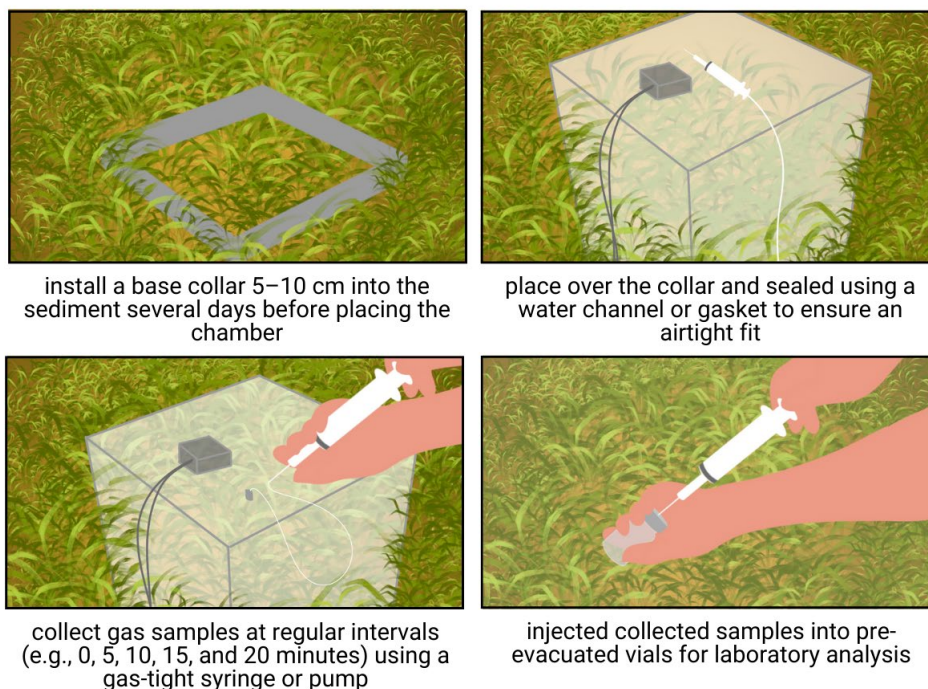


Figure 17: Sample Static Chamber set-up

Field Measurement Procedure

Measurements are carried out during periods of stable environmental conditions and ideally repeated across different tidal stages or seasons. After sealing the chamber onto the collar, gas samples are withdrawn from the headspace at fixed time intervals (e.g., 0, 2, 4, 6, and 8 minutes). Gas samples are either analyzed in situ using a portable CO₂ detector or stored in evacuated glass vials for later laboratory analysis.

Use a measurement setup appropriate to exposed or inundated conditions and document the surface enclosed. Measurements made only on exposed sediment shall not be assumed to represent flooded periods. Where flooded periods contribute to the annual estimate, use an appropriate measurement method or a justified estimation approach.

Flux Calculation

Soil or sediment CO₂ flux is calculated from the rate of change in chamber headspace CO₂ mole fraction using the Ideal Gas Law:

$$F_{CO_2} = \frac{\Delta C}{\Delta t} \times \frac{V}{A} \times \frac{P}{RT} \times M_{CO_2} \times 3600 \quad \text{Equation 41}$$

Where:

- F_{CO_2} = mass flux rate of CO₂ (mg CO₂ /m²·h)
- $\Delta C/\Delta t$ = Rate of change in CO₂ mole fraction, expressed in mol/(mol·s). Convert a slope measured in ppm/s or μmol/(mol·s) by multiplying by 10⁻⁶ before substitution.
- V = effective chamber volume (m³)
- A = chamber footprint area (m²)
- P = atmospheric pressure (Pa, where 1 atm = 101,325 Pa)
- R = universal gas constant (8.314 Pa·m³/(mol·K))
- T = chamber air temperature (K = °C+273.15)
- M_{CO_2} = Molar mass of CO₂ (44,010 mg/mol)
- 3600 = Time conversion factor (seconds per hour)

For molar flux, omit M_{CO_2} and the factor 3600. The resulting flux is in mol CO₂/(m²·s); multiply by 10⁶ for μmol CO₂/(m²·s) or by 10³ for mmol CO₂/(m²·s).

Integrate fluxes over representative diurnal, tidal and seasonal conditions to estimate annual CO₂ emissions. Convert annual emissions from Mg CO₂/ha/yr to Mg C/ha/yr by multiplying by 12/44 where a carbon-mass expression is required. Include these emissions in project accounting only where they are not already represented in the stock-change or gain–loss estimate. Positive flux indicates CO₂ emission; negative flux indicates CO₂ uptake.

