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**BLUE CARBON POTENTIAL OF THE OLD CAALUAN MANGROVE
CONSERVATION AREA, TINAMBAC: BIOMASS AND CARBON STOCK
ASSESSMENT**

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29 August 2026

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This Special Problem of **ZIPPORA VALERIE ZUÑIGA** titled: “**BLUE CARBON POTENTIAL OF THE OLD CAALUAN MANGROVE CONSERVATION AREA, TINAMBAC: BIOMASS AND CARBON STOCK ASSESSMENT**” is hereby accepted by the Faculty of Management and Development Studies, U.P. Open University, in partial fulfillment of the requirements for the degree **Master of Environment and Natural Resources Management.**

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DECLARATION

This is to certify that:

- I. The special problem comprises only my original work towards the MENRM, except were indicated in the Preface
- II. Due acknowledgment has been made in the text to all other material used
- III. The special problem is fewer than 25,000 words in length, exclusive of tables, maps, bibliographies, and appendices.

ZIPPORA VALERIE ZUÑIGA

Name

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First and foremost, I give my highest praise and deepest gratitude to our Lord Jesus Christ, whose guidance, strength, and grace made possible the completion of this manuscript, *“Blue Carbon Potential of the Old Caaluan Mangrove Conservation Area, Tinambac: Biomass and Carbon Stock Assessment.”* Truly, the Lord Jesus is our sovereign God, who arranges and aligns everything in His perfect time. He has been my wisdom and strength, especially in moments of weakness and discouragement.

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Finally, I dedicate this work to all who believe in the importance of protecting our mangrove ecosystems. This manuscript is not only a product of research but also a testament to collective effort, inspiration, and faith.

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Abstract

Mangrove forests are recognized as important blue carbon ecosystems because of their capacity to sequester and store substantial amounts of atmospheric carbon. This study assessed the biomass and carbon stock potential of the Old Caaluan Mangrove Conservation Area in Tinambac, Camarines Sur, Philippines. Specifically, biomass and carbon stocks were estimated in three *Rhizophora stylosa* plantation stands aged 7, 10, and 15 years using stratified quadrat sampling and standardized allometric equations. Measurements of diameter at breast height, tree height, and stand density were used to determine aboveground biomass and corresponding carbon stocks.

Results revealed that the 15-year-old plantation stand exhibited the highest biomass (54.50 t ha^{-1}) and carbon stock ($24.53 \text{ t C ha}^{-1}$), associated with larger mean diameter at breast height (8.32 cm) and tree heights ranging from 12 to 13 m. The 7-year-old stand recorded higher biomass and carbon stock values than the 10-year-old stand despite its younger age, primarily because of its greater stem density. These findings indicate that plantation age, stand density, and stand structure are important determinants of carbon accumulation and storage in mangrove ecosystems.

The results demonstrate the substantial blue carbon potential of the Old Caaluan Mangrove Conservation Area and underscore its ecological importance for climate change mitigation, coastal protection, biodiversity conservation, and community resilience. The study provides baseline information that can support local carbon accounting, mangrove management, and conservation planning. Furthermore, the findings establish a foundation for long-term monitoring and future assessments

that incorporate belowground biomass, soil carbon, and sediment carbon pools to improve estimates of total ecosystem carbon storage.

Keywords: blue carbon, mangrove biomass, carbon stock, *Rhizophora stylosa*, climate change mitigation

I. INTRODUCTION

Mangroves, together with tidal marshes and seagrasses, are classified as blue carbon ecosystems due to their remarkable ability to store large amounts of carbon and maintain long-term carbon sequestration. These coastal habitats play an essential role in regulating greenhouse gas emissions and mitigating the rise of atmospheric carbon dioxide. In tropical and subtropical intertidal zones, mangroves are highly productive and promote rapid sediment deposition, enabling them to capture, transform, and retain atmospheric CO₂ within coastal sediments over extended periods. This process also facilitates the movement of organic carbon from nearshore areas to offshore marine systems (Choudhary et al., 2024).

Globally, mangrove ecosystems are recognized as among the most ecologically valuable and biologically productive coastal habitats. Functioning at the intersection of land and sea, they are considered among the most dynamic ecosystems on the planet (Camacho, 2020). Their contribution to climate change mitigation is particularly evident in their ability to absorb carbon and reduce the impacts of sea-level rise, saltwater intrusion, and tidal surges. Choudhary, Dhar, and Pawase (2024) emphasize that mangroves are among the most effective blue carbon ecosystems in tropical regions, with carbon sequestration being their most critical service. Broad-leaved mangrove forests, covering about 14 million hectares worldwide, can absorb up to 1,000 kilograms of carbon dioxide per hectare daily during peak growth seasons, while releasing approximately 730 kilograms of oxygen. Mangrove ecosystems, as vital components of coastal environments, are increasingly recognized as among the most effective ocean-based solutions for mitigating climate change due to their exceptional carbon sequestration capacity, alongside their rich natural resource value. Recent global assessments affirm their critical role in capturing substantial amounts of carbon

and contributing to climate regulation (Nellemann & Corcoran, 2009; Barbier et al., 2011).

In line with the United Nations Sustainable Development Goals (SDGs), countries such as the Philippines have committed to advancing climate action (SDG 13) and conserving marine and coastal ecosystems (SDG 14). Mangrove restoration directly supports these goals by strengthening resilience against climate hazards and promoting sustainable management of coastal habitats (Connor, 2015). Despite their importance, mangroves remain vulnerable, with projections suggesting a potential global decline of 10–15% by 2100 (Zommers et al., 2016). Their ability to store and sequester carbon underscores their role as natural allies in the global effort to combat climate change.

