2025

METHODOLOGY FOR CARBON REMOVAL THROUGH MANGROVE RESTORATION

Version 2.0

July 17, 2025

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I. SUMMARY

This methodology establishes a scientific, standardized approach for climate change mitigation through the restoration of degraded and deforested mangroves. It sets its scope in terms of included carbon pools and greenhouse gases, target areas, and eligible species. It also sets the requirements for additionality, right of land use, legal compliance, project duration, crediting period, retroactivity, project boundaries, technical documentation, reporting, and data management, as well as the procedures for estimating greenhouse gas (GHG) emission reductions and carbon sequestration achieved by restoration projects, focusing on biomass and soil organic carbon (SOC). The methodology also sets requirements regarding additional project contributions to biodiversity, environment and society and the Sustainable Development Goals.

ACRONYMS AND ABBREVIATIONS

aOCP	Ases On-Chain Protocol
CH4	Methane
CO2	Carbon dioxide
GHG	Greenhouse gas
GIS	Geographic Information System
ITTE-aOCP	aOCP Internal Team of Technical Experts
N2O	Nitrous oxide
PSF	Project Submission Form
SOC	Soil Organic Carbon
UN	United Nations

DEFINITIONS

See the definitions relevant to this document in the most recent version of the aOCP Program Definitions document.

II. Overall components

II.1 Methodology Scope

Climate change mitigation from reduced GHG emissions and carbon sequestration through restoration of deforested and degraded mangroves (degraded mangroves below the 70% carbon stock threshold compared to undisturbed mangroves of the same type).

II.2 Carbon Pools

Included: Tree biomass and soil organic carbon (SOC).
Excluded: Non-tree biomass, deadwood, and litter are conservatively excluded.

II.3 Greenhouse Gases

Included: Methane (CH_4). CO_2 is accounted as biomass stock changes.
Excluded: Nitrous oxide (N_2O) (deemed insignificant).

II.4 GHG Emission Sources

II.4.1 Baseline emissions

Potential emissions from:

- Mangrove degradation
- Deforested mangroves converted to other land uses/land covers
- Flooded rice crops
- Use of synthetic fertilizers.

II.4.2 Project Implementation Emissions

Potential emissions from rewetting of previously drained mangroves.

II.5 Land Eligibility

The following areas are eligible for the implementation of projects:

Eligible area	Means of evidence
Previously degraded mangrove below the 70% of carbon stock threshold, compared to undisturbed mangroves of the same type.	- Remote sense analysis. - Local studies.
Previously deforested mangroves converted to crops, cattle rising, or degraded areas unable of unassisted recovery.	- Remote sense images.

The project area must not have experienced degradation, deforestation, or fires in the 24 months prior to the start of the project. This will be demonstrated through historical remote sense images.

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.

II.6 Eligible Species

Projects must use only native mangrove species historically documented in the project area. Species selection should be based on:

Element	**Means of evidence**
Historical distribution records.	Technical/academic documentation.
Hydro geomorphological conditions of the site.	Official Geographic Information System (GIS) layers or ad-hoc GIS layers with supporting documentation.
Natural zonation patterns of mangroves.	Official GIS layers or ad-hoc GIS layers with supporting documentation.
Tolerance to current salinity conditions and hydrological regime (unless they occur naturally within the project area or nearby areas).	Technical/academic documentation.

III. Project Requirements

III.1. Additionality

Projects must comply with the aOCP additionality rules.

III.2. Right of Use

The project developer must provide evidence of the rights of use of the project area for carbon removals and biodiversity credits certifications (and, optionally, for soil and water credits, as appropriate) throughout the project lifetime. If the project developer is the landowner, it must provide a copy of the title deed. If the project developer is not the landowner, this may be done by signing a contract with the landowner, usufruct contracts, government concessions, or formalized community agreements, as applicable.

III.3. Law compliance

Projects must comply with all applicable environmental regulations, including restoration permits, environmental impact studies and land use change authorizations when required. The project proponent must present a legal compliance check, which will present a list of relevant laws, along with a brief description of their relevance to the project and a brief analysis of the project's compliance. The legal compliance check must also analyze how the project is aligned with national wetland conservation policies and international commitments on climate change.

III.4. Project duration

As stipulated in the Permanence, Additionality, and Avoidance of Double Counting Standard, aOCP has established a minimum project duration of 40 years to ensure permanence. This permanence will be guaranteed by a contract of the same duration signed with aOCP.

III.5. Crediting period

40 years. The crediting period is equivalent to the project lifespan defined by aOCP (aOCP Protocol Project Standard V.2.1.).

III.6. Retroactivity

Up to five years before the date of the initial submission of the Project Submission form (PSF) and accompanying documentation, according to the aOCP Project Standard V.2.1. The project must provide evidence of previous effective action to conserve and restore mangroves in the proposed project area during the intended retroactivity period.

III.7. Project Boundaries

The project developer must provide the following spatial information:

- A general polygon (in .shp format) corresponding to the total area over which the developer has proven legal rights carbon removals and biodiversity credits certifications (and, optionally, for soil and water credits, as appropriate). This polygon constitutes the maximum limit within which the project activities can be implemented.
- Operational sub-polygons (also in .shp format) responding 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.
- A shape file with the required stratifications:
  - Baseline degraded mangrove strata.
  - Baseline deforested mangrove strata (other land uses/land covers).
  - Project strata of degraded mangrove under restoration.
  - Project strata of planted mangrove.
  - Baseline and project implementation soil strata.
- Shapefile(s) with other spatialized environmental relevant information (hydrological regime, soil types, etc.).

