ASES ON-CHAIN PROTOCOL

METHODOLOGY FOR THE ISSUANCE OF VERIFIED CARBON CREDITS FOR MANGROVE PROJECTS

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TABLE OF CONTENTS

INDEX OF TABLES

INTRODUCTION

This methodology establishes the technical procedures for the quantification, monitoring, and verification of carbon capture in mangrove restoration projects under the Ases On-Chain Protocol (aOCP). The methodology applies to mangrove restoration and reforestation projects in previously degraded coastal and riparian areas, with a minimum time horizon of 40 years. It exclusively considers the use of native mangrove species historically documented in the project region.

The method quantifies two main reservoirs: tree biomass (aboveground and belowground) and soil organic carbon (up to 1 meter deep).

For the initial assessment of credit generation potential, only tree biomass is considered, adopting a conservative approach. During the implementation phase, both compartments are monitored using a combination of field measurements and remote sensing techniques.

The methodology presents innovative elements such as the integration of machine learning (Random Forest) with field data for spatially explicit estimates, an adaptive monitoring system that considers different frequencies for biomass and soil, specific deduction factors that ensure conservative estimates, and a robust framework for uncertainty and risk management.

The methodology also incorporates rigorous quality control and assurance procedures, including standardized sampling protocols, cross-validation of estimates, a structured documentation and reporting system, and periodic technical audits.

The implementation of this methodology allows for the ex-ante estimation of the project's carbon credit generation potential, the precise and conservative quantification of carbon sequestration, and the reliable monitoring of changes in carbon stocks. All of this leads to the generation of carbon credits with high environmental integrity.

I. BIODIVERSITY APPROACH

Biodiversity is fundamental to maintaining the stability and functioning of ecosystems; each species plays a specific role in its habitat, interacting with other species and contributing to the health and resilience of the ecosystem. Loss of species can trigger ecological imbalances and have negative effects on the food chain and natural processes.

Biodiversity credits have been developed as a way to address the problem of species loss by promoting their conservation and rewarding those who take positive actions for their creation.

The carbon market has centered on degraded habitats that require funding to be protected and repaired from the consequences of climate change, and the areas that need to preserve biodiversity but exhibit signs of degradation, deforestation, or disturbance have typically gone unnoticed by the market. This approach intends to offer a brand-new source of funding for international biodiversity conservation initiatives.

Every project funded by the aOCP program must include biodiversity preservation and protection as a fundamental element. As a result, this approach should be applied in programs devoted to regenerative agriculture, forest management, urban forest management, and water flow restoration.

Credits are generated through projects that encourage conservation or restoration, representing certain amounts of benefits. In the aOCP protocol, to calculate the benefit of the project and objectively estimate the number of credits, the actions taken in favor of biodiversity are evaluated based on three key variables:

- Area preserved
- Restored area
- Ecological condition of the intervened area

In the context of complexity, biodiversity refers to the amount and variety of various living forms and interactions present in an ecosystem. The greater an ecosystem's biodiversity, the greater its complexity and resilience. This is because diverse species and interactions provide multiple paths for energy and nutrient input, which aids in maintaining ecosystem function even when certain components are absent.

II. DEFINITIONS

Terms Related to Carbon and Climate

- **Additionality:** Principle stating that emission reductions or removals would not have occurred in the absence of the project. Includes:
- **Financial additionality:** The project would not be viable without the income from carbon credits
- **Ecological additionality:** Natural restoration would not occur without active intervention
- **Aboveground Biomass (AGB):** All living biomass above the ground, including stems, branches, bark and leaves. Expressed in megagrams per hectare (Mg/ha).
- **Underground Biomass (UBB):** All living root biomass. Fine roots less than 2 mm in diameter are excluded due to their high turnover rate.
- **Blue Carbon:** Carbon captured and stored by coastal ecosystems, including mangroves, salt marshes and seagrass beds.
- **Soil Organic Carbon (SOC):** Organic component of the soil, derived from the partial decomposition of organic materials—In mangroves it can reach several meters deep.
- **Carbon Dioxide Equivalent (CO_2e):** A standardized measure that expresses the global warming potential of different greenhouse gases in terms of CO_2.

Project Related Terms

- **Reference Area:** Mangrove area with ecological conditions similar to the project area, used to compare the evolution of the ecosystem without intervention.
- **Stratum:** Subdivision of the project area based on homogeneous characteristics (species, density, age, environmental conditions).
- **Leakage:** Increase in GHG emissions that occur outside the project boundaries but is attributable to project activities.
- **Permanence:** Duration of carbon storage in the ecosystem. In mangrove projects, a minimum of 40 years is required.
- **Sampling Unit:** Area defined for systematic measurements of project parameters (typically 100-400 m^2 plots).

Methodological Terms

- **Allometric Equations:** Mathematical relationships that estimate the total or partial biomass of a tree based on easily measured variables (DBH, height).
- **Conversion Factor:** Coefficient used to convert:
  - Biomass to carbon (0.47 for aboveground biomass, 0.39 for belowground)
  - Carbon to CO_2e (44/12 = 3.67)
- **Baseline:** Scenario that represents the conditions and emissions that would occur in the absence of the project.
- **Crediting Period:** Time interval during which a project can generate carbon credits (40 years for mangrove projects).

Technical Terms of Mangrove

- **Hydroperiod:** Pattern of water level fluctuation in the mangrove, including frequency, duration and depth of flooding.
- **Natural Regeneration:** Process of establishing and developing mangrove seedlings without direct human intervention.
- **Hydrological Restoration:** Restoring natural water flow patterns, which are essential for ecosystem health.