In the Philippines, the Department of Science and Technology–Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD) highlight the ecological and socio-economic functions of mangrove ecosystems. These coastal forests act as natural shields against storm surges, safeguard biodiversity, and provide significant carbon storage. They also sustain coastal communities through fisheries, aqua-silviculture, timber harvesting, and eco-tourism. On average, Philippine mangroves hold about 401.8 tons of biomass per hectare and store roughly 176.8 tons of carbon (Lasco & Pulhin, 2000).

Rehabilitation of mangrove ecosystems in tropical countries like the Philippines is a crucial strategy for addressing climate change and its cascading impacts. These forests act both as absorbers and emitters of carbon dioxide, playing a dynamic role in the global carbon cycle (ENFOR, 2004; Gevaña et al., 2008). Protecting and restoring mangroves is essential to sustain their climate mitigation functions. Reliable data on their carbon sequestration capacity is needed to guide evidence-based forest

management and policy interventions. With proper stewardship, mangroves can be enhanced to capture and store carbon in their biomass and soils, while also serving as natural coastal defenses that protect communities from storm surges, sea-level rise, and other climate-related hazards.

Banacon Island in Bohol Province provides a notable example of successful mangrove rehabilitation. Camacho et al. (2011) documented strong carbon sequestration potential in plantations of varying ages (15, 20, and 40 years) as well as natural stands. Results showed that the 40-year-old plantation stored the highest carbon density at about 370.7 tons per hectare, followed by the 15-year-old stand with 208.5 tons per hectare, the 20-year-old stand with 149.5 tons per hectare, and the natural stand with 145.6 tons per hectare. These findings confirm that Banacon's mangrove forests are healthy and capable of storing significant carbon. Sustained collaboration between local communities and government agencies, along with policies that provide incentives and livelihood support, is vital to maintain and enhance these carbon stocks.

II. REVIEW OF LITERATURE

Global Perspectives on Blue Carbon Ecosystems

Mangroves, seagrasses, and tidal marshes are collectively identified as blue carbon ecosystems because of their unique ability to capture and store atmospheric carbon over long periods. Worldwide, mangroves are regarded as some of the most productive and ecologically valuable coastal habitats, functioning across both land and sea environments (Camacho, 2020). Their capacity to absorb as much as 1,000 kilograms of carbon dioxide per hectare daily during peak growth seasons highlights their critical role in climate regulation (Choudhary, Dhar, & Pawase, 2024).

Mangroves and Climate Change Mitigation

Mangrove ecosystems deliver multiple services, including carbon sequestration, shoreline protection, and biodiversity support. Research consistently affirms their effectiveness as ocean-based solutions for climate regulation (Nellemann & Corcoran, 2009; Barbier et al., 2011). However, global projections warn of a possible 10–15% decline in mangrove cover by 2100 due to climate change pressures (Zommers et al., 2016). This vulnerability underscores the urgency of conservation and rehabilitation initiatives.

Philippine Context and Ecological Value

In the Philippines, mangroves are essential for coastal resilience, fisheries, and community livelihoods. The Department of Science and Technology – Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (DOST-PCAARRD) emphasize their socio-economic functions, including aqua silviculture, eco-tourism, and timber harvesting. On average, mangrove forests in the Philippines contain about 401.8 tons of biomass per hectare, with an estimated 176.8

tons of carbon stored per hectare (Lasco & Pulhin, 2000). These values provide a national benchmark against which site-specific assessments, such as the Old Caaluan Mangrove Conservation Area, can be compared. Rehabilitation projects have demonstrated their dual role as both emitters and absorbers of carbon dioxide, reinforcing their importance in climate-responsive management (Gevaña, Pulhin, & Tapia, 2008).

Case Studies of Mangrove Rehabilitation

Banacon Island in Bohol Province serves as a model for successful mangrove reforestation. Camacho et al. (2011) reported that older plantations, particularly those around 40 years old, stored up to 370.7 tC/ha significantly higher than younger stands. This illustrates the long-term carbon sequestration potential of rehabilitated mangrove ecosystems and highlights the importance of sustained collaboration between communities and government agencies.

Local Significance of Old Caaluan, Tinambac

The Old Caaluan Mangrove Conservation Area, covering 72 hectares and hosting 29 species, is recognized as one of Camarines Sur's most sustainable conservation projects. Managed by EDMERO and supported by Bantay Bakawan, it has received multiple awards, including the DENR's Gawad Iba Ka Juan and Saringaya Awards. Its ecological, educational, and socio-economic contributions position it as a living laboratory and a strategic site for carbon stock assessment (Province of Camarines Sur, 2024).

III. STATEMENT OF THE STUDY

Mangrove ecosystems are increasingly recognized as critical blue carbon habitats due to their capacity to sequester and store atmospheric carbon, thereby contributing significantly to climate change mitigation. In the Philippines, mangroves not only serve as natural coastal defenses but also sustain livelihoods and biodiversity. Despite their ecological importance, many mangrove areas remain vulnerable to degradation, underscoring the need for scientific assessments that can guide conservation and policy interventions.

The Old Caaluan Mangrove Conservation Area in Tinambac, Camarines Sur, spanning 72 hectares and hosting 29 mangrove species, represents one of the province's most sustainable conservation initiatives. Managed by the Provincial Government through EDMERO and supported by the Bantay Bakawan program, the site has been recognized nationally for its ecological and socio-economic contributions. However, while its role in coastal protection and community empowerment is well established, there is limited empirical data on its biomass and carbon sequestration potential.