Applicability in Salt Marshes

Static chambers are suitable for:

- Soil CO₂ efflux in intact, degraded, or restored marshes
- Projects involving hydrological reconnection or invasive species removal
- Assessing early restoration phases where disturbance-related respiration may be elevated

They are particularly useful in marshes with shallow organic horizons, where soil carbon mineralization can respond quickly to drainage, salinity shifts, or vegetation changes.

C7.1.2 Eddy Covariance (Ecosystem-Scale CO₂ Exchange)

Eddy covariance (EC) provides continuous measurements of CO₂ exchange at the ecosystem scale. An instrument tower above the marsh canopy captures turbulent fluxes and produces high-resolution NEE data.

Although EC is valuable for long-term research on marsh productivity and climate response, it is generally beyond the requirements and logistical capacity of project-level blue carbon monitoring. Salt marsh EC setups must address unique challenges such as rapidly changing surface roughness, tidal flooding, and strong coastal winds. These characteristics increase uncertainty and demand specialized post-processing, including filtering low-turbulence periods and correcting for water vapor and tidal influences.

EC is therefore acknowledged as a complementary research method but is not required for blue carbon project accounting.

C7.1.3 Annual Emissions and Reporting

When chamber data are used, annual estimates are generated by integrating flux measurements over representative time intervals that capture seasonal and tidal variability:

$$E_{annual} = 10^{-5} \sum_{i=1}^n (F_{CO_2,i} \times \Delta t_i) \quad \text{Equation 42}$$

Where:

- E_{annual} = Annual CO₂ emissions (Mg CO₂/ha/yr).
- $F_{CO_2,i}$ = Representative flux for interval i (mg CO₂/(m²·h)).
- Δt_i = Duration represented by interval i (hours), with the intervals covering the reporting year.

The factor 10⁻⁵ converts mg/m² to Mg/ha.

Annual CO₂ emissions are converted to carbon units using:

$$C_{annual} = \frac{E_{annual}}{3.67} \quad \text{Equation 43}$$

Final results are expressed in Mg C/ha/yr. Metadata should include chamber specifications, collar installation depth, vegetation treatment (intact vs clipped), measurement timing, and sample storage or analytical methods.

C7.1.4 Uncertainty Considerations

Uncertainty arises from chamber leakage, temperature fluctuations, sediment disturbance during collar insertion, spatial heterogeneity in marsh vegetation, and analytical precision. Replicated measurements across multiple points within each stratum are needed to adequately characterize spatial variability. Standard error propagation or Monte Carlo simulation may be applied following the general uncertainty guidance provided in the protocol.

C.8 Uncertainty and QA/QC

Salt marsh carbon accounting involves uncertainties arising from measurement limitations, natural variability, and methodological assumptions. Establishing clear precision targets, reporting transparently, and applying strong QA/QC practices are critical to reducing these uncertainties and ensuring credibility.

C8.1 Sources of Uncertainty

Uncertainties in salt marsh carbon assessments stem from two main domains: carbon measurement parameters and ecosystem area estimates.

Carbon Measurement Parameters

These uncertainties relate to the estimation of carbon densities, accumulation rates, and emission factors within each stratum.

a. Sampling Uncertainty

- Variability in carbon density (CD) across plots, particularly soil organic carbon (SOC), which often varies with depth.
- Uncertainty in carbon burial rate (CAR) estimates from SET–MH or ^{210}Pb dating, due to variability in sediment deposition and carbon fraction of new material.
- Limited representativeness of sample plots when scaling to the project area.

b. Model Uncertainty

- Use of allometric or empirical equations for biomass estimation in shrub-dominated marshes, which may not fully reflect local vegetation conditions.
- Reliance on Loss on Ignition (LOI)–based conversions to estimate %C_{org} from organic matter, which may introduce bias if not calibrated with elemental analysis.

c. Measurement Uncertainty

- Errors in field and lab procedures, such as soil core compaction, incomplete recovery, or disturbance during extraction.

- Instrumental and analytical errors, including bulk density determination, uncorrected carbonate presence, or transcription errors in sample logging.
- Use of generic biomass carbon fractions (e.g., 0.45–0.50) when site-specific values are not available.

Distribution Area

Uncertainty also arises from determining the extent and stratification of salt marshes within the project boundary.