II.1. List of Acronyms

General Acronyms

aOCP	Ases On-Chain Protocol
AGB	Above Ground Biomass
BGB	Below Ground Biomass
BTP	Total Biomass of the Plantation
DAP	Chest Circumference at Height
DR	Diameter above the Root
MAE	Mean Absolute Error
NDVI	Normalized Difference Vegetation Index
PSF	Project Submission Form
SOC	Soil Organic Carbon
SOM	Soil Organic Matter

Institutions and References

CIFOR	Center for International Forestry Research
CONABIO	National Commission for the Knowledge and Use of Biodiversity
CONAFOR	National Forestry Commission
GEDI	Global Ecosystem Dynamics Investigation
INEGI	National Institute of Statistics and Geography

Units of Measurement

cm	centimeter
g	gram
ha	hectare
kg	kilogram
Mg	megagram (metric ton)
m	metro
tCO_2e	tons of carbon dioxide equivalent

III. Applicability conditions

III.1. Eligibility and Regulatory Compliance

Mangrove restoration projects must demonstrate eligibility under the Ases On-Chain Protocol (aOCP) by meeting specific additionality and permanence criteria. Financial additionality must be evidenced through an investment analysis demonstrating that the project would not be viable without carbon credit revenues. ***Ecological additionality requires documentation supporting the need for active intervention for ecosystem recovery.***

The project must comply with all applicable environmental regulations, including restoration permits, environmental impact studies and land use change authorizations when required. It must also be aligned with national wetland conservation policies and international commitments on climate change.

III.2. Temporal and Site Status Criteria

The maximum age allowed for projects is five years from their start to their registration in the aOCP protocol. The project area must not have experienced degradation, deforestation or fires in the 24 months prior to the start of the project. In exceptional cases where there is recent degradation, the project developer must present:

- Technical evidence documenting the state of vulnerability of biodiversity and ecosystem services.
- Analysis of the causes of degradation and its impact on ecosystem functionality.
- Justification of the immediate need for intervention to prevent irreversible losses.
- Detailed plan of the proposed restoration actions.

III.3. Ecological Criteria and Species

The methodology applies exclusively to projects that restore or conserve native mangrove species historically documented in the project area.

Species selection should be based on:

- Historical distribution records
- Hydro geomorphological conditions of the site
- Natural zonation patterns of mangroves
- Tolerance to current salinity conditions and hydrological regime

III.4. Technical and Operational Aspects

III.4.1 Duration and Monitoring

Projects must establish a minimum commitment of 40 years, during which a monitoring system will be implemented that includes:

- Annual survival and growth assessment
- Quarterly monitoring of hydrological conditions
- Biennial assessment of ecosystem structure
- Five-year soil carbon sampling
    - In the case of soil carbon sampling, these assessments will begin at Year 5 of the project following the methodology listed in Annex I.

III.4.2. Required Documentation

The project must maintain detailed records including:

- Complete forest inventories
- Initial establishment data
- Records of management interventions
- Periodic monitoring results

III.4.3. Rights of Use

The project developer must demonstrate legal rights to the area throughout the permanence period by:

a) Property titles
b) Usufruct contracts
c) Government concessions
d) Community agreements formalized

III.5. Spatial Delimitation and Eligible Areas

The spatial delineation of the project establishes the geographic framework for accurately quantifying and monitoring carbon removals. The project developer must provide the geospatial project area information described in ***"Section II.5.1. Spatial Structure"***; the three levels of classification of project areas are: general polygon, sub-polygons and strata.

III.5.1. Spatial Structure

The **general polygon** corresponds to the total area over which the developer has proven legal rights, whether through property titles, usufruct contracts, concessions, or formalized agreements with legal validity. This polygon constitutes the maximum limit within which the project activities can be implemented.

Within this general polygon, the developer will define operational **sub-polygons** that respond to the different planned activities and the ecological characteristics of the site. The delimitation of these sub-polygons must be based on historical evidence of the presence of mangroves.

The developer must also **stratify the sub-polygons** according to the specific conditions of each area, considering the state of degradation, the type of substrate, the hydrological regime and the mangrove species historically present.

The EIET-aOCP will verify that the proposed areas meet the eligibility criteria through analysis of the documentation submitted and field visits. The team may request modifications to the delimitation if it identifies inconsistencies or ineligible areas.

III.5.2. Geospatial Documentation

The project developer must deliver geospatial files that include:

- The complete polygon of the area to be registered
- Sub-polygons according to activities to be implemented
- Stratification by land use and vegetation status
- The selected reference area

For each geospatial file, the developer must include complete metadata to verify the source and quality of the information, including:

- ***Institution generating information***
- ***Dataset Title***
- ***Year of evaluation and publication***
- ***Spatial scale or resolution***
- ***Data format***
- ***Source of access or official repository***

The EIET-aOCP will carry out the final technical validation of all spatial documentation submitted and maintain an updated digital record of project information.

III.6. Evaluation of Ecological Degradation Factors

Accurate identification of the factors that have caused mangrove degradation is essential to ensure the effectiveness and permanence of restoration actions. This section establishes the requirements for the analysis of the causes of degradation and their relationship to the proposed interventions.

III.6.1. Analysis of Degradation Causes

The project developer must perform a comprehensive analysis of degradation factors that include:

The identification of hydrological alterations that affect the mangrove, documenting modifications in water flow patterns, changes in hydrological connectivity, and alterations in flooding regimes. This analysis must be supported by technical evidence such as historical records, field measurements, and analysis of multi-temporal satellite images.