This study seeks to address this gap by quantifying the biomass and carbon stock of selected mangrove stands in Old Caaluan using standardized methodologies and allometric equations. By establishing a scientific baseline, the research aims to strengthen local climate action strategies, inform evidence-based forest management, and support policy development that integrates conservation with sustainable livelihood opportunities. Ultimately, the study underscores the importance of mangrove ecosystems as natural allies in climate resilience and environmental stewardship.

IV. OBJECTIVES OF THE STUDY

Given its ecological, educational, and socio-economic value, Old Caaluan presents a strategic opportunity for carbon stock assessment and climate-responsive management. By applying standardized methodologies similar to those used in Banacon, this study aims to:

1. Quantify the biomass and carbon sequestration capacity of the Old Caaluan mangrove forest using standardized methodologies comparable to those applied in the Banacon case study.
2. Establish a scientific baseline for integrating Old Caaluan's carbon stock data into local climate action strategies and forest management planning.
3. Support policy development by identifying conservation-linked livelihood opportunities and incentive mechanisms for communities dependent on mangrove resources.

IV. RATIONALE

Mangrove ecosystems are vital for climate resilience, coastal defense, and sustainable livelihoods. The long-term success of Banacon Island in Bohol demonstrates how community-led reforestation can evolve into a powerful carbon sink, with older plantations storing up to 370.7 tons of carbon per hectare. This precedent underscores the climate value of sustained mangrove rehabilitation.

In Tinambac, Camarines Sur, the Old Caaluan mangrove site (72 hectares) serves as a crucial coastal buffer, improving water quality and supporting fisheries and wildlife. Hosting 29 mangrove species, it doubles as a living laboratory for universities and is safeguarded through the Bantay Bakawan program. Importantly, Old Caaluan forms part of the 345-hectare Calauan Mangrove Area, recognized as one of the most sustainable environmental conservation and protection projects in the province.

The Calauan Mangrove Area was awarded 2nd Runner Up in the DENR's 3rd Gawad Iba Ka Juan Award (2024). Managed by EDMERO, it not only protects communities from storm surges but also provides livelihoods, serves as a field laboratory, and thrives through strong collaboration with Bantay Bakawan and local stakeholders.

The Provincial Government of Camarines Sur, through EDMERO, also received the 18th and 23rd Saringaya Awards for Local Government Units, an annual recognition given by DENR Bicol (DENR V) to honor individuals, groups, and organizations whose contributions inspire communities to become vanguards of Mother Nature. With multiple recognitions, Camarines Sur now holds the distinction of being a Hall of Famer of the Saringaya Awards, further strengthening its commitment

to environmental protection and conservation, and motivating continued efforts to safeguard natural resources.

Together, these milestones highlight how CamSur's mangrove ecosystems and environmental programs deliver ecological resilience, academic value, and community empowerment, positioning the province as a leader in coastal resource management and environmental stewardship.

V. SCOPE AND LIMITATIONS

Scope

This study focuses on the assessment of biomass and carbon stock within the 72-hectare Old Caaluan Mangrove Conservation Area in Tinambac, Camarines Sur. The research specifically targets *Rhizophora stylosa* stands of varying ages (7, 10, and 15 years), applying standardized quadrat sampling and allometric equations (Komiya et al., 2005) to estimate aboveground and root biomass. The study integrates community participation, particularly through the Bantay Bakawan program and EDMERO staff, to ensure local relevance and strengthen conservation stewardship. Results are intended to establish a scientific baseline for carbon sequestration capacity, inform climate-responsive forest management, and support policy development linking conservation with sustainable livelihoods.

Limitations

The study is limited to selected plantation stands within Old Caaluan and does not encompass the entire mangrove area or other species beyond *Rhizophora stylosa*. Biomass and carbon stock estimates rely on non-destructive allometric equations, which, while widely accepted, may not capture site-specific variations in wood density or belowground carbon pools. Stand age classification is based on community interviews, historical records, and available documentation, which may introduce uncertainties in plantation dating. Seasonal variations, natural disturbances such as typhoons, and broader ecological interactions were not measured in this study. As such, findings provide a baseline rather than a comprehensive account of long-term carbon dynamics.

VI. DESCRIPTION OF THE STUDY AREA

The study was conducted in the Old Caaluan Mangrove Conservation Area, a 72-hectare coastal forest located in Tinambac, Camarines Sur, Philippines. This site forms part of the larger 345-hectare Calauan Mangrove Area, recognized as one of the province's most sustainable conservation and protection projects. The mangrove forest serves as a vital coastal buffer, shielding nearby communities from storm surges, tidal flooding, and saltwater intrusion, while simultaneously supporting fisheries, wildlife habitats, and local livelihoods.

Old Caaluan hosts 29 mangrove species, dominated by *Rhizophora stylosa*, and functions as a living laboratory for academic institutions such as Ateneo de Naga University, CBSUA, Partido State University, and the University of Nueva Caceres. The area is managed by the Provincial Government of Camarines Sur through the Environmental Disaster Management and Emergency Response Office (EDMERO), in partnership with the Bantay Bakawan program and local barangay stakeholders.

Beyond its ecological role, Old Caaluan has received multiple recognitions, including the DENR's Gawad Iba Ka Juan Award (2024) and the Saringaya Awards, positioning Camarines Sur as a Hall of Famer in environmental stewardship. These awards highlight the site's success in integrating conservation, livelihood support, and community empowerment.