- a. Remote Sensing and Mapping Errors: Misclassification due to waterlogging, spectral similarity with mudflats, or blurred imagery can reduce accuracy, often in the 60–85% range.
- b. Stratification/Interpretation Uncertainty: Errors in delineating vegetation zones (e.g., low marsh vs. high marsh) during mapping. Classification accuracy and uncertainty in estimated ecosystem area are related but distinct measures. Area uncertainty shall be assessed using appropriate reference data and estimation procedures rather than inferred directly from overall classification accuracy.
- c. Horizontal Fluxes and Erosion: The fate of eroded marsh carbon (redeposited offshore vs. oxidized and emitted) introduces additional uncertainty in the carbon budget.

General Categories

Uncertainties can be broadly classified as:

- a. Variability Uncertainty – natural spatial and temporal heterogeneity (e.g., species composition, sediment type, tidal influence).
- b. Quality Uncertainty – errors from data gaps, poor management, or misclassification during field surveys or remote sensing interpretation.

C8.2 Reporting uncertainty in stocks and sinks

Transparent reporting of uncertainty is essential for credibility. Standard conventions include:

- Report uncertainty at the confidence level used to assess the adopted precision target, identifying the confidence interval and its absolute and relative half-width. Where another confidence level is required for reporting or certification, report it separately and label it clearly.
- Reporting carbon stocks in Mg C/ha for a defined soil depth, and converting to Mg CO₂/ha using the molecular mass ratio (×3.67) where required.
- State the adopted precision target, confidence level and whether the percentage represents confidence-interval half-width or full width. Assess and propagate uncertainty in

accordance with main Chapter 6. Apply any uncertainty deduction only as required by the applicable certification framework.

- Applying the principle of conservatism when high uncertainty cannot be avoided, by reporting values likely to understate rather than overstate carbon benefits.

C8.3 Recommended QA/QC Procedures

Quality Assurance (QA) and Quality Control (QC) are necessary to minimize errors, ensure transparency, and meet verification standards. The following practices are recommended for salt marsh projects:

1. **Field Data Quality Checks:** Collect duplicate biomass quadrat samples or soil cores in at least 10% of plots. If differences exceed acceptable thresholds, measurements should be reviewed or repeated. Conduct field sampling in the same season for each monitoring cycle to minimize seasonal or phenological bias.
2. **Data Sheet and Entry QA:** Use standardized field data sheets or waterproof notebooks. Data should be reviewed daily and typed entries cross-checked against original records. Maintain an error log for any corrections or anomalies.
3. **Instrument Calibration and Maintenance:** Field instruments such as GPS units, balances, and measuring tapes should be calibrated or verified regularly. Laboratory equipment, including ovens, elemental analyzers, and muffle furnaces, must have calibration and maintenance logs.
4. **Sample Handling and Lab QA/QC:** Apply chain-of-custody protocols from field to laboratory. Include replicates, blanks, and standards in laboratory analyses. For soil samples, ensure inorganic carbon is corrected or removed before calculating %C_{org} (e.g., acid treatment prior to analysis).
5. **Spatial Data QA:** Salt marsh extent maps derived from remote sensing should be validated with ground-truthing surveys. Cross-check mapping with field GPS points, drone imagery, or stratified vegetation surveys to reduce misclassification error.
6. **Statistical QA and Sampling Review:** Assess sampling adequacy against the precision target documented in Section C3.5. Distinguish variability among plots, expressed by the coefficient of variation, from uncertainty in the estimated mean. Investigate outliers and document their treatment; do not discard valid observations solely because they are extreme. Reassess sample size using the observed variability.

By explicitly addressing uncertainties in biomass, soils, and mapped area—and by applying rigorous QA/QC protocols—salt marsh blue carbon projects can ensure that their estimates are scientifically credible and suitable for inclusion in national GHG inventories or voluntary carbon market methodologies.

C.9 Methodological Levels for Salt Marsh Carbon Accounting

The Methodological Level system provides guidance for selecting and documenting methods used to estimate salt marsh ecosystem extent, carbon stocks, carbon stock changes, and relevant greenhouse gas emissions.

Three methodological levels—Basic, Standard, and Advanced—are distinguished by the specificity, representativeness, calibration, and validation of the underlying data and estimation methods.

These levels are specific to the methodology and do not correspond directly to IPCC Tier 1, Tier 2, or Tier 3. They describe methodological approaches rather than mandatory sets of instruments. A higher methodological level does not automatically demonstrate greater accuracy or lower uncertainty. Uncertainty shall be assessed independently in accordance with Chapter 6 of the Main Text and Section C.8 of this Annex.

The tables below provide examples of methods corresponding to each level. They do not replace the minimum sampling, measurement, accounting, or monitoring requirements specified elsewhere in the methodology. Different methodological levels may be applied to different carbon pools and accounting components within the same project.