Characterization of changes in the physicochemical conditions of the site, including variations in water and soil salinity, modifications in soil characteristics, and alterations in sedimentation patterns. This information should be supported by field data and laboratory analysis.

Documentation of direct anthropogenic impacts such as deforestation, land use change, infrastructure construction or resource extraction. This assessment should include a temporal analysis of the observed changes and their spatial distribution in the project area.

III.6.2. LINKAGE WITH RESTORATION ACTIONS

The developer must establish the direct relationship between the identified degradation factors and the proposed restoration actions. For each documented degradation factor, the following must be specified:

Specific interventions designed to address each cause of degradation, detailing how these actions will contribute to reversing the identified impacts and restoring ecosystem functionality.

Indicators that will be used to monitor the effectiveness of interventions in reversing degradation factors, including measurement methods and frequency of evaluation.

III.6.3. TECHNICAL APPROVAL

The EIET-aOCP will assess the robustness of the degradation analysis and its link to the proposed actions. This assessment will consider:

- The strength of the evidence presented is to support the identification of degradation factors.
- The relevance and potential effectiveness of proposed interventions to address the identified causes.
- The feasibility of the proposed monitoring system to assess the reversal of degradation factors.

The EIET-aOCP may request additional information or modifications to the proposed interventions if it determines that the proposed interventions do not adequately address the identified degradation drivers.

IV. METHODOLOGICAL CONSIDERATIONS

IV.1. CARBON RESERVES CONSIDERED

This methodology considers carbon compartments that contribute significantly to the total carbon balance of the mangrove ecosystem and can be measured and monitored reliably and cost-effectively.

IV.1.1. CARBON STOCKS INCLUDED & EXCLUDED

The methodology's parameters and the factors that will be considered when using it are listed in the following table:

Non-woody biomass, both aboveground (grasses and herbs) and belowground (fine roots), is excluded due to its high turnover rate and relatively minor contribution to long-term carbon storage. Leaf litter and dead wood are also excluded due to their high temporal and spatial variability, as well as the methodological difficulties in measuring them accurately and consistently. Table 1 presents the detailed list of the compartmentalized carbon reserve inclusions.

TABLE 1. COMPARTMENTALIZED CARBON RESERVES

Carbon reserve		Includes	CO_2 removals	Baseline	Leaks
Biomass of trees	*Aerial*	Trunks, branches, bark	✓	✓	✓
	Underground	Roots	✓	✓	✓
Non-woody biomass	*Aerial*	Grasses, herbs, etc.	✕	✕	✕
	Underground	Roots	✕	✕	✕
Floor		Organic matter	✓	✓	✓
Leaf litter and dead wood		Leaves, fallen branches	✕	✕	✕

IV.1.2. GREENHOUSE GASES

The project developer must account for CO_2 emissions in all included compartments. CH_4 emissions are optional due to the high uncertainty in their quantification, although the developer may include them if robust measurement methodologies are available.

N_2O emissions are excluded due to their low relevance in mangrove ecosystems, where anoxic conditions favor complete denitrification to N_2.

IV.1.3. ADDITIONAL EMISSION SOURCES

The EIET-aOCP will verify the inclusion of emissions associated with site preparation when activities such as burning existing biomass or opening channels are carried out. In these cases, a 15% deduction will be applied on the baseline to consider N_2O and CH_4 emissions, unless the developer presents scientific evidence justifying a different value.

Emissions from the use of fossil fuels in project activities (transportation, management operations) are considered negligible and can be omitted from the calculation.

TABLE 2. ADDITIONAL EMISSIONS

Source	Gas	Included	Justification
Emissions from mineral soils in wetlands (baseline and CO_2 removal)	CO_2	✓	Considered as part of carbon reserves
	CH_4	Optional	Methane (CH_4) emissions from mangroves may partially offset the benefits of carbon sequestration in these ecosystems. However, estimates are subject to high uncertainty due to emissions variability and methodological limitations, highlighting the need for more detailed studies.[1]
	N_2O	✕	N_2O emissions in mangrove ecosystems are often considered low due to the prevailing anoxic conditions in their soils, which favor complete denitrification, resulting mainly in the release of N_2 rather than N_2O. Furthermore, existing studies indicate that N_2O emission rates in mangroves are significantly lower compared to other coastal ecosystems.[2]
Other emissions: Site preparation	CH_4 and N_2O	✓	When the existing Baseline 'tree' and 'non-tree' biomass is burned for land preparation purposes, and/or channel opening and flooding is performed, an additional 15% must be deducted from the Baseline. This is to account for the N_2O and CH_4 emissions released during these processes. Another value may be used for the deduction if it is supported by scientific literature.
Other emissions: Burning fossil fuels	CH_4 and N_2O	✕	Non-CO_2 greenhouse gas emissions from the use of fossil fuels in project activities (e.g. flights, management operations, etc.) are negligible and can therefore be omitted.

The EIET-aOCP will perform carbon accounting based on the information submitted by the developer and may request adjustments or additional information when necessary.

V. APPLICATION OF THE METHODOLOGY

This methodology is applied at different stages of the project life cycle, adapting to the specific needs of each stage while maintaining the scientific rigor necessary to guarantee the integrity of the carbon credits generated.

V.1. APPLICATION STAGES

At the time of registration, the project developer must provide all necessary information and documentation, including data on planting activities, site characteristics and initial conditions of the project. The EIET-aOCP will calculate the carbon credit generation potential, based initially

[1] (Pham et al., 2024)
[2] (Alongi, 2018)

on above- and below-ground tree biomass. This initial conservative approach minimizes the uncertainties associated with other, more complex compartments.