The mangrove stands within Old Caaluan vary in age, with plantations established approximately 7, 10, and 15 years ago. These stands provide an ideal setting for biomass and carbon stock assessment, offering insights into how stand age, stem density, and species composition influence carbon sequestration capacity.

VII. METHODOLOGY

A. Sampling Design and Stand Age Determination

A stratified sampling approach using quadrat sampling will be employed to assess biomass and carbon stocks across representative mangrove stands in Old Caaluan. Sampling plots will be selected based on three key criteria: stand age, species composition, and site accessibility. Each plot will measure 10 m × 10 m, consistent with standard forestry protocols.

To determine stand age, site selection will be guided by the approximate age of mangrove plantations, categorized as P-7, P-10, and P-15. These classifications correspond to estimated planting periods of 7, 10, and 15 years, respectively. Data will be triangulated from community interviews and historical records, including:

- DENR permit records and reforestation project documents, particularly those issued through CENRO-Goa and PENRO-Camarines Sur, which may indicate planting dates and project durations.
- LGU environmental program archives and reforestation reports including EL Verde Project by the Provincial Government of Camarines Sur, documenting municipal and barangay-level mangrove rehabilitation efforts.
- Available archived photo documentation and satellite imagery, to visually assess canopy development and infer stand maturity.
- Barangay resolutions and meeting minutes, referencing community-led planting or conservation initiatives.
- Academic field records from local universities, especially those with prior ecological assessments or student fieldwork in the area.

These sources will supplement and validate oral histories gathered through community interviews, enabling a more accurate classification of mangrove stands into young, intermediate, and mature age categories.

B. Diameter at Breast Height (DBH) Measurement

Diameter at Breast Height (DBH) is a standard forestry metric used to assess tree size and biomass. In this study, DBH will be measured for all mangrove trees with a diameter of ≥ 2.5 cm, following established protocols for tropical coastal forests. Measurement procedures will include:

- Height Reference: DBH will be measured at 1.3 meters above ground level, consistent with international forestry standards.
- Tools Used: A diameter tape or caliper will be used to ensure accurate readings, especially for trees with irregular stems.
- Multiple Stems: For trees with multiple stems branching below breast height, each stem ≥ 2.5 cm will be measured separately and treated as individual trees for biomass estimation.
- Sloped Terrain or Prop Roots: For species like *Rhizophora spp.* with prominent prop roots, DBH will be measured above the highest prop root where the stem is relatively straight.
- Recording: DBH values will be recorded to the nearest 0.1 cm, and used as input for species-specific or general allometric equations to estimate biomass.

This standardized approach ensures consistency across sampling plots and supports accurate application of biomass models.

C. Biomass and Carbon Stock Estimation

Biomass estimation will utilize species-specific and general allometric equations as presented in Table 1 of Camacho et al. (2011), which are adapted from Komiyama et al. (2005). These equations are widely accepted for mangrove biomass studies in Southeast Asia. Using Komiyama allometric equations is both practical and standard for Southeast Asian mangroves, offering a non-destructive, repeatable, and accessible approach that can be readily applied by local schools and communities engaged in mangrove research and conservation.

For species focus, this study emphasizes *Rhizophora stylosa*, ensuring methodological consistency and comparability with regional studies. Concentrating on *Rhizophora* strengthens the reliability of biomass and carbon stock estimates, facilitates cross-site benchmarking, and enhances the transferability of lessons learned to other restoration projects across Southeast Asia.

- General allometric equations for mangroves:

$$W_{agb} = 0.247\rho (D^2)^{1.23}$$

- where W_{agb} is the aboveground biomass; ρ is wood density of the species (g/cm^3) and D is diameter at breast height (cm).

- For *Rhizophoras spp.*, root biomass (AGB) will be calculated using the equation:

$$W_R = 0.199 \rho^{0.899} (D^2)^{2.22}$$

- where W_R is the root biomass (kg); ρ is wood density of the prop roots and D is diameter at breast height (cm).

Above ground biomass will be comprise the biomass of stem, branches and leaves while root biomass includes the biomass of stilt roots and pneumatophores.

These equations are explicitly listed in Table 1 of the cited study and will be applied consistently across all sampling plots. Biomass values will be converted to carbon stock using the Intergovernmental Panel on Climate Change (IPCC) default conversion factor of 0.47. Carbon density will be expressed in tons per hectare (tC/ha).

D. Community Integration in the Sampling Process

To strengthen the participatory aspect of the study and ensure local relevance, community members and LGU representatives will be actively integrated into the field sampling process. Their involvement will be structured as follows:

- **Trained Field Assistants:** Selected community members particularly Bantay Bakawan personnel and EDMERO CamSur ENRM staff will be oriented on basic field protocols such as plot establishment, DBH measurement, species identification, and data recording. Importantly, the use of Komiyama allometric equations will be highlighted as a non-destructive, repeatable, and accessible method. This ensures that local schools, communities, and conservation groups can continue applying the same methodology for monitoring mangrove biomass and carbon stocks, even beyond the scope of this study.
- **LGU-Tinambac Technical Support:** Staff from the Municipal Environment and Natural Resources Office (MENRO), particularly their Coastal Resource Management unit, and Old Caaluan barangay officials will be invited to participate as technical guides and logistical coordinators. Their familiarity with site conditions and historical interventions will be essential in validating sampling locations and stand age classifications.
- **Integration into IEC and Feedback Loops:** The sampling activities will be paired with informal information-sharing sessions, allowing community participants to understand the purpose and potential applications of biomass and carbon stock

data. The practicality of Komiyama equations will be emphasized during these sessions, reinforcing their value as a tool that communities and schools can adopt for ongoing mangrove stewardship. Findings will be shared with LGU and community stakeholders through feedback meetings and IEC materials.