Means of evidence:

Supporting documentation/historic satellite images.

For GIS data and historic satellite images, the project developer must provide complete metadata, including:

- Dataset title.
- Author institutions.
- Year of evaluation and publication.
- Spatial scale or resolution.
- Data format.
- Resource location/identification of official repository.

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

III.8. Project Rationale and Technical Documentation

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

- MOE
- Project developer must provide documentation on historical land use and productive activities for at least a decade prior to the start of the project.

The aOCP-ITTE shall assess the degradation analysis considering:

- Evidence strength supporting degradation factor identification.
- Relevance and effectiveness of proposed interventions.
- Feasibility of proposed monitoring system for reversal of degradation factors.
- Additional information or modifications request if interventions don't adequately address degradation and deforestation drivers.

The project developer must do an analysis of the factors that have caused mangrove degradation and loss and how the proposed intervention addresses these factors to ensure the effectiveness and permanence of restoration actions, including measurement methods and frequency of evaluation. This analysis must include, as appropriate:

- Documentation of direct anthropogenic impacts like deforestation, land use change, infrastructure construction, or resource extraction.
- Identification of hydrological changes affecting mangroves.
- Documentation of changes in water flow patterns, connectivity, and flooding regimes.
- Use of technical evidence like historical records, field measurements, and satellite images.
- Characterization of site's physicochemical conditions.
- Temporal analysis of observed changes and their spatial distribution in the project area.

The project developer must also 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.

III.9. Reporting

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

- Detailed documentation of the methods, models, and parameters used in carbon estimates.
- Detailed description of the methods and statistical analysis used to process and analyze the data collected.
- Evaluation of the obtained results and their relationship with the implemented interventions.
- An assessment of significant changes in site conditions or project implementation that could affect carbon estimates.
- Technical Recommendations for optimizing results, including areas requiring special attention and propose adjustments to monitoring strategies or restoration interventions where necessary.

The project must maintain detailed records including:

- Complete forest inventories.
- Initial establishment data.
- Records of management interventions.

III.10. Data Management

The aOCP-ITTE oversees project data management, which includes:

Field data. The aOCP-ITTE 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.

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 aOCP-ITTE.

III.11. Quality assurance and Quality control

Quality assurance and control are comprised of the following elements:

III.11.1. Field Quality Assurance

The aOCP-ITTE implements a rigorous quality assurance system for field activities focused on:

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 aOCP-ITTE staff**, who verify the correct application of protocols, and the quality of the data collected.

III.11.2. Quality Control in Laboratory Analysis

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

III.11.3. 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 aOCP-ITTE maintains detailed records of all validation procedures, including model performance metrics and adjustments made to improve the accuracy of estimates.

III.12. Uncertainty and Risk Management

The aOCP-ITTE oversees uncertainty and risk analysis. The project developer oversees the implementation of the mitigation measures.

III.12.1. Uncertainty Assessment

The aOCP-ITTE 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 organic 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.

III.12.2. Risk Analysis

The aOCP-ITTE 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.

III.12.3. Mitigation Measures

The aOCP-ITTE 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.

III.13. Other Required Contributions

Projects applying to Verified Carbon Credits (VCCs) using this methodology must also contribute to the elements presented in the following sections.

III.13.1. Biodiversity

Every project that participates in the aOCP shall be positive for biodiversity. This will be assessed as a condition *sine qua non* for registration and monitored along the life of the project. Successful outcomes will be recognized with Verified Biodiversity-Based Credits (VBBC).

Project proponents must also apply the aOCP Methodology for Biodiversity Assessment. In addition to carbon credits, projects will also be able to certify biodiversity credits.

III.13.2. Environment and Society

The aOCP requires Project Proponents to demonstrate that their Project Activity does not adversely affect the environment and society in any way, while contributing to the mitigation of climate change and improving biodiversity.

Project Proponents can demonstrate this accomplishment by following the Environment and Social Safeguards Standard.

III.13.3. Sustainable Development Goals

The aOCP Program offers Project Proponents the chance to voluntarily demonstrate that their Project Activity helps to achieve the United Nations Sustainable Development Goals (SDGs). The impact of projects' contributions to the UN SDGs will also be taken into account either through the use of an external tool or a similar methodology proposed by the project proponent that helps to clearly identify and quantify Projects' contribution to the achievement of UN SDGs.

The tool will be used to evaluate the project's contribution to the SDGs during both project validation and project activities verification.

IV. Certification cycle

IV.1. Registration

The project developer must submit all required information and documentation, including data on planting activities, site characteristics, and initial project conditions.

IV.2. Development of the Monitoring Plan

The aOCP-ITTE 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.

IV.3. Estimation of Mitigation Potential

The aOCP-ITTE will estimate the carbon credit potential as described in the Baseline and Ex-ante calculation sections.

IV.4. Validation

aOCP-ITTE will conduct direct field measurements of trees and soil to obtain detailed carbon stock data and review GHG baseline and project emission factors, refining initial estimates as needed, according to the procedures described in the calculations section.