During the validation and monitoring stages, the EIET-aOCP will conduct direct field measurements of both trees and soil samples. These assessments will provide more detailed and specific data on carbon stocks, allowing initial estimates to be adjusted as necessary. The EIET-aOCP will be responsible for calculating the differences in carbon stocks relative to the relevant comparison point. For the initial calculation of the credit generation potential, this involves comparing the expected biomass when the trees reach maturity with the initial state of the project. During monitoring, the EIET-aOCP will determine the difference in carbon stock between the time of measurement and the baseline state, allowing the net change in carbon stocks over time to be assessed.

The EIET-aOCP will perform all necessary conversions, including converting carbon units to CO_2e using the standard factor of 44/12. It will also apply deductions for project-generated emissions and associated leakage to obtain the net carbon balance and thus determine the number of carbon credits to be issued.

Specific procedures for quantifying each component are detailed in the following subsections.

V.2. Quantification of Carbon Reserves

This section sets out the general framework for quantifying carbon stocks in mangrove restoration projects. The methodology considers two main compartments that are assessed independently: tree biomass (aboveground and belowground) and soil organic carbon. Tree biomass will be continuously monitored throughout the project's lifetime, whereas soil carbon will be assessed and monitored beginning at Year 5 of the project. After the initial soil carbon analysis, soil carbon should be tested every 3-5 years, dependent upon the specific project. The project developer must provide the necessary baseline data for initial quantification, including information on planting activities and site characteristics.

The EIET-aOCP is responsible for establishing the carbon baseline and carrying out both initial and monitoring estimates. To do so, it will implement a system that combines direct measurements on sample plots with advanced remote sensing and modelling techniques.

Specific procedures for quantifying carbon in tree biomass and soil are detailed in the following subsections.

V.2.1 Carbon Reserves in Aerial and Underground Biomass

This section details the procedures for quantifying carbon stored in tree biomass, both for ex ante assessment of project potential and for monitoring during its implementation.

Ex Ante Estimate

To estimate the potential for carbon credit generation, the EIET-aOCP will perform calculations based on the allometric equations developed by Adame et al. (2013). The total biomass per tree for each species is determined using the following formula:

$$BTree, i = AGBtree, i + BGBtree, i$$

Where:

$B_{Tree,i}$ = total biomass per tree of species i (kg)

$AGB_{Tree,i}$ = aboveground biomass per tree of species i (kg)

$BGB_{Tree,i}$ = belowground biomass per tree of species i (kg)

For this initial calculation, the EIET-aOCP will use average tree diameters from the Mexican Carbon Program database, selecting data from studies conducted in the state where the project is located or in neighboring states.

The expected total biomass of the plantation is then calculated using:

$$BTPex-ante = (\sum(BTree,i \times ntree,i)) \times (\frac{0.9}{1000})$$

Where:

$BTP_{ex\text{-}ante}$ = expected biomass of the plantation (Mg)

$B_{Tree,i}$ = total biomass per tree of species i (kg)

$n_{Tree,i}$ = number of planted trees of species i

0.9 = expected survival factor (90 %)

This calculation follows a conservative approach by assuming a baseline of zero and excluding any potential biomass increase from natural regeneration.

Quantification During Monitoring

The EIET-aOCP will implement a spatial modelling system that integrates remote sensing data with field measurements to estimate biomass across the project area. The procedure consists of the following steps:

Model Preparation

The EIET-aOCP establishes training points systematically distributed in the project area. For these points, the following are extracted:

- GEDI 2020-layer biomass values as a base reference
- Biophysical variables derived from satellite images (NDVI, EVI, SMI)
- Radar polarization parameters (VV-VH, VH-VH)

Model Training

A Random Forest model is developed using GEDI biomass values as the dependent variable and satellite biophysical variables as predictors.

Prediction and Validation

The model is applied to the biophysical variables of the monitoring year to generate a biomass distribution map. Validation must achieve:

- Coefficient of determination (R^2) ≥ 0.75

- Relative absolute mean error ≤ 20%
- Relative root mean square error ≤ 25%

If these thresholds are not met, the EIET-aOCP will make iterative adjustments until satisfactory results are obtained.

V.2.2. Soil Carbon Reserves

Sampling Design

The EIET-aOCP will determine the number of sampling units per stratum using a statistical approach that considers the expected variability in soil-carbon content and the level of precision required. The number of samples (n) will be calculated using the following equation:

$$n = (t^2 \times s^2)/(E^2 \times \bar{x}^2)$$

Where:

t: t-value for the desired confidence level (usually 95%)

s^2: estimated variance of carbon content

E: acceptable relative error (typically 10%)

$\bar{x}$: estimated mean carbon content

For the initial estimation of variance and mean, the EIET-aOCP will use data from previous studies conducted under similar environmental conditions.

Quantification Procedure

Beginning at Year 5 of the project, and every 3-5 years following the initial assessment, the quantification of soil carbon reserves is carried out in four sequential stages:

Sampling Point Measurement

The EIET-aOCP will carry out or supervise soil sampling following the procedures established in the international reference protocols detailed in Annex 1. These protocols provide the technical specifications and good practices for field sampling, ensuring the quality and representativeness of the samples.

The sampling depth and the number of layers to be assessed will be determined following the technical and practical considerations described in Annex 2, which analyses the implications of different sampling strategies and provides a framework for optimizing the trade-off between accuracy and cost-effectiveness.