C9.1 Methodological Levels for Carbon Stock Estimation

Accounting component	Level 1 – Basic	Level 2 – Standard	Level 3 – Advanced
Ecosystem Area / Extent	Existing salt marsh distribution maps or available spatial datasets, supported by appropriate field confirmation and documented limitations.	Locally or regionally developed salt marsh maps with systematic field validation, suitable spatial resolution, and consistent delineation of marsh extent and strata.	Detailed site-specific maps supported by rigorous field validation, documented classification accuracy, and appropriate assessment of spatial uncertainty.
Aboveground Biomass (AGB)	Standardized quadrat-based biomass measurements	Representative, stratified biomass measurements using	Detailed site-specific biomass measurements or

Accounting component	Level 1 – Basic	Level 2 – Standard	Level 3 – Advanced
	combined with applicable published carbon fractions.	locally or regionally appropriate carbon fractions and estimation parameters.	locally calibrated and validated estimation models, potentially supported by additional structural or spatial data where appropriate.
Belowground Biomass (BGB)	Field-derived biomass information or applicable published root-to-shoot relationships, where permitted by the selected method.	Representative root and rhizome measurements across relevant strata, or locally appropriate biomass relationships supported by field data.	Detailed site-specific belowground biomass measurements or locally calibrated and validated estimation models, with enhanced depth or temporal characterization where justified.
Soil Organic Carbon (SOC)	SOC estimation using site-measured soil depth, dry bulk density, and organic carbon concentration determined through an applicable laboratory method and justified conversion factors.	Representative, stratified SOC measurements supported by locally appropriate or calibrated analytical procedures and appropriate replication.	Detailed site-specific SOC estimation using replicated, vertically resolved measurements and validated analytical procedures where warranted.

The methodological level of an accounting estimate shall be determined from the collective suitability and quality of its underlying data and estimation procedures. The use of individual instruments or analytical techniques associated with a higher level does not automatically determine the level of the resulting estimate.

Where remote sensing or spatial models are used to estimate aboveground biomass, their application shall be supported by appropriate field calibration and validation. Estimates of belowground biomass derived from aboveground vegetation characteristics or remotely sensed information shall be supported by locally appropriate relationships and field measurements. Seasonal or temporal variability shall be considered where relevant to the estimation method.

C9.2 Methodological Levels for Carbon Stock Change and GHG Estimation

Accounting approach / component	Level 1 – Basic	Level 2 – Standard	Level 3 – Advanced
Stock-Difference Method	Comparison of carbon stock estimates at two comparable time points, supported by measured changes in relevant accounting inputs and appropriately justified published parameters.	Repeated, representative measurements using locally appropriate parameters and consistent sampling and estimation methods.	Detailed repeated measurements supported by site-specific calibration, validation, and enhanced characterization of spatial or temporal variability.
Gain–Loss Method	Estimation using applicable published rates or factors for carbon gains and losses, supported by relevant project activity and spatial data.	Estimation using locally representative measurements or parameters for the principal gains and losses, supplemented by published factors where justified.	Detailed site-specific estimation of relevant gains and losses, supported by direct measurements or locally calibrated and validated models.
GHG Emissions, where applicable	Estimation using appropriate published emission factors representative of relevant environmental conditions.	Estimation using locally representative emission factors, supported by site observations or targeted measurements.	Estimation using site-specific measurements or validated models, with appropriate characterization of temporal and environmental variability.
Sediment accretion and surface elevation measurements, where relevant	Applicable published sediment-accumulation information or basic site observations, with justification of their relevance to the intended estimate.	Site-based measurements using suitable methods, such as marker horizons or surface elevation tables.	Replicated or longer-term measurements, potentially supplemented by radiometric dating or other validated techniques where appropriate.

Sediment accretion, surface elevation change, and radiometric dating provide measurements or estimation inputs that may support the applicable carbon-accounting approach. They do not constitute separate ecosystem-level accounting approaches.

Where GHG emissions are required for project accounting, their quantification shall not be omitted solely because a Basic methodological level is applied. Direct flux measurements, where used, shall be interpreted according to the emission source or exchange process being measured and shall not automatically be treated as equivalent to net ecosystem carbon sequestration.

C.10 Monitoring

Monitoring in salt marsh projects is the systematic collection, management, and analysis of data to quantify changes in carbon stocks and greenhouse gas (GHG) emissions within the project boundary over time. Monitoring serves to:

- Ensure that carbon sequestration and emission reductions are real, measurable, and verifiable.
- Track the condition, extent, and stratification context of salt marsh ecosystems and associated carbon pools.
- Detect deviations from the baseline scenario and confirm that project activities are implemented as planned.
- Provide the basis for ex-post crediting under relevant certification schemes.