This integrated approach not only enhances data accuracy and field efficiency but also reinforces community engagement, transparency, and long-term stewardship of mangrove resources. By embedding a methodology that is both scientifically robust and community-accessible, the study ensures continuity of monitoring and empowers local stakeholders to sustain conservation outcomes.

E. Integration of Bantay Bakawan in Stand Age Determination and Result Dissemination

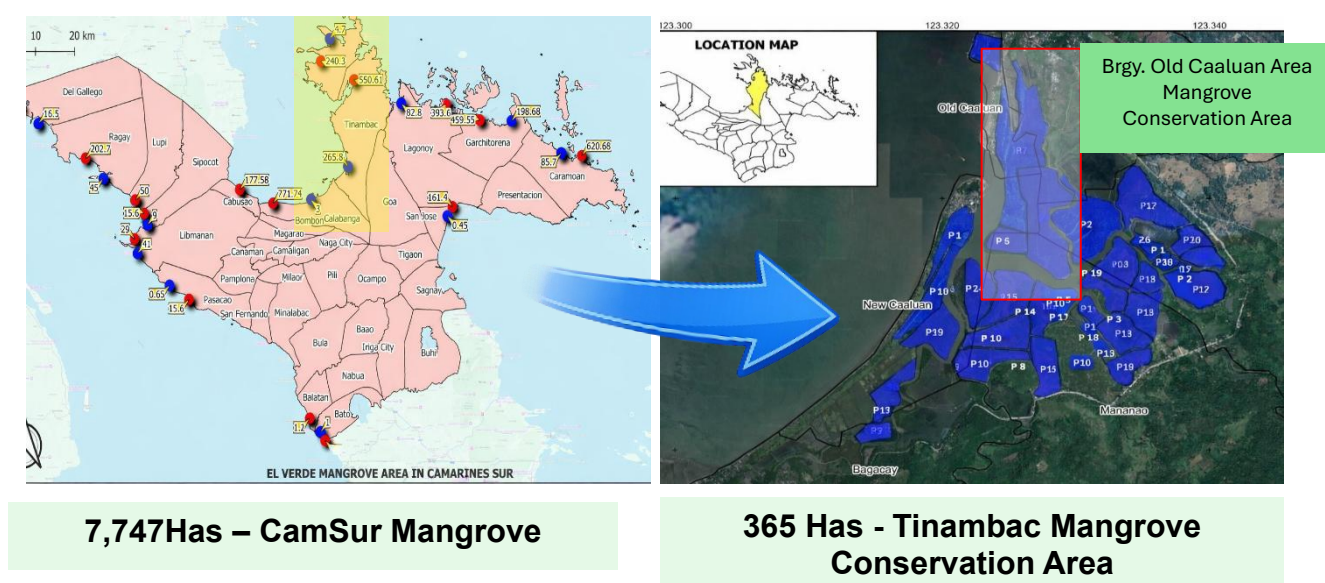
To reinforce community participation and align scientific assessment with local stewardship, members of the Bantay Bakawan will be actively engaged in the fieldwork component of this study, particularly in determining mangrove stand age. Their involvement will be structured as follows:

E.1. Fieldwork Role and Responsibilities

- **Key Informants for Historical Validation:** Bantay Bakawan members will serve as primary informants during community interviews, providing firsthand accounts of planting activities, site rehabilitation efforts, and observed changes in mangrove structure over time.
- **Site-Level Verification:** Their familiarity with specific plantation blocks will be critical in validating stand age classifications (e.g., P-7, P-10, P-15), especially where formal records are incomplete or unavailable.

- **Field Guides and Local Coordinators:** They will assist in identifying plot boundaries, navigating access routes, and coordinating with barangay officials to ensure smooth field operations.
- **Participatory Mapping:** Bantay Bakawan members may be involved in sketch mapping or GPS tagging of plantation zones, contributing to spatial accuracy and community ownership of the data.

Figure 8.1. CamSur Mangrove Conservation Area and Tinambac Focus Site.



E.2. Result Dissemination and Incentive Justification

- **Focused Feedback Sessions:** Upon completion of data analysis, results particularly those related to biomass, carbon stock, and stand age will be presented to Bantay Bakawan members through barangay-level feedback meetings. These sessions will include visual summaries and IEC materials tailored to their role and understanding.
- **Integration into Livelihood-Conservation Incentive Frameworks:** The validated stand age data will support the justification of performance-based incentives under programs such as cash-for-work or food-for-work, carbon stewardship

schemes, or enhanced Bantay Bakawan support. This ensures that their contributions are directly linked to measurable ecological outcomes.

- Recognition and Endorsement: Their role will be formally acknowledged in LGU reports and project documentation, reinforcing their legitimacy as community-based resource managers and strengthening their access to future support mechanisms.

F. Data Analysis

Descriptive statistics will be used to compare carbon densities across stand ages and species. Results will be analyzed to identify trends in carbon sequestration potential and to inform policy recommendations for climate-responsive mangrove management.