For each sampling point, the EIET-aOCP will calculate the carbon density at each assessed depth:

$$SOCd,p = DA \times Pp \times \%C \times 100$$

Where:

SOCd,p: Soil organic carbon density for depth p (Mg/ha)

DA: Apparent density for depth p (g/cm³)

Pp: Thickness of layer p (cm)

%C: Percentage of organic carbon in the soil for the depth p

Extrapolation by Stratum

The EIET-aOCP will use geostatistical techniques to extrapolate point results to the entire stratum. This process includes:

1. Analysis of the spatial distribution of carbon values using variograms
2. Application of interpolation techniques (such as ordinary kriging) to generate continuous carbon content surfaces
3. Cross-validation to assess the accuracy of interpolation

The average carbon density for each stratum will be calculated using all interpolated points within its boundaries.

Calculation of Reserves by Stratum

The EIET-aOCP will calculate the total carbon stock for each stratum:

$$SOCe = (\sum SOCd,p) \times Ae$$

Where:

SOCe: Total organic carbon in the soil stratum (Mg)

∑SOCd,p: Sum of carbon densities at all depths evaluated (Mg/ha)

Ae: Area of the stratum (ha)

Project Level Integration

Finally, the EIET-aOCP will determine the total soil carbon stock for the entire project:

$$SOCt = \sum SOCe$$

Where:

SOCt: Total organic carbon in the project soil (Mg)

∑SOCe: Sum of organic carbon of all strata (Mg)

V.2.3. Change in Aerial and Underground Biomass

This section sets out the procedures for quantifying net changes in project carbon stocks, considering that biomass and soil carbon assessments occur at different times.

V.2.3.1. Ex Ante Evaluation

The initial assessment of credit-generating potential considers only projected changes in tree biomass by stratum. The EIET-aOCP calculates the projected change for each stratum as the difference between the estimated biomass at year 40 and the reference scenario set to zero:

$$\Delta BTe = BTPex - ante,e - 0$$

Where:

ΔBTe: Projected change in total biomass of the stratum (Mg)

BTPex-ante,e: Expected biomass of the plantation at year 40 in the stratum (Mg)

The total projected change for the project is obtained by adding the changes in all strata:

$$\Delta BTp = \sum \Delta BTe$$

V.2.3.2. Monitoring During Implementation

During the operational phase, the EIET-aOCP will assess changes in carbon stocks considering the different measurement times for each compartment.

Changes in Biomass

For each stratum, the EIET-aOCP calculates the change in biomass by comparing any monitoring period (tx) with its reference period (t0):

$$\Delta Be = Be,tx - Be,t0$$

Where:

ΔBe: Change in stratum biomass (Mg)

Be,tx: Biomass of the stratum in the monitoring period

Be,t0: Biomass of the stratum in the reference period

The total change in biomass of the project in period tx is obtained by summing up the changes of all strata:

$$\Delta Bt = \sum \Delta Be$$

Changes in soil carbon

Similarly, for each stratum, the EIET-aOCP calculates the change in soil carbon stocks by comparing any monitoring period (ty) with its reference period (t0):

$$\Delta SOCe = SOCe,ty - SOCe,t0$$

Where:

ΔSOCe: Change in soil organic carbon of the stratum (Mg)

SOCe,ty: Organic carbon of the stratum in the monitoring period

SOCe,t0: Organic carbon of the stratum in the reference period

V.2.3.3. Integration of Changes

The EIET-aOCP maintains an up-to-date record of changes in each compartment, clearly identifying the corresponding measurement periods. To report the total change in the project's carbon stocks, the most recent measurements available for each compartment are used:

$$\Delta Ct = \sum \Delta Be(tx) + \sum \Delta SOCe(ty)$$

Where:

tx: Most recent period of biomass measurement

ty: Most recent period of soil carbon measurement

This flexible approach allows the EIET-aOCP to accurately track changes in carbon stocks, respecting the different monitoring cycles required for each compartment while maintaining the integrity of the estimates.

V.3. Reference Scenario for Emissions

The reference scenario establishes the baseline against which the project benefits in terms of greenhouse gas emissions reduction and sequestration will be assessed. This section details the methodology for determining the emissions that would occur in the absence of the restoration activities.

V.3.1. Determination of Reference Scenario Compartments

The EIET-aOCP will assess three main elements to establish the reference scenario:

- Progressive ecosystem degradation, including ongoing loss of stored carbon. This assessment considers historical trends in cover loss and degradation drivers identified in the initial site characterization.
- Natural emissions from the degraded ecosystem, particularly CO_2 emissions from the oxidation of organic matter in exposed or altered soils.
- Emissions associated with productive activities and land-use that existed prior to the start of the project. The project developer must provide detailed information on management practices and historical economic activities at the site.

V.3.2. Temporal and Spatial Analysis

The EIET-aOCP will base the reference scenario on a comprehensive analysis that integrates multiple sources of information. The developer must provide documentation on historical land use and productive activities for at least a decade prior to the start of the project.

To validate this information, the EIET-aOCP will analyze historical data on land cover change in the project area, assessing trends in mangrove degradation or loss. This analysis will be complemented by an assessment of current site conditions, including the state of vegetation and soil degradation, as well as changes in hydrology.

Comparison with reference areas that present similar conditions of degradation and land use patterns, but which will not be affected, will allow the projection of the probable evolution of the area in the absence of the project.

V.3.3. Quantification of Emissions

The EIET-aOCP will calculate the reference-scenario emissions considering both natural degradation processes and emissions associated with previous land use. This quantification will provide a conservative estimate of the emissions that will be avoided through the project's restoration activities.