IV.5. Project Monitoring

The aOCP-ITTE shall establish a monitoring system spanning the entire project duration including:

- **Annual survival and growth assessment**. Carried annually through satellite image analysis, complemented by field validation every two years.
- Quarterly monitoring of hydrological conditions.
- Biennial assessment of ecosystem structure.
- Three- to Five-year soil organic carbon sampling.

The specific frequency is determined by considering site characteristics and the expected rate of carbon accumulation.

IV.6. Verification

The aOCP-ITTE conducts periodic technical audits based on the monitoring plan designed for the project 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.

V. Calculations of the Climate Change Mitigation Potential and Achievements

This calculation table will be replaced by normal text and equations using the equations editor. Here is an example of how it would look.

V.1. Initial Stratification

To make ex-ante and ex-post estimates, it is necessary to stratify the areas of the baseline and project scenarios, as well as, subsequently, the areas in which the project is implemented.

For the baseline scenario, project area is stratified according to existing significative biomass differences due to e.g., different mangrove degradation levels, different mangrove types, different post deforestation land use or land cover.

For soil organic carbon (whose strata would usually be the same for the baseline scenario and for the project implementation), project area is stratified according to existing significative differences in soil organic carbon due to e.g., different mangrove types or different pos-deforestation land use/land cover at the beginning of project implementation.

For project implementation, project area is stratified according to the mitigation activities to be implemented, considering possible significant differences (corresponding to more than one stratum) within each of these mitigation activities, which could be degraded mangrove restoration and deforested mangrove restoration (each with one or more strata, depending on the implementation plans; e.g., if there are more than one restoration model for each degraded or deforested area to be restored).

Examples of baseline biomass, project biomass and soil organic carbon stratification are presented in **Erreur ! Source du renvoi introuvable.**.

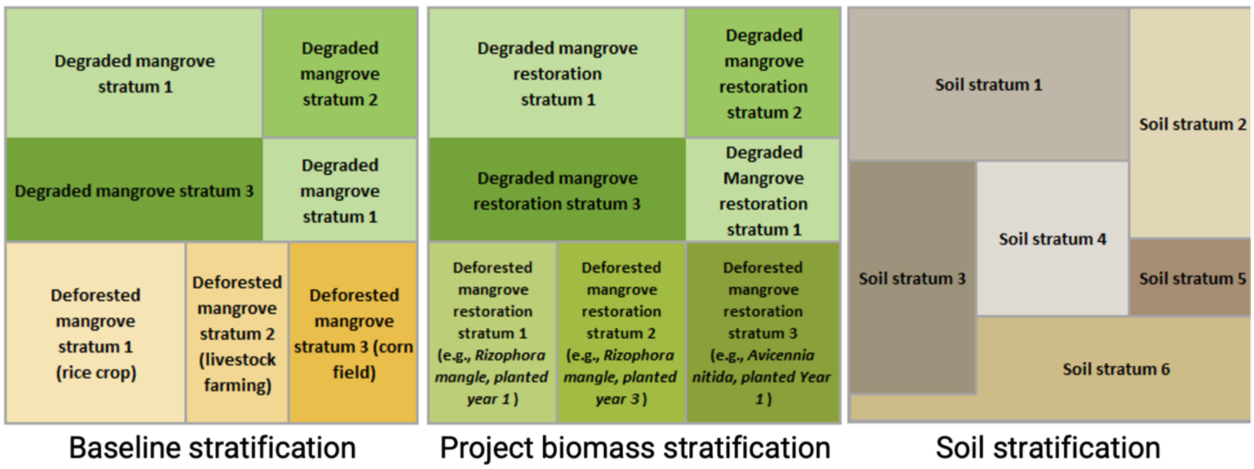

FIGURE 1. EXAMPLES OF BASELINE, PROJECT BIOMASS AND SOIL STRATIFICATIONS

V.2. BASELINE BIOMASS CARBON STOCKS OF DEGRADED MANGROVES

Based on the stratification of the baseline scenario, biomass carbon stocks in degraded mangrove strata are calculated based on the following variables:

TABLE 1. BASELINE BIOMASS CARBON STOCKS OF DEGRADED MANGROVES

Variable		Units	Source, description and/or comments
$BLSA_a$	Area of degraded biomass stratum a of the baseline scenario.	ha	
a	Index of degraded biomass stratum of the baseline scenario.		
$BLBCS_a$	Biomass carbon stock per hectare of degraded stratum a of the baseline scenario (before project implementation).	$t\text{-}CO_2/ha$	**For degraded mangroves:** From forest inventories, remote sensing or existing studies for the same region and mangrove type. "Degraded" must have less than 70% of biomass carbon stocks compared to the biomass carbon stocks of undegraded mangrove of the same type.
A	Total number of degraded baseline strata.		

V.3. Baseline Biomass Carbon Stocks of Deforested Areas

Biomass carbon stocks in deforested strata are calculated and stored in the following variables:

Table 2. Baseline biomass carbon stocks of deforested areas

Variable		Units	Source, description and/or comments
$BLSA_b$	Area of deforested biomass stratum b of the baseline scenario.	ha	
b	Index of deforested biomass stratum of the baseline scenario.		
$BLBCS_b$	Biomass carbon stock per hectare of degraded stratum a of the baseline scenario.	t-CO2/ha	**For (previously) deforested mangroves:** From field inventories or existing studies for the same region, land-use, and crop type (e.g., pastures; corn, sorghum, banana crops).
B	Total number of deforested baseline strata.		