C10.1 Monitoring Plan

The monitoring approach must be defined in the Project Monitoring Plan prepared at validation. This shall include:

- Parameters to be measured – Included pools (aboveground biomass, belowground biomass, and soil organic carbon) and applicable non-CO₂ GHG emissions required for project accounting
- Frequency of measurement – Defined by carbon pool and aligned with expected rates of change. Measurements should be conducted under comparable, site-appropriate seasonal and phenological conditions across monitoring periods.
- Field and remote sensing methods – Consistent with Sections C.3–C.8. Methods should remain stable across campaigns (e.g., same quadrat size, core depth, slicing scheme, LOI to CHN calibration).

- Strata and plot management – Maintain permanent plots/transects where possible. Plot relocation must be supported by GPS/RTK markers to reduce variance and ensure temporal comparability.
- Data management – QA/QC procedures, uncertainty estimation, metadata standards, and archiving of all raw data (field sheets, photos, GNSS tracks, lab worksheets).

C10.2 Monitoring Schedule

Monitoring frequency varies by carbon pool due to differences in turnover and detectability of change.

Table 1: Minimum monitoring frequency by carbon pool

Carbon Pool / Parameter	Minimum Frequency	Notes
Aboveground biomass (AGB)	Every 1–2 years (more frequent if there is disturbance)	Permanent quadrats/transects preferred; sample during peak biomass season.
Belowground biomass (BGB)	Every 1-2 years (more frequent if there is disturbance)	Collected with cores; maintain consistent depth and diameter.
Soil organic carbon (SOC)	Every 10 years (5 years for early restoration)	Core to ≥ 1 m depth; use consistent slicing scheme; carbonate removal protocols unchanged.
Sediment accretion (MH/SET plates)	Annual (seasonal where feasible)	Co-locate with SOC cores; calculate carbon burial using BD and %C _{org} .
Isotope geochronology (^{210}Pb , ^{137}Cs)	One-off per stratum (repeat every 15–20 years or after major shifts)	Validates long-term burial rates.
Areal extent / strata area	Annual–biennial	Remote sensing updates validated with field surveys.
CH ₄ /N ₂ O emissions	Seasonal or annual campaigns	Where applicable, quantify emissions using direct measurements or justified applicable factors. For direct measurements, use campaigns representative of relevant seasonal and tidal conditions. Document exclusions under main Section 10.4.

Assess relevant GHG emissions in both the baseline and project scenarios. A source shall not be excluded merely because the project does not claim a flux benefit. Apply the exclusion provisions of main Section 10.4 and document their justification.

C10.3 Parameters and Data Collection

Monitoring should include both activity data (extent, distribution, condition) and carbon measurement parameters (biomass, SOC, CAR).

Table 2: Key Monitoring Parameters for Salt Marsh Ecosystems

Parameter	Carbon Pool / Component	Unit	Measurement / Analytical Method	Field / Lab Equipment	Notes
Species composition	AGB/BGB	–	Field ID; photo vouchers	Field guide; GPS camera	Supports stratification by vegetation type (grass vs. shrub marsh).
Cover (%)	AGB context	%	Visual classes or point-intercept	Quadrat frame	Observer calibration required.
Shoot/stem density	AGB	stems m ⁻²	Count within quadrats (0.25–1 m ²)	Quadrat; tally sheet	Pair with canopy height for biomass inference.
Canopy height	AGB	cm	Ruler/meter stick	Meter stick	Measure average and maximum.
AGB/BGB dry mass	Biomass C	g m ⁻² ; Mg ha ⁻¹	Quadrat harvest or coring, oven-dry	Core tubes; oven; balance	Ensure consistent sampling area/depth.
Bulk density (BD)	SOC	g cm ⁻³	Dry mass ÷ core volume	Cores; calipers; oven; balance	Correct for compaction.
%C _{org} (soil)	SOC	% dry mass	CHN analysis (preferred) or LOI regression; carbonate removal required	Elemental analyzer; muffle furnace; HCl	Apply consistent acidification.