V.4. Calculation of Net Carbon Dioxide Capture

This section sets out the procedures for determining the net carbon dioxide sequestration of the project, integrating changes in carbon stocks with baseline scenario emissions and applying appropriate deduction factors.

V.4.1. Conversion to CO_2E

The EIET-aOCP will convert all carbon stock changes to carbon dioxide equivalent using the stoichiometric conversion factor:

$$\Delta CO_2e = \Delta C \times (44/12)$$

Where:

ΔCO_2e: Change expressed in tons of CO_2 equivalent

ΔC: Change in carbon stocks (Mg C)

44/12: Conversion factor based on molecular weight ratio

V.4.2. Deduction Factors

The EIET-aOCP will apply three deduction factors to ensure a conservative estimate of climate benefits:

Uncertainty Factor (IF):

$$IF = [(EB \times PB) + (ES \times PS)] \times FIA$$

Where:

EB: Combined error in biomass estimates

ES: Combined error in soil estimates

PB and PS: Proportions of carbon in biomass and soil with respect to the total

FIA: Aggregation increase factor (1.1 - 1.3)

Buffer Factor (FB):

$$FB = RN + RA + RG$$

Where:

RN: Natural risk factor (0.05 - 0.15)

RA: Anthropogenic risk factor (0.05 - 0.15)

RG: Management risk factor (0.02 - 0.10)

Project Emissions Factor (EF):

$$EF = (EP + EM) / CC$$

Where:

EP: Emissions from site preparation (tCO_2e)

EM: Annual emissions from maintenance (tCO_2e)

CC: Total projected carbon capture (tCO_2e)

V.4.3. NET CATCH CALCULATION

The EIET-aOCP will calculate the initial net sequestration considering changes in carbon stocks and avoided emissions from the reference scenario:

$$Net\ Capture = [(\Delta Bt \times 44/12) + (\Delta SOCt \times 44/12)] + Avoided\ Emissions$$

Where:

∆Bt: Total change in biomass of the project (Mg C)

∆SOCt: Total change in soil carbon (Mg C)

Avoided Emissions: Reference scenario emissions (Mg CO_2e)

V.4.4. FINAL ESTIMATE AND ISSUANCE OF CREDITS

The determination of the number of credits available for issuance is based on the systematic application of deduction factors to verify net carbon sequestration. This process ensures that the credits issued represent real, permanent and quantifiable climate benefits.

The EIET-aOCP calculates the number of credits using the following equation:

$$Available\ Credits = Net\ Catch \times [1 - (FI + FB + FE)]$$

Where:

Net Capture represents the total verified change in carbon stocks, expressed in tCO_2e

FI corresponds to the uncertainty factor determined by the precision of the measurements

FB represents the buffer factor that ensures the permanence of the carbon captured

FE reflects the emissions associated with the implementation of the project

The result of this calculation determines the maximum number of credits that can be issued for the period assessed. The EIET-aOCP conducts a thorough review of the deduction factors at each monitoring cycle to ensure that they accurately reflect current project conditions and associated risks. This periodic assessment ensures the environmental integrity of the credits issued and the robustness of the quantification system.

V.4.4.1. Periodicity of Issue

The EIET-aOCP establishes a credit issuance schedule (contingent table) aligned with the project monitoring cycles. The issuance of credits based on changes in biomass can be done annually, while credits related to soil-carbon are issued according to the monitoring frequency established for this compartment (5 years).

Issuance of credits occurs only after the EIET-aOCP has assessed and calculated the carbon stock changes and applied all applicable deduction factors, and the aOCP-approved independent verifier has signed off on the Verification Report. This process ensures that each credit issued represents one ton of CO_2e effectively captured and verified.

V.5. Methodological Parameters

This section details the standardized parameters that the EIET-aOCP uses to ensure consistency and accuracy in carbon quantification.

V.5.1. Parameters for Biomass Estimation

Table 3. Parameters for Biomass Estimation

Parameter	Value/Method	Reference	Application Notes
Carbon Factor in Aboveground Biomass	0.47	Kauffman & Donato (2012)	Applicable to all mangrove species
Carbon Factor in Underground Biomass	0.39	Kauffman & Donato (2012)	Includes all roots >2mm
Allometric Equation	***	***	**DRH:** Diameter at Root Height
Allometric Equation	***	***	**DBH:** Diameter at Breast Height
Survival Factor	0.9	CONAFOR (2009)	Adjustable with technical evidence

****** Species-Dependent***

V.5.2. Parameters for Soil Analysis

Table 4. Parameters for Soil Analysis

Parameter	Method/Specification	Frequency	Grades
Apparent density	Gravimetric method	3-5 years	Drying at 105°C
Organic Carbon	Elemental analysis	3-5 years	Certified Laboratory

Organic Matter	Loss on ignition	3-5 years	Combustion at 550°C
Sampling Depth	Variable according to project	-	See Annex 2

V.5.3. Deduction Factors

Table 5. Deduction Factors

Factor	Range	Components	Adjustment Criteria
Uncertainty (FI)	Variable	Error in biomass (EB) and soil (ES)	According to measurement accuracy
Buffer (FB)	0.12-0.40	RN (0.05-0.15) + RA (0.05-0.15) + RG (0.02-0.10)	According to risk assessment
Emissions (EF)	Variable	(EP + EM) / CC	According to project activities

V.5.4. Conversion Factors

Table 6. Conversion Factors

Parameter	Worth	Application	Grades
CO_2 to C	44/12	Final conversion to CO_2e	Stoichiometric factor
Hectares to m²	10,000	Area conversions	Standard factor
kg to Mg	0.001	Unit conversion	Standard factor

VI. Monitoring and Verification

This section establishes the procedures and requirements for the ongoing monitoring and verification of the climate benefits generated by the restoration project.