V.4. Total baseline biomass carbon stocks

Total baseline biomass carbon stocks are calculated as:

$$TBLBCS = \sum_{a=1}^{A} BLSA_a \times BLBCS_a + \sum_{b=1}^{B} BLSA_b \times BLBCS_b \qquad \text{Eq. 1}$$

Table 3. Total baseline biomass carbon stocks

Variable		Units	Source, description and/or comments
TBLBCS	Total baseline biomass carbon stocks (of degraded and previously deforested mangroves).	$t\text{-}CO_2$	This value represents the benchmark against which the project's performance will be measured. No projection of growth or further degradation.

This value represents the benchmark against which the project's performance will be measured. There is no projection of growth or further degradation.

V.5. Baseline soil organic carbon stocks

For each soil organic carbon stratum, SOC sampling is required. Each stratum requires a different number of samples, according to its variability. The number of required samples of each stratum -c- is calculated as:

$$n_c = \frac{t^2 \times {s_c}^2}{E^2 \times x^2} \qquad \text{Eq. 2}$$

Table 4. Baseline soil organic carbon stocks

Variable		Units	Source, description and/or comments
c	Index of soil stratum.		
n_c	Number of SOC sampling plots required for soil stratum c.		
T	Student's t value for the desired confidence level (95%).		
s_c	Estimated carbon variance of SOC of soil stratum c.	$t\text{-}CO_2$/ha	Pre-sampling or literature review.
E	Acceptable relative error (10%).		
x	Estimated mean SOC content of soil stratum c.	$t\text{-}CO_2$/ha	Pre-sampling or literature review.

SOC accounts only for ex-post (project implementation) estimations. This value is not required for ex-ante estimations and acts as a reference level, with no projection of improvement or further degradation.

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 aOCP-ITTE will calculate the carbon density at each assessed depth:

$$SOC_d = AD_d \times LT_d \times POC_d \times 100 \qquad \text{Eq. 3}$$

Variable		Units
$SOCD_d$	Soil organic carbon density at layer d.	$t\text{-}CO_2$/ha
d	Index of soil layer.	
AD_d	Apparent density of layer d.	
LT_d	Thickness of layer d.	cm
POC_d	Percentage of organic carbon in soil of layer d.	

The results obtained for the different soil layers should be added together to obtain a weighted average SOC for each sampling point.

Once the number of soil samples required for each soil stratum in the project area has been calculated, the average carbon stocks per hectare for each stratum are calculated, and these values are used to calculate the total SOC for the project area. This will be considered the SOC reference level, against which the gains from implementing the project will be calculated. Possible SOC gains or losses in the absence of the project will not be considered.

$$BLSOC = \sum_{c=1}^{NSS} (BSOCHA_c \times BSOCA_c) \quad \text{Eq. 4}$$

Variable		Units
BLSOC	Baseline SOC stock.	t-CO_2
c	Index of soil stratum.	
NSS	Number of soil strata.	
$BSOCHA_C$	Baseline SOC stock per hectare of soil stratum c.	t-CO_2/ha
$BSOCA_C$	Area of baseline soil stratum c.	ha

V.6. Other-than-C GHG Baseline Emissions from Mangroves Converted to Rice Fields

The conversion of mangroves to rice fields creates conditions conducive to methane emissions. This occurs mainly because rice cultivation takes place in flooded soils, creating anoxic environments that favor the activity of methanogenic microorganisms. Studies on this subject show that rice fields established on former mangrove soils have significantly higher methane emissions than the original ecosystems.

Include GHG emissions generated in the baseline scenario if part or all the deforested area has been used for flooded rice cultivation. Emissions from this source can only be included if the project includes methane emissions in the project scenario.

The Intergovernmental Panel on Climate Change (IPCC) recommends the use of specific emission factors for rice paddies, adjusted for variables such as water management, residue incorporation, soil type, and climate.

To be included in the net project calculations, project developer must also include CH4 emissions from restored mangroves. For any given year y (counted from the project start date), cumulative other-than-C GHG baseline emissions from mangroves converted to rice fields are calculated as:

$$BLCH4RE_y = RCA \times CH4RCEF \times y \quad \text{Eq. 5}$$

TABLE 5. OTHER-THAN-C GHG BASELINE EMISSIONS FROM MANGROVES CONVERTED TO RICE FIELDS

Variable		Units	Source, description and/or comments
$BLCH4RE_y$	Cumulative other-than-C GHG baseline emissions from mangroves converted to rice fields until year y of project implementation.	$t\text{-}CO_2$	
y	Year of calculation.		
RCA	Rice crops area.	ha	
CH4RCEF	Annual CH4 rice crop emission factor.	$t\text{-}CO_2/ha/yr$	Literature review or direct measurement.