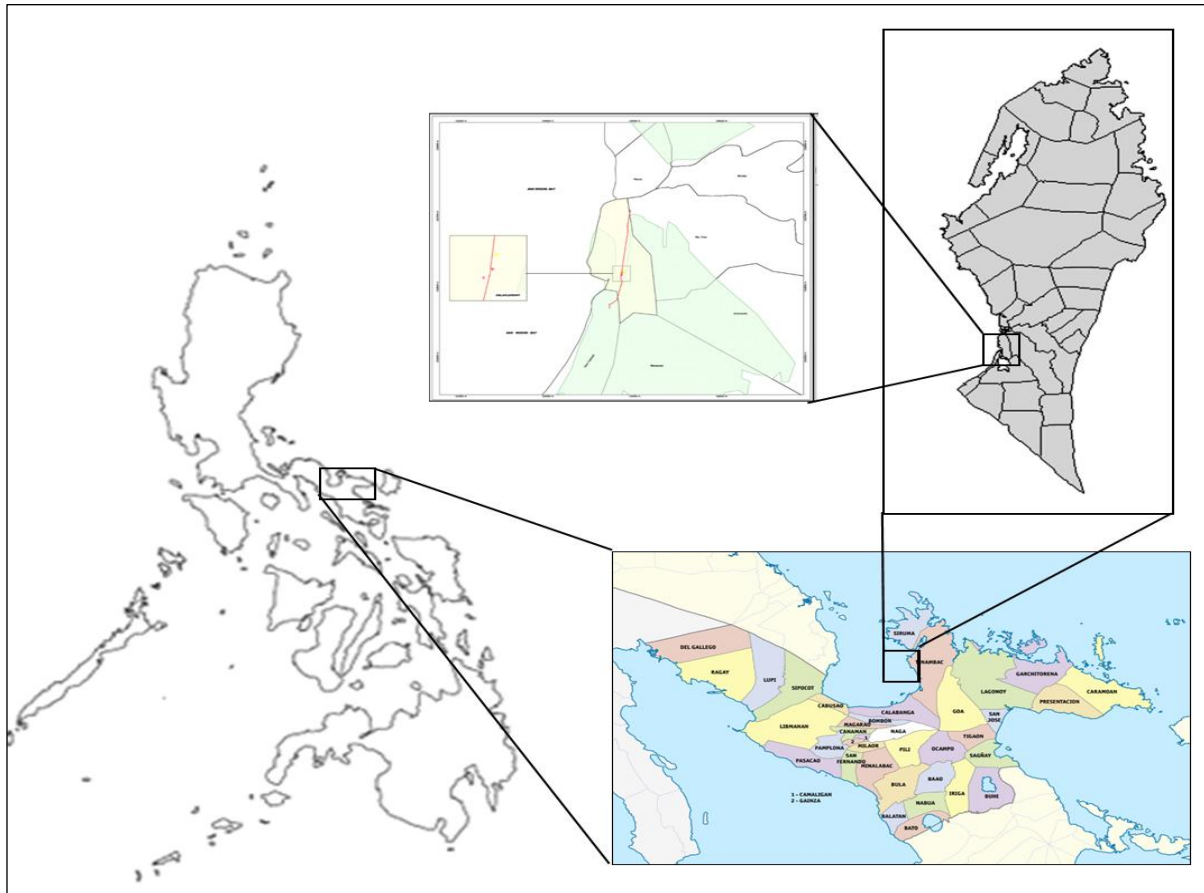
Table 8.1

Study Plan

Date	Activity	Methodology
Nov 7–9, 2025 (First or second weekends of November)	Secure LGU and Barangay permit; Site visit to identify sampling plots	Letter of permission submitted to MENRO-Tinambac and Barangay Captain of Old Caaluan; Ocular visit guided by Head of Bantay Bakawan for site identification
Nov 30, 2025	Establish sampling plots; Conduct DBH, height, and species identification	Establish three (10 × 10 m) plots per site, spaced at least 20 m apart; Record DBH, height, and species using tape measure, ruler, GPS, and notebook; Research assistants and Bantay Bakawan staff assist in data collection
December 14, 2025	Interview with Bantay Bakawan and LGU staff	Conduct focus group discussion with Bantay Bakawan and LGU staff for the discussion of policy development for livelihood opportunities and incentive mechanism
December 15–20, 2025	Process and analyze field data	Apply allometric equations for biomass and carbon estimation; Generate preliminary graphs and tables
December – January 2026	Final Paper writing	Drafting of the Final Manuscript

Note. Activities are sequenced to align with permitting, fieldwork, stakeholder engagement, and manuscript preparation.

Figure 8.2. Location of Study Site.



Source: Province of Camarines Sur, Environmental and Natural Resources Management Unit. (2024). Barangay Old Caaluan mangrove zoning [GIS shapefile].

VIII. RESULTS

Species Composition

Across the sampling sites, the stands were dominated by *Rhizophora stylosa*. The 7-year-old plantation (P-7) recorded the highest stem density, ranging from 82 to 98 stems per plot, with an average DBH of 3.81 cm and a height range of 5.0–6.0 m. The 10-year-old plantation (P-10) had 36–58 stems per plot, with an average DBH of 5.09 cm and a height range of 10.0–11.0 m. The 15-year-old plantation (P-15) recorded 37–55 stems per plot, with the largest average DBH of 8.32 cm and a height range of 12.0–13.0 m.

Biomass and Carbon Stock

Biomass and carbon stock varied across the three plantation stands. The 15-year-old stand (P-15) exhibited the highest biomass at 54.50 t/ha and carbon stock at 24.53 tC/ha. The 7-year-old stand (P-7) recorded biomass of 28.59 t/ha and carbon stock of 12.86 tC/ha. The 10-year-old stand (P-10) had the lowest values, with biomass of 24.28 t/ha and carbon stock of 10.93 tC/ha.