VI.1. Monitoring Systems & Frequency of Measurements

The EIET-aOCP implements a comprehensive monitoring system that combines advanced remote sensing techniques with periodic field measurements. This approach allows for efficient and accurate monitoring of changes in carbon stocks while minimizing operational costs.

VI.1.1. Tree Biomass

Biomass assessment is carried out annually through satellite image analysis, complemented by field validation campaigns every two years. This frequency allows for the detection of significant changes in the mangrove structure while maintaining an appropriate balance between precision and operational efficiency.

VI.1.2. Soil Carbon

Beginning at Year 5 of a project, soil carbon monitoring is conducted at three- to five-year intervals, recognizing the more stable nature of this compartment. The specific frequency is determined by considering site characteristics and the expected rate of carbon accumulation.

VI.2. Verification Procedures

The EIET-aOCP conducts periodic technical audits to verify the accuracy and reliability of reported data. These audits include:

- Validation of estimation models by comparison with independent field measurements.
- Review of laboratory sampling and analysis procedures to ensure compliance with established standards.
- The evaluation of the consistency and quality of the reported data, including the documentation of methodological changes or adjustments in the parameters used.

VI.2.1. Reporting Requirements

Monitoring reports prepared by the EIET-aOCP must follow a standardized format that includes:

- Detailed documentation of the methods and parameters used in carbon estimates.
- The results of the measurements carried out, including raw data and relevant statistical analysis.
- An assessment of significant changes in site conditions or project implementation that could affect carbon estimates.

VII. Quality Assurance and Control

This section establishes procedures to ensure the quality and reliability of all data and analyses generated during carbon quantification and monitoring in mangrove restoration projects.

VII.1. Field Quality Assurance

The EIET-aOCP implements a rigorous quality assurance system for field activities that focuses on three key aspects:

1. Standardized training of technical staff in measurement and data recording protocols. This training includes practical measurement exercises to ensure consistency between different technicians.
2. Verification of the condition, operation and proper use of basic measuring instruments such as measuring tapes, measuring rods and GPS. This verification is carried out before each field campaign to ensure reliable measurements.
3. Direct supervision of sampling campaigns by experienced EIET-aOCP staff, who verify the correct application of protocols, and the quality of the data collected.

VII.2. Quality Control in Laboratory Analysis

Soil sample analyses are carried out exclusively in EIET-aOCP approved laboratories that demonstrate compliance with international standards.

VII.3. Data Validation and Modelling

Data generated by remote sensing and modelling are subjected to a systematic validation process. This process includes checking the quality of the satellite images used, assessing the accuracy of the Random Forest model, and comparing results with independent field measurements.

The EIET-aOCP maintains detailed records of all validation procedures, including model performance metrics and adjustments made to improve the accuracy of estimates.

VII.4. Data Management and Storage

A comprehensive data management system is implemented to ensure the traceability and security of all information generated by the project. This system includes protocols for regular data backup, document version control, and verification procedures for data entry.

All documentation related to quality assurance and control is kept up to date and available for review during technical audits conducted by EIET-aOCP.

VIII. Uncertainty and Risk Management

This section sets out the framework for systematically identifying, assessing, and managing sources of uncertainty and risks that could affect the climate benefits of mangrove restoration projects.

VIII.1. Uncertainty Assessment

The EIET-aOCP conducts a systematic assessment of sources of uncertainty in carbon quantification. For biomass measurements, uncertainty mainly arises from variability in field measurements, error associated with allometric equations, and the accuracy of the spatial estimation model. For soil carbon, the main sources of uncertainty include natural spatial variability, sampling accuracy, and the accuracy of laboratory analyses.

Uncertainty is quantified using rigorous statistical analysis that considers the propagation of errors throughout the measurement and estimation chain. This analysis underpins the uncertainty factor applied in the final credit calculation.

VIII.2. Risk Analysis

The EIET-aOCP assesses three main categories of risks that could affect the permanence of captured carbon and reflects these in the Nat5 Score. Natural risks include extreme weather events, changes in hydrological patterns, and pest or disease impacts. Anthropogenic risks consider pressures from land use change, social conflicts, and incompatible economic activities. Management risks relate to the developer's technical and financial capacity to maintain the project in the long term.

The risk assessment is updated annually or when significant changes in project conditions occur. This assessment determines the buffer factor applied to the credits generated.

VIII.3. Mitigation Measures

The EIET-aOCP requires each project to develop and implement specific strategies to mitigate the identified risks. These strategies should include preventive measures such as establishing buffer zones, strengthening local governance, and developing technical capacities. Response protocols are also required for events that could compromise the permanence of the captured carbon.

The effectiveness of mitigation measures is regularly assessed as part of the monitoring process, allowing for adjustments to strategies as necessary.

IX. Documentation and Reporting

This section sets out documentation requirements that ensure transparency and traceability in carbon quantification for mangrove restoration projects.

IX.1. Technical Documentation of the Project

The project developer must provide detailed documentation justifying the technical and operational feasibility of the proposed activities. This documentation must include:

IX.1.1. Site Characterization

The project area description should present a comprehensive analysis of current ecological conditions, land use history, and identified degradation factors. Evidence supporting this characterization should include historical records, georeferenced maps, and systematic photographic documentation of the site.