Parameter	Carbon Pool / Component	Unit	Measurement / Analytical Method	Field / Lab Equipment	Notes
Sediment accretion rate	SOC burial	mm yr ⁻¹	Marker horizon (feldspar/sand) or subsurface plate	MH/plates; pins	Link with BD and %C _{org} for CAR.
Long-term burial (CAR)	SOC burial	g C m ⁻² yr ⁻¹	²¹⁰ Pb/ ¹³⁷ Cs age–depth models	Vibracorer; spectrometer	Report model choice and uncertainty.
Areal extent / strata area (A _{i,t})	All	ha	Remote sensing (Sentinel/Landsat/UAV) with ground-truthing	GNSS; UAV imagery	Provide accuracy (confusion matrix).
CH ₄ /N ₂ O emissions (where applicable)	GHG emissions	mg m ⁻² h ⁻¹	Static chamber method with lab analysis	Chambers; gas analyzer	Assess applicability using site conditions. Use measurements or justified applicable factors; document exclusions under main Section 10.4.

C10.4 Tools and Methods

Field methods shall follow those in Sections C.3–C.7 of this Annex.

Remote sensing data may be used to:

- Detect salt marsh extent and boundary changes.
- Support stratification by vegetation type, cover, and elevation.
- Identify disturbances (erosion, dieback, conversion).

Data sources may include Sentinel-2, Landsat, UAV imagery, and other regionally available high-resolution datasets.

C10.5 Quality Assurance / Quality Control (QA/QC) and Uncertainty Assessment

Projects shall implement QA/QC procedures to minimize measurement error and bias:

- Crew training before each campaign; inter-observer calibration for cover, density, and height.
- Standardized data sheets and metadata; daily reviews; photographic records of plots and cores.
- Cross-checks of $\geq 10\%$ of plots/cores by independent observers; GNSS-verified relocation of permanent plots.
- Laboratory QA/QC: replicate analyses ($\geq 10\%$), blanks and standards, maintain LOI $\leftrightarrow$ CHN calibration curves, document carbonate removal.
- Remote sensing QA: accuracy assessment (confusion matrix); reconcile detected changes with field verification.
- Method change log: document and justify any deviations.

Estimate uncertainty for each included pool and the project total in accordance with Section C8 and main Chapter 6. Where sampling precision does not meet the adopted target, review the sampling design and increase sampling where necessary. Any uncertainty deduction shall follow the applicable certification requirements.

C10.6 Reporting Templates

These templates support consistent reporting of salt marsh monitoring results under this annex and the main methodology. Complete the applicable fields for each reporting period, retain the supporting field, laboratory, spatial and calculation records, and cross-reference them using unique identifiers. Expand rows as needed. Enter “not applicable” with a reason where a field does not apply; distinguish zero, not measured and missing data. The templates do not replace the project design document, approved monitoring plan or underlying calculation files.

Report quantities with their units, measurement dates and spatial and depth boundaries. Use carbon fractions as decimals (for example, 0.02), while organic-carbon percentages are entered as percentage values (for example, 2 for 2%). Keep carbon stocks, stock changes and GHG balances distinct. Report uncertainty under main Chapter 6 and use the applicable monitoring schedule; these templates introduce no new default factors or monitoring frequencies.

For projects covering more than one ecosystem, identify the contribution of each annex and consolidate shared sources, leakage and project-level results once. Annualized rates are not additional amounts to be added to reporting-period totals.

Template R1: Project and reporting period

Field	Entry
Project name and identifier	
Country, locality and proponent	
Report identifier, version and preparation date	
Reporting period start and end; duration and annualization basis	
Project start date and activity type; implementation completed during this period	
Applicable methodology and annex versions; monitoring-plan identifier	
Project boundary/map version and total area (ha)	
Baseline scenario and additionality documentation reference; changes since previous report	
Accounting approach by pool or component; methodological level and justification reference	
Previous report reference; changes in methods, boundaries or strata and comparability assessment	
Prepared by; internal reviewer; organization, roles and dates	

Template R2: Strata and spatial changes

One row per stratum. Areas must refer to dated, non-overlapping accounting units. Attach the boundary-change reconciliation where strata were split, merged, gained or lost; do not interpret an area change alone as a carbon-stock change.

Stratum ID	Habitat and management condition	Start area (ha)	End area (ha)	Map dates and versions	Area uncertainty reference	Change and evidence reference

Template R3: Monitoring implementation

One row per parameter or sampling component. Attach the sampling design and environmental observations required to interpret the measurements. Report the number of independent sampling units, distinguishing subsamples and repeat observations.

Parameter or pool and stratum	Method and SOP version	Planned frequency and dates	Actual dates and independent sample count	Responsible team	Deviation and corrective action	Data and QA record reference

Template R4: Biomass carbon stock summary

Repeat for each stratum, measurement date and scenario where biomass stocks are used. Supporting field records must preserve the original measurements and conversions; this table reports the resulting stratum estimates.