Plot-Level Estimates

Within the 15-year-old stand, Plot 3 recorded the largest biomass estimate of 85.94 t/ha and carbon stock of 38.67 tC/ha. In the 7-year-old stand, Plot 2 recorded biomass of 41.37 t/ha and carbon stock of 18.62 tC/ha. Plot-level variations were observed across all stands, reflecting differences in stem density and DBH measurements.

IX. ANALYSIS AND DISCUSSION

Species composition

Table 10.1 below showed the species composition across the sampling sites. The sites were dominated mostly by *Rhizophora stylosa* with varying diameter and height in each plantation sites. The 7-year-old plantation showed the highest number of stems with maximum of 98 stems followed by 10-year-old plantation with 58 stems. As for the diameter, 15-year-old plantation has the highest average DBH with the value of 8.32 cm. Same with the height of trees, the 15-year-old plantation has the value of 12-13 meters range. The 15-year-old plantation was expected to have the largest DBH and highest stands because of its older age. Figure 10.1 showed the general view of the different plantations sampling sites.

Figure 10.1. General view of the mangrove plantations. A) 10 years b) 7 years c) 15 years.



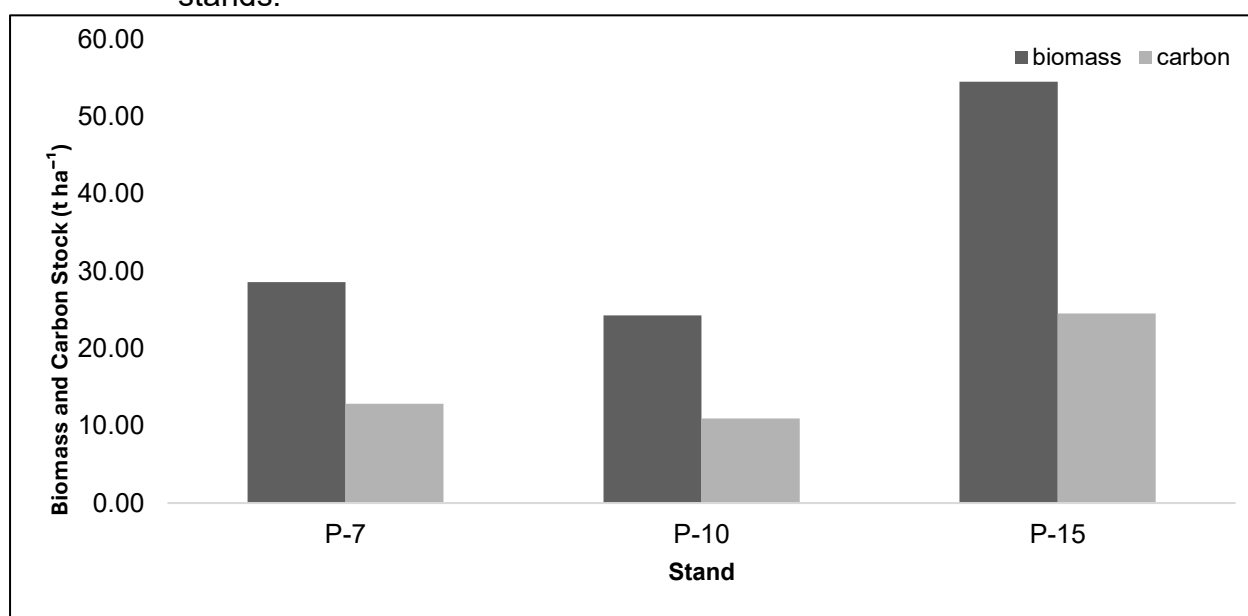
Table 10.1

Stand Characteristics and Stem Density of *Rhizophora stylosa* Plantations Across Sampling Sites

Stand	Stems per plot	DBH range (cm)	Average DBH (cm)	Height Range (m)
P-7	82 – 98	3.20-4.30	3.81	5.0-6.0
P-10	36 – 58	4.16-6.21	5.09	10.0-11.0
P-15	37 – 55	8.07-8.20	8.32	12.0-13.0

Note. DBH = diameter at breast height. P-7, P-10, and P-15 represent 7-year-old, 10-year-old, and 15-year-old *Rhizophora stylosa* plantations, respectively.

Figure 10.2. Summary of biomass and carbon stock across different plantation stands.



Note. Biomass and carbon stock values are expressed in tons per hectare (t ha^{-1}). The 15-year-old plantation (P-15) recorded the highest biomass and carbon stock among the sampled stands.

Biomass and carbon storage

Figure 10.2 showed the summary of biomass and carbon stock across the three plantation sites which highlighted the 15-year-old plantation have largest biomass with 54.50 ton^{-1} and carbon stock with 38.67 ton^{-1} . These values are supported by large DBH (8.07-8.20cm) and height range of 12.0-13.0 m. Despite that 7-year-old plantation has higher number of stem counts, it has still smaller DBH range (3.2-4.3)

compare to the 10-year-old and 15-year-old plantation. Among the sampling sites, Plot 3 in P-15 has the largest biomass estimates with 85.94 ton⁻¹ and carbon stock with 38.67 ton⁻¹.