V.7. OTHER-THAN-C GHG BASELINE EMISSIONS FROM THE APPLICATION OF SYNTHETIC FERTILIZERS TO CROPS

Some deforested mangrove areas may be converted to agricultural crops that consume fertilizers, which can generate GHG emissions. The average annual emissions per fertilizer application can be used as a reference value for calculating this type of emission in the baseline scenario. For any given year y (counted from the project start date), cumulative other-than-C GHG baseline emissions from the application of synthetic fertilizers to crops are calculated as:

$$BLCFE_y = RCA \times CFEF \times y \quad \text{Eq. 6}$$

TABLE 6. OTHER-THAN-C GHG BASELINE EMISSIONS FROM THE APPLICATION OF SYNTHETIC FERTILIZERS TO CROPS

Variable		Units	Source, description and/or comments
$BLCFE_y$	Cumulative other-than-C GHG baseline emissions from the application of synthetic fertilizers to crops from the beginning of project implementation until year y.	$t\text{-}CO_2$	
RCA	Crops area.	ha	The area of crops that were subject to the application of synthetic fertilizers in the project area at the beginning of the project implementation.

Variable		Units	Source, description and/or comments
CFEF	Annual crop fertilization emission factor.	t-CO_2/ha/yr	The GHG emission factor for fertilizer application to crops must be supported by specific studies published for the same type of crop in the region where the project is implemented or by reasonable documentation evidencing fertilizer application in specific areas.

V.8. Total Baseline GHG Emissions

Total baseline GHG emissions are calculated as:

$$BLTGHGE_y = BLCH4_y + BLCFE_y \qquad \text{Eq. 7}$$

Table 7. Total baseline GHG emissions

Variable		Units
$BLTGHGE_y$	Cumulative baseline total GHG emissions from the beginning of project implementation until year y.	t-CO_2

V.9. Ex-ante Calculation of Project Mitigation Potential

V.9.1. Ex-ante Project Mitigation Potential of Restoring Degraded Mangroves

The biomass gains from restoring degraded mangroves are calculated by dividing the biomass difference between intact and degraded mangroves by the estimated years for full recovery. For example, if an intact mangrove has 440 t-CO2/ha and a degraded one has lost 60% (264 t-CO2/ha), and restoration is estimated to take 20 years, the annual recovery rate would be 264 ÷ 20 = 13.2 t-CO2/ha/year. For any year y (counted from the beginning of project implementation), the cumulative project biomass carbon stock gain of each stratum -a- of degraded mangrove is calculated as:

$$PBCSG_{a,y} = BLCH4_y + BLCFE_y, \quad \text{for y<=YFFR} \qquad \text{Eq. 8}$$

Table 8. Ex-ante project mitigation potential of restoring degraded mangroves

Variable		Units
$PBCSG_{a,y}$	cumulative project biomass carbon stock gain of stratum a from the beginning of project implementation until year y.	t-CO_2/ha
y	year of calculation.	
$PBIMCS_a$	Biomass carbon stock per hectare of intact mangrove type like that of degraded mangrove forest a.	t-CO_2/ha
$BLBCS_a$	Biomass carbon stock per hectare of degraded stratum a of the baseline scenario (before project implementation).	t-CO_2/ha

Variable		Units
YFFR	Years required for full recovery of carbon stocks of degraded mangrove stratum d.	
$BLSA_a$	Area of degraded biomass stratum a of the baseline scenario.	ha
a	Index of degraded biomass stratum of the baseline scenario.	

The total biomass carbon gain for all degraded strata under restoration for all the project duration is calculated as:

$$TPBCS = \sum_{a}^{A} PBCSG_{a,PD} \qquad \text{Eq. 9}$$

Provided that, for each stratum, PD <=YFFR.

Variable		Units
TPBCS	Total project biomass carbon stock gain of all degraded mangrove areas.	$t\text{-}CO_2$
PD	Project duration	years
A	Total number of degraded baseline strata.	

V.9.2. Ex-ante project mitigation potential of restoring deforested mangroves

The potential for carbon removal in the strata of restored deforested mangroves is estimated by applying a table of current annual increment (CO2 equivalent) corresponding to the species planted in each stratum and accumulating the results from the start of planting to the project duration.

$$EXBCS_f = \sum_{t}^{PD} EXCAI_{f,t} \times BSPCA_f \qquad \text{Eq. 10}$$

TABLE 9. EX-ANTE PROJECT MITIGATION POTENTIAL OF RESTORING DEFORESTED MANGROVES

Variable		Units	Source, description and/or comments
$EXBCS_f$	Total ex-ante biomass carbon storage of stratum f.	$t\text{-}CO_2$	
f	Index of ex-ante planted mangrove stratum.		
$EXCAI_{f,t}$	Current Annual Increment of CO2 removed by the species planted in stratum f, in year t.	$t\text{-}CO_2/ha/yr$	Literature review.
$BSOCA_f$	Area of project planted mangrove stratum f.	ha	
PD	Project duration	years	

The total ex-ante biomass carbon storage potential of all projected restoration of deforested mangroves is calculated as:

$$TEXBCS = \sum_{f}^{TF} EXBCS_f \qquad \text{Eq. 11}$$

Variable		Units
TEXBCS	Total ex-ante biomass carbon storage of all reforested mangrove strata.	$t\text{-}CO_2$
TF	Number of deforested restoration strata.	