Field	Entry
Stratum ID; measurement date; scenario or observed inventory	
Independent plot/quadrat/core count and sampling-design reference	
Stratum area (ha) and spatial-record reference	

Pool	Mean dry biomass (Mg/ha)	Carbon fraction or parameter reference	Mean carbon stock (Mg C/ha)	Stratum carbon stock (Mg C)	Calculation and uncertainty reference
Aboveground living biomass					
Belowground living biomass					

Retain the following in the linked field and laboratory records:

- Plot, quadrat and core identifiers; coordinates and reference system; measurement date, tidal state, vegetation season and team.
- Species composition, cover (%), stem or shoot density (number/m²) and vegetation height (cm), where collected.
- Aboveground harvest area (m²), biomass corer internal diameter (cm), core area (cm²), sampled root/rhizome depth (cm), and separate dry masses (g).
- Living-root separation and dead-material allocation; drying, weighing and carbon-fraction records linked to sample identifiers.
- For spatially modelled biomass, calibration and independent validation records, field-supported belowground relationships, and treatment of seasonal variability.

If carbon fractions differ among samples or species, calculate carbon before aggregation and cite the detailed calculation rather than imposing a single mean fraction. Do not add a subtotal to its component pools.

Template R5: Soil carbon and depth basis

Use one core record for each sampled core and one layer row for each analyzed interval. The layer table may be supplied as a linked electronic schedule.

Field	Entry
Stratum, plot and core identifiers; date and coordinates	
Corer internal diameter (cm); penetration and recovered lengths (cm)	
Actual assessed depth (cm); refusal or other limitation	
Compression assessment and any correction; interval and volume basis	
Living-root/rhizome removal; retained dead material and pool allocation	
Laboratory/SOP reference; carbon analysis method; carbonate treatment and dry-mass basis	
Core photographs, chain-of-custody and sample register references	

Sample ID	Assessed depth interval (cm)	Dry bulk density (g/cm ³)	Organic carbon (%)	Layer stock (Mg C/ha)	Laboratory and calculation reference

Stratum ID	Common reporting depth (cm)	Independent core count	Mean SOC (Mg C/ha)	Stratum SOC (Mg C)	Uncertainty and calculation reference

Normally report measured stocks within 0–100 cm. Report shallower stocks at their actual depth and deeper stocks separately. Do not extrapolate a shallow stock to 1 m by a depth ratio. Identify any estimated unmeasured intervals separately and document their justification and uncertainty. Use a consistent depth basis for comparisons; document interval-boundary treatment and design-consistent averaging of cores.

Template R6: Carbon stock change

Complete the panel applicable to each pool and scenario. Where methods differ among pools, document their boundaries and demonstrate that the same change is not counted twice. These are carbon results, not project GHG benefits. For stock difference, change equals end stock minus start stock. For gain–loss, net change equals gains minus losses. Divide the interval change by elapsed years for the annualized result.

Stock difference panel

Interval start and end: _____. Elapsed years: _____. Scenario: _____.
Area/depth comparability and boundary-change reconciliation: _____.

Stratum and pool	Start stock (Mg C)	End stock (Mg C)	Change (Mg C)	Annualized change (Mg C/yr)	Calculation reference

Gain and loss panel

Interval start and end: _____. Elapsed years: _____. Scenario: _____.
Rate integration and spatial scaling reference: _____.

Stratum and pool	Gains over interval (Mg C)	Losses over interval (Mg C)	Net change (Mg C)	Annualized net change (Mg C/yr)	Calculation and overlap check reference

Apply area once when converting per-hectare quantities to stratum totals. Preserve negative net changes. Where accretion or radiometric burial informs gains, record method, assessed dates/depths, rate units, carbon concentration convention, and whether the estimate is gross accumulation or net burial. Keep surface-elevation change distinct from accretion. Do not add historical interval rates as simultaneous annual gains or subtract losses already represented by a net burial estimate.

Template R7: GHG accounting summary

Complete the component ledger separately for baseline and project scenarios, using the same reporting period and compatible accounting boundaries. Link annual schedules where required. Include each term once, documenting overlap between stock changes, respiration and other measured fluxes.

Scenario and year/period	Source or removal and spatial scope	Gas or carbon basis	Input amount and unit	Conversion or GWP reference	Signed result (tCO ₂ e)	Calculation and overlap-check reference

Use positive values for emissions and negative values for removals in scenario balances. A stock increase converted to a removal therefore enters with the opposite sign to the positive stock-change result. Document use of 44/12 for carbon-to-CO₂ conversion and applicable 100-year GWPs for CH₄/N₂O. Identify whether measurements are expressed as gas mass or carbon/nitrogen mass and document any necessary conversion before applying GWP.