IX.1.2. Implementation Plan

The developer must submit, together with the PSF, a detailed plan specifying the restoration methods selected, the species to be used, and the proposed hydrological and management interventions. This document must include a timeline that clearly identifies the implementation phases and key milestones of the project.

IX.1.3. Monitoring Plan

The EIET-aOCP develops the monitoring plan once the project has been pre-registered. This plan establishes specific procedures and protocols for monitoring carbon stocks, including the location of sampling plots, frequency of measurements, and data collection methods.

IX.2. Primary Records

IX.2.1. Field Data

The EIET-aOCP maintains a structured recording system that documents all field measurements. This system includes standardized formats for data collection, georeferenced photographic records, and notes on conditions observed during sampling.

IX.2.2. Laboratory Analysis

Approved laboratories must submit complete technical reports documenting the analytical methods used, the results obtained, and the corresponding quality control indicators. These reports must include the chain of custody of the samples and calibration certificates for the equipment used.

IX.3. Monitoring Reports

The EIET-aOCP generates periodic reports that document the monitoring results and evaluate the project's performance in terms of carbon capture. These reports provide a comprehensive assessment that allows verification of compliance with the established objectives and provides the basis for the issuance of carbon credits.

IX.3.1. Data Analysis

Monitoring reports present a detailed description of the methods used to process and analyse the data collected. This section documents the application of the Random Forest model, the validation procedures implemented, and the statistical analyses underlying the carbon estimates. The documentation includes the specific parameters used at each stage of the analysis, ensuring reproducibility of the results.

IX.3.2. Evaluation of Results

Each report presents a comparative analysis that assesses the evolution of carbon stocks in the project. This assessment includes the quantification of the observed changes in biomass and soil carbon, supported by maps that illustrate the spatial distribution of these changes. The analysis considers the trends observed in different strata and their relationship with the implemented interventions.

IX.3.3. Technical Recommendations

The reports conclude with a comprehensive assessment of project performance and specific recommendations for optimizing results. These recommendations identify areas requiring special attention and propose adjustments to monitoring strategies or restoration interventions where necessary. Recommendations are based on technical analysis of the results and consider the specific conditions observed at the site.

X. References

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ANNEX 1: REFERENCE MANUALS AND PROTOCOLS FOR SAMPLING IN MANGROVES

This methodology is based on internationally recognized protocols for the assessment and monitoring of carbon in mangrove ecosystems. The following documents provide the technical basis for the procedures described:

Base Protocol:

Kauffman, JB, Donato, DC, & Adame, MF (2013). "Protocol for measuring, monitoring and reporting mangrove carbon stocks, biomass and structure". CIFOR. This protocol establishes standardized procedures for quantifying carbon stocks in mangroves, including sampling design, biomass measurement and soil analysis. It forms the main methodological basis for the field procedures detailed in this document. https://www.cifor-icraf.org/knowledge/publication/3749/

FAO Guide:

"The Mangrove Carbon Estimator and Monitoring Guide" (FAO). This guide complements the base protocol with specific guidelines for the integration of remote sensing techniques in mangrove carbon monitoring, providing methodological frameworks for combining field data with spatial analysis. https://openknowledge.fao.org/server/api/core/bitstreams/2114792c-0a21-4bc9-a743-bb7bac296665/content

Implementation Example:

"Blue Carbon Assessment for Mangrove Systems in Seychelles" provides a practical example of the implementation of the protocol of Kauffman and Donato (2012) and Howard et al. (2014), demonstrating its applicability and adaptation to specific contexts.https://www.bluecarbonlab.org/wp-content/uploads/2023/06/Mangrove-Assessment_FinalReport_May162023_for-web.pdf

The procedures described in this methodology have been developed following these international standards, adapting them when necessary to ensure their applicability in the context of mangrove restoration projects in Mexico.

Annex 2: Considerations on Sampling Depth in Mangrove Soils

This appendix examines the technical and practical implications of various soil sampling strategies in mangrove restoration projects, aiming to optimize the balance between accuracy and cost-effectiveness.

Technical Considerations

Carbon Dynamics in Mangrove Soils

Surface Layers (0–30 cm)

The upper soil layers are the most dynamic and responsive to restoration, characterized by:

- High biological activity and organic matter incorporation rates
- Sensitivity to vegetation changes and environmental conditions
- Increased vulnerability to oxidation and carbon loss during degradation

Deeper Layers (30–100 cm)

In contrast, deeper soil layers exhibit:

- Greater stability in carbon content
- Long-term carbon accumulation over centuries
- Susceptibility to hydrological changes and salinity variations

Practical Implications

Advantages of Surface Sampling (0–30 cm)

- Lower laboratory analysis costs
- Simplified field logistics
- Reduced risk of technical errors
- Easier collection of representative samples

Limitations of Surface Sampling

- Potential underestimation of carbon losses in degraded sites
- Inability to detect changes in deeper carbon stores
- Possible underestimation of total restoration benefits

Recommended Sampling Strategy

To ensure cost efficiency while maintaining robust data collection, the EIET-aOCP may adopt a differentiated approach based on project-specific conditions:

Standard Sampling

- Comprehensive assessment of surface layers (0–30 cm) at all sampling points
- Increased monitoring frequency to capture early restoration effects

Complementary Sampling

- Targeted evaluation of deep layers (30–100 cm) at strategically selected sites
- Reduced monitoring frequency for deep layers
- Site selection based on environmental gradients and degradation patterns

This approach balances cost-effectiveness with a comprehensive understanding of carbon dynamics throughout the soil profile.