V.9.3. EX-ANTE PROJECT EMISSION REDUCTION POTENTIAL

The potential for reducing GHG emissions resulting from the implementation of the project is equivalent to the other-than-C emissions of the baseline scenario ($BLTGHGE_t$) during the projected duration. This potential for reducing GHG emissions is the basis for determining the economic viability of the project. For each planted area, emissions reductions begin in the year of plantation.

$$EXPGHGER = \sum_{t}^{PD} BLTGHGE_t \qquad \text{Eq. 12}$$

TABLE 10. EX-ANTE PROJECT EMISSION REDUCTION POTENTIAL

Variable		Units
EXPGHGER	Project ex-ante potential GHG emission reduction.	$t\text{-}CO_2$
PD	Project duration.	years

V.9.4. Ex-ante Total Project Mitigation Potential

To estimate the total ex-ante mitigation potential of the project, soil organic carbon and deduction factors are excluded. The potential is then calculated as:

$$EXTMP = TPBCS + TEXBCS + EXPGHGER \qquad \text{Eq. 13}$$

Table 11. Ex-ante total project mitigation potential

Variable		Units
EXTMP	Ex-ante total mitigation potential	t-CO_2
TPBCS	Total ex-ante project biomass carbon stock gain of all degraded mangrove areas.	t-CO_2
TEXBCS	Total ex-ante biomass carbon storage of all reforested mangrove strata.	t-CO_2
EXPGHGER	Project ex-ante potential GHG emission reduction.	t-CO_2

V.10. Project Implementation

V.10.1. Degraded Mangrove Restoration

Apply the same procedure established for degraded mangrove restoration defined for the ex-ante calculations. The carbon stock gain for the degraded stratum a under restoration from the beginning of project implementation until year y (counted from the beginning of project implementation) is then calculated as:

$$TPBCSG_y = \sum_{a}^{y} (BLBCS_a + PBCSG_a \times y) \qquad \text{Eq. 14}$$

Table 12. Degraded mangrove restoration

Variable		Units
$TPBCSG_y$	Total project biomass carbon stock gain of all degraded mangrove areas from the beginning of project implementation until year y.	t-CO_2
y	year of calculation.	

V.10.2. Deforested Mangrove Restoration

The restoration of previously deforested mangroves requires the planting of mangrove trees and their ongoing care. Carbon stocks in previously deforested and restored areas can be estimated through field inventories, remote sensing measurements, or a combination of both.

For estimates based on field sampling, the number of plots required for each mangrove plantation stratum -g- is estimated using a procedure similar to that used for SOC sampling:

$$n_g = \frac{t^2 \times s_g{}^2}{E^2 \times x^2}$$ Eq. 15

TABLE 13. DEFORESTED MANGROVE RESTORATION

Variable		Units
g	Index of planted mangrove stratum.	
n_g	Number of tree sampling plots required for planted stratum g.	
t	Student's t value for the desired confidence level (95%).	
s_g	Estimated carbon variance of tree biomass of planted stratum g.	$t\text{-}CO_2$
E	Acceptable relative error (10%).	
x	Estimated mean SOC content of planted mangrove stratum g.	$t\text{-}CO_2$

Once the number of samples required for each mangrove plantation stratum -g- in the project area has been calculated, the average carbon stocks per hectare for each stratum are calculated, and these values are used to calculate the total tree carbon stocks for the project area.

The carbon stocks of each sampled tree are calculated as:

$$TCO2 = (TSB \times BEF + TSB \times RSR \times 44/12)$$ Eq. 16

Variable		Units
$t\text{-}CO_2$	Total tree CO_2.	$t\text{-}CO_2$
TSB	Tree stem biomass (including bark).	$t\text{-}CO_2$
BEF	Species-specific biomass expansion factor	
RSR	Species-specific root to shoot ratio.	
WD	Species-specific wood density.	g/cm3

Based on the carbon stocks in trees, the carbon stocks in biomass per hectare for a year t are calculated for each stratum -g- of planted mangrove and recorded as PPMCSHA. Based on this variable and the area of planted mangrove for each stratum g (PPMA_g), the project planted mangrove carbon stocks in year y for all strata is calculated as:

$$PPMCS_y = \sum_{g}^{TG} PPMCSHA_g \times PPMA_g$$ Eq. 17

Variable		Units
$PPMCS_y$	Project planted mangrove carbon stocks in year t, counted from the beginning of project implementation.	$t\text{-}CO_2$
y	Year of calculation.	
g	Index of planted mangrove stratum.	
TG	Total number of mangrove planted strata.	
$PPMCSHA_g$	Project planted mangrove carbon stocks per hectare of stratum g.	$t\text{-}CO_2/ha$
$PPMA_g$	Area of project planted mangrove stratum g.	ha

V.10.3. Mangrove Rewetting Project Emissions

Rewetting restores anaerobic soil conditions favorable for methanogenic archaea, the microorganisms responsible for producing methane from decomposing organic matter. Rewetting previously deforested mangroves can increase methane emissions. When mangroves are cleared and then rewetted and the vegetation restored, several processes can enhance methane (CH4) production and release, especially in areas with a large water surface and low salinity. If the mangroves restoration project requires rewetting, then it must estimate the associated methane emissions.