Accounting item	Reporting-period result (tCO ₂ e)	Annualized result (tCO ₂ e/yr)	Calculation reference
Net baseline GHG balance			
Net project GHG balance			
Baseline minus project before leakage			
Leakage deduction			
Net GHG benefit after leakage			

Calculate net GHG benefit as baseline balance minus project balance minus leakage under main Section 9.6. Leakage deductions shall not be negative. Do not add avoided emissions again where already represented in the baseline–project difference. For a multi-ecosystem project, provide the consolidated project table once and cross-reference each annex contribution.

Field	Entry
Applicable uncertainty/conservativeness adjustment, amount, unit and rule reference, or not applicable	
Non-permanence or reversal treatment and evidence reference, where applicable	
Relationship between reported benefit, any adjusted result and the consolidated project report	

Apply a deduction or buffer only where required by the applicable certification framework; identify its rule and calculation separately. Report any applicable adjustment separately and identify its rule and calculation. These reported estimates are not an issuance or certification decision.

Template R8: Uncertainty statement

Repeat this record for each material estimate and the consolidated result. Where an uncertainty budget is lengthy, attach it and retain its identifier here.

Field	Entry
Estimate identifier, scenario, period and spatial/pool/depth scope	
Point estimate and unit	
Standard error or other uncertainty measure; identify its type and unit	
Confidence level and interval limits, where applicable	
Relative precision measure and definition; adopted target and source, where applicable	
Sampling design, independent sample count and estimation/propagation method	
Included sources: sampling, model, carbon fraction, laboratory, area and other material sources	
Shared errors/covariance and area weighting; treatment of omitted sources	
Calculation reference, limitations and any additional sampling or corrective action	

Distinguish standard error, coefficient of variation and confidence-interval width. Do not treat them as interchangeable or combine incompatible uncertainty measures.

Template R9: Parameters and exclusions

Parameter register — one row per applied factor, model or conversion, including carbon fractions, allometry, LOI calibration, emission factors and GWP values as applicable.

Parameter ID and use	Value or equation and unit	Source with page/table/version	Site/species/depth applicability	Uncertainty or calibration evidence	Calculation reference

Exclusion register — record included, excluded and zero-valued terms distinctly. Assess project-level cumulative exclusions under main Section 10.4.

Pool, GHG or leakage term	Included/excluded/zero	Basis and applicable provision	Estimated omitted contribution (tCO ₂ e)	Evidence reference	Reassessment trigger

Field	Entry
Project-level cumulative de minimis assessment reference and period	
Combined contribution of terms tested (tCO ₂ e) and estimation basis	
Net GHG benefit before leakage used as denominator (tCO ₂ e)	
Calculated percentage, conclusion and treatment of non-positive/undefined denominator	
Evidence that exclusions do not overstate benefits; treatment of any adverse pool change	

Do not use a pool's share of standing carbon stock as the significance denominator. A non-positive or undefined denominator does not demonstrate that an exclusion passes. A source is not excluded merely because no flux benefit is claimed.

Template R10: QA review and risk follow-up

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Dataset or calculation ID	Check performed and coverage	Finding or limitation	Correction and status	Reviewer and date	Evidence/version reference

Cover field completeness, calibration, sample traceability, laboratory checks, data-entry review, units, formulas, spatial/depth comparability and double-counting checks as applicable. Retain original records and document corrections rather than silently replacing them.

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Risk/event ID and date	Affected stratum and extent (ha)	Observed or potential effect	Action, owner and due date	Accounting/reversal assessment reference	Follow-up status and evidence

Field	Entry
Raw field/laboratory records, photographs and spatial archive location	
Calculation files, SOP versions, parameter sources and uncertainty files	
Outstanding issues and their effect on the reported results	
Prepared by and date; internal technical review by and date	
Independent verification status and statement reference, if available	

Retain records under the main methodology's retention requirements. Internal review does not constitute independent verification.

C.11 Regional Parameter Tables

Salt Marsh Vegetation Species in the East and Southeast Asia Region

Table 3: Salt marsh Species

Species	Common Name
<i>Spartina alterniflora</i>	Saltwater cordgrass
<i>Phragmites australis</i>	Common reed
<i>Suaeda japonica</i>	Seepweed
<i>Suaeda maritima</i>	Seepweed
<i>Artemisia fukudo</i>	Asian coastal wormwood
<i>Salicornia europaea</i>	Glasswort
<i>Limonium tetragonum</i>	Square-stem statice
<i>Carex scabrifolia</i>	Sedge
<i>Zoysia sinica</i>	Seaside lawngrass
<i>Porteresia coarctata</i>	-

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