To estimate methane emissions due to the rewetting of previously drained mangrove areas, the project shall assign an emission factor based on the time elapsed since rewetting. This emission factor should be based on field measurements or academic studies applicable to the project circumstances in terms of the species analyzed, tidal and flood cycles, and climatic conditions. If such studies are not available, methane emissions will be estimated at 33% of the carbon removals from biomass.

$$PRME_t = \sum_{i=y}^{t} PRMEFHA_y \times PRA_y \qquad \text{Eq. 18}$$

For t≥y.

Table 14. Mangrove rewetting project emissions

Variable		Units
$PRME_t$	Project methane emissions from rewetting in year t.	$t\text{-}CO_2$
t	Year of calculation.	
i	Year index (since rewetting).	
y	Rewetting year (counted from the beginning of the project).	
$PRMEFHA_y$	Annual methane emission factor of rewetted areas for year y since rewetting.	$t\text{-}CO_2/ha/yr$
PRA_t	Project rewetted area in year y.	ha

V.10.4. PROJECT SOIL ORGANIC CARBON

Soil carbon will be quantified during project implementation following the same procedure used for the baseline scenario. Soil strata can be the same or different to those defined for the baseline scenario. COS strata must be different if project implementation results in subdivisions of strata defined for the baseline scenario; for example, if a previously deforested area is restored on two significantly different dates.

$$n_h = \frac{t^2 \times {s_h}^2}{E^2 \times x^2} \qquad \text{Eq. 19}$$

This calculation is not required for ex-ante estimations, but it is required for ex-post estimations. This value acts as a reference level, with no projection of improvement or further degradation.

TABLE 15. PROJECT SOIL ORGANIC CARBON

Variable		Units
h	Index of project soil stratum.	
n_h	Number of SOC sampling plots required for project soil stratum h.	
t	Student's t value for the desired confidence level (95%).	
s_h	Estimated carbon variance of SOC of project soil stratum h.	t-CO_2/ha
E	Acceptable relative error (10%).	
x	Estimated mean SOC content of soil stratum h.	t-CO_2/ha

Once the number of soil samples required for each soil stratum in the project area has been calculated, the average carbon stocks per hectare for each stratum are calculated, and these values are used to calculate the total SOC for the project area in a year t.

The procedure of sampling at different depths is the same defined for the baseline SOC sampling. See Eq. 2.

$$PSOC_y = \sum_{h}^{TH} PSOCHA_h \times PSOCA_h \qquad \text{Eq. 20}$$

Variable		Units
$PSOC_y$	Project SOC stock in year y counted from the beginning of project implementation.	t-CO_2
y	Year of calculation.	
h	Index of project soil stratum.	
TH	Total number of project soil strata.	

Variable		Units
$PSOCHA_h$	Project SOC stock per hectare of project soil stratum h.	t-CO_2/ha
$PSOCA_h$	Area of project soil stratum h.	ha

V.10.5. Deduction Factors

The following deduction factors must be applied to the project implementation calculations.

V.10.5.1. Uncertainty Factor

$$UF = (BEE \times BCP + SEE \times SOCP) \times AIF \qquad \text{Eq. 21}$$

Table 16. Uncertainty Factor

Variable	
UF	Uncertainty factor.
BEE	Biomass estimation error.
SEE	Soil estimation error.
BCP	Proportion of carbon from biomass.
SOCP	Proportion of soil organic carbon.
AIF	Aggregation increase factor.

V.10.5.2. Buffer Factor

$$BF = NRF + ARF + MRF \qquad \text{Eq. 22}$$

Table 17. Buffer Factor

Variable	
BF	Buffer factor.
NRF	Natural risk factor.
ARF	Anthropogenic risk factor.
MRF	Management risk factor.

V.10.6. Net Cumulative GHG Mitigation Due to Project Implementation

For a year y of project implementation, the net GHG mitigation due to project implementation is calculated as:

$$NGHGM_y = \left(\mathbf{TPBCSG}_y + \mathbf{PPMCS}_y + \mathbf{PSOC}_y + \mathbf{BLTGHGE}_y - \mathbf{TBLBCS} - \mathbf{BLSOC} - \mathbf{PRME\_t}\right) \times (1 - UF) \times (1 - BF) \qquad \text{Eq. 23}$$

TABLE 18. NET CUMULATIVE GHG MITIGATION DUE TO PROJECT IMPLEMENTATION

Variable		Units
$NGHGM_y$	Net cumulative GHG mitigation from the beginning of project implementation until year y.	$t\text{-}CO_2$
$TPBCSG_y$	Total project biomass carbon stock gain of all degraded mangrove areas from the beginning of project implementation until year y.	$t\text{-}CO_2$
$PPMCS_y$	Project planted mangrove carbon stocks in year t, counted from the beginning of project implementation.	$t\text{-}CO_2$
TBLBCS	Total baseline biomass carbon stocks (of degraded and previously deforested mangroves).	$t\text{-}CO_2$
$PSOC_y$	Project SOC stock in year y counted from the beginning of project implementation.	$t\text{-}CO_2$
$BLTGHGE_y$	cumulative baseline total GHG emissions from the beginning of project implementation until year y.	$t\text{-}CO_2$
BLSOC	Baseline SOC stock.	$t\text{-}CO_2$
$PRME_t$	Project methane emissions from rewetting in year t.	$t\text{-}CO_2$
UF	Uncertainty factor.	NA
BF	Buffer factor.	NA

VI. CREDITS CALCULATION

At the end of each monitoring period and upon project verification, the aOCP-ITTE will calculate the number of credits to be certified as the net carbon stocks gain from project implementation during the monitoring period. Defining t1 and t2 as the beginning and the end years of the monitoring period, the credits earned are calculated as:

$$EC = NGHGM_{t2} - NGHGM_{t1} \quad \text{Eq. 24}$$

TABLE 19. CREDITS CALCULATION

Variable		Units
$NGHGM_{t2}$	Net cumulative GHG mitigation at the final year of project monitoring to be verified.	$t\text{-}CO_2$
$NGHGM_{t1}$	Net cumulative GHG mitigation at the final year of the previous monitoring period.	$t\text{-}CO_2$

VII. Document History

Version	Date	Comments
1.0	December, 2024	• First version of the methodology
2.0	July 17, 2025	• Version approved and released by the aOCP Steering Committee under the aOCP V.2.0 Framework. • The methodology was renamed and restructured, while respecting its methodological essence.

Annex 1. Methodological sequence for calculating credits obtained during a monitoring period

Procedure		Comments/description
Stratify baseline scenario and project implementation areas		
	Baseline degraded mangrove strata	These strata are defined based on significant carbon stock differences among existing degraded mangrove areas where the project will be implemented.
	Baseline deforested mangrove strata (other land uses/land covers)	These strata include previously deforested mangroves with other-than-mangrove land cover or land uses (crops, cattle rising).
	Project strata of degraded mangrove under restoration	These strata are usually the same as the baseline degraded mangrove strata.
	Project strata of planted mangrove	These strata may differ from baseline deforested mangrove strata by subdivisions according to year of planting or species/combination of species used.
	Soil strata for baseline and project implementation	These strata are defined based on expected significant carbon stock differences among areas where the project will be implemented. Strata should be similar between baseline scenario and project implementation.
Calculate the Baseline scenario carbon stocks and GHG emissions		
	Baseline biomass carbon stocks of degraded mangroves	From forest inventories, remote sensing or existing studies for the same region and mangrove type. "Degraded" mangroves must have less than 70% of biomass carbon stocks compared to the biomass carbon stocks of undegraded mangrove of the same type. Undegraded mangroves and mangroves degraded above this limit are not eligible for project implementation.
	Biomass carbon stocks of undegraded mangroves of similar type to degraded mangroves	For this value, the project must use data on biomass carbon stocks in structurally similar undegraded mangroves to the degraded mangroves that will be included in the project. These data must be duly supported by field studies or scientific literature applicable to the same project region.
	Baseline biomass carbon stocks of deforested areas	The project must use data on biomass carbon stocks of existing land use/land cover strata of baseline areas to be restored. These data must be duly supported by field studies, technical or scientific literature applicable to the same project region and land use/land cover type.
	Total baseline biomass carbon stocks	Calculated as the summation of degraded mangroves and other land uses/land covers.
	Baseline soil organic carbon stocks	Calculated from field sampling.
	Other-than-C GHG baseline emissions from mangroves converted to rice fields	Calculated based on crop areas and a CH_4 annual emission factor from rice field. This factor must be duly supported by field studies or scientific literature applicable to the same project region.

Procedure		Comments/description
	Other-than-C GHG baseline emissions from the application of synthetic fertilizers to crops	Calculated based on crop areas and a CH4 annual emission factor each land use that usually use synthetic fertilizers. This factor must be duly supported by field surveys or publications applicable to the same project region and land use.
	Total baseline GHG emissions	Calculated as the summation of rice field emissions plus emissions from the use of synthetic fertilizers.
Ex-ante calculation of project mitigation potential		
	Ex-ante project mitigation potential of restoring degraded mangroves	Calculated based on an annual carbon stock restoration rate for each degraded mangrove stratum since the beginning of project implementation.
	Ex-ante project mitigation potential of restoring deforested mangroves	Calculated on cumulative current annual increments for each plantation type (i.e., mangrove species or specific combination of species).
	Ex-ante emission reduction potential	Calculated based on the baseline GHG annual emission factors defined for rice crops and other fertilizer-consuming land used, since the year of starting of restoration (considering that restoration areas may start restoration in different years).
	Ex-ante total mitigation potential	Summation of the tree previous values. Soil Organic Carbon (SOC) is not considered for the ex-ante calculation of the project mitigation potential.
Project implementation		
	Degraded mangrove restoration	Calculated based on an annual carbon stock restoration rate for each degraded mangrove stratum since the beginning of project implementation.
	Deforested mangrove restoration	Based on field sampling, eventually mixed from remote sensing techniques.
	Mangrove rewetting project emissions	CH4 annual emission factor(s) based on field measurements or academic studies applicable to the project circumstances in terms of the species analyzed, tidal and flood cycles, and climatic conditions. If such studies are not available, methane emissions will be estimated at 33% of the carbon removals from biomass.
	Project soil organic carbon	Calculated from field sampling.
	Deduction factors	Based on uncertainty risks and a buffer factor.
GHG mitigation from project implementation		
	Cumulative net GHG mitigation	Balance of all baseline and project implementation carbon stocks and GHG emission factors.
	Net GHG mitigation during the monitoring period (=earned credits)	cumulative mitigation gain of project, compared to the previous monitoring period.

Annex 2. 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 3. 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 aOCP-ITTE 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.