Surprisingly, the 7-year-old plantation has higher biomass and carbon stock values compare to 10-year-old plantation with bigger tree diameter. This observation can be attributed to the higher number count of stems with 82-98 stems per plot compare to 36-58 stems per plot of 10-year-old plantation. The 15-year-old plantation also have fewer stems per plot (37-55), but it has the largest range of tree diameter and height. On average, the total biomass and carbon stock in P-7 were 28.59 ton⁻¹ and 12.86 ton⁻¹, respectively. While, the biomass and carbon stock of P-10 were 24.28 ton⁻¹ and 10.92 ton⁻¹, respectively. In general, the biomass and carbon stock follow this trend: P-15 > P-7 > P-10. In addition, younger trees showed higher resilience and full recovery to typhoon damage in just two years compared to larger trees that can impacted by strong winds. Larger and old trees also decrease its capacity to epicormic sprouts needed for recovery (Villamor et al., 2016 & Primavera et al., 2016).

Table 10.2

Biomass and Carbon Stocks of *Rhizophora stylosa* Plantations in Old Caaluan, Tinambac, Camarines Sur

Stand	Above Ground		Root		Total	
	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)
P-7						
Plot 1	11.07	4.98	3.61	1.63	14.68	6.61
Plot 2	32.28	14.53	9.09	4.091	41.37	18.62
Plot 3	22.58	10.16	7.13	3.21	29.71	13.37
Average	21.98	9.89	6.61	2.97	28.59	12.86
SD	10.62	4.78	2.78	1.25	13.380	6.02
P-10						
Plot 1	4.19	1.89	1.46	0.66	5.65	2.54
Plot 2	48.57	21.86	12.78	5.75	61.35	27.61

Stand	Above Ground		Root		Total	
	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)
Plot 3	4.26	1.92	1.58	0.71	5.84	2.63
Average	19.01	8.55	5.27	2.37	24.28	10.93
SD	25.60	11.52	6.50	2.93	32.10	14.45
P-15						
Plot 1	30.48	13.72	8.96	4.03	39.44	17.75
Plot 2	29.86	13.44	8.27	3.72	38.13	17.16
Plot 3	68.52	30.84	17.42	7.84	85.94	38.67
Average	42.95	19.33	11.55	5.20	54.50	24.53
SD	22.14	9.96	5.10	2.29	27.23	12.25

Note. Biomass and carbon values were estimated using the allometric equations of Komiyama et al. (2005) and converted using the IPCC default carbon conversion factor of 0.47. Values represent the mean and standard deviation (SD) of three sampling plots. P-7, P-10, and P-15 refer to 7-year-old, 10-year-old, and 15-year-old *Rhizophora stylosa* plantation stands, respectively.

Table 10.3

Comparison of Biomass and Carbon Stocks Between *Rhizophora stylosa* Plantations in Old Caaluan, Tinambac, Camarines Sur and Banacon Island, Bohol

Note. Old Caaluan values were derived from the present study using the allometric

Old Caaluan, Tinambac, CamSur			Banacon Island, Bohol		
<i>(This Study)</i>			<i>(Camacho et al, 2011)</i>		
Plantation Stand Age	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)	Plantation Stand Age	Biomass (t ha ⁻¹)	Carbon (t ha ⁻¹)
P- 7	28.59	12.86	P-15	462	208.5
P- 10	24.28	10.93	P-20	149.5	331.9
P- 15	54.50	24.53	P-40	823.7	370.7

equations of Komiyama et al. (2005). Banacon Island values were adapted from Camacho et al. (2011). Biomass and carbon stocks are expressed in tons per hectare (t ha⁻¹). Stand ages between study sites are not directly equivalent and are presented for comparative benchmarking purposes only.

From the same study of Camacho et al (2011), they also conducted biomass and carbon stock assessment on mangrove plantation in Banacon, Bohol. Their findings showed higher biomass and carbon stock compare to the findings of this study. This was mainly because they have larger scope of study site and the age of the stands are older. The 40-year-old plantation has already accumulated a biomass

of 823.7 ton-1 and carbon stock of 370.7 ton-1. The age of plantation was directly correlated to the biomass and carbon stock acquired by the mangroves. In addition, the P-15 stand from the study of Camacho also has higher biomass (462 ton-1) and carbon stock (208.5 ton-1) compare to the P-15 this study with biomass of 54.50 ton⁻¹ and carbon stock of 24.53-1. This difference was attributed to the higher number of stems per plot and larger tree diameter. There were also environmental factors that affect the growth of mangrove plantations such as topography, hydrology, erosion, and exposure to wave action (Kaly and Jones 1998; Samson and Rollon 2008). Other studies that measured also the biomass and carbon stock assessed a natural mangrove forest which was difference with this study that only focuses on *Rhizophora* species, which was used as the plantation material. In the findings of Lesaca et al. (2025), *Rhizophora* species were the dominant species in both sites. *Rhizophora apiculata* had the highest tree biomass (6,493.17 kg and 1,569.60 kg) and carbon storage (3.12 Mg ha⁻¹ and 0.737 Mg ha⁻¹) in Cantiasay and Nonoc of Surigaos City, respectively. While the result from the study of Buncag et al. (2025) of mangrove forest in Zamboanga Del Norte, showed that the estimated total aboveground biomass of the mangrove is 253.47 Mg/ha-1 equivalent to the aboveground total carbon stock which is 114.06 Mg C/ha-1. Both finding highlight the vital role of mangrove forests in carbon storage and their contribution to the reduction of carbon dioxide deposits.

Mangrove ecosystem across Southeast Asia differs in terms of species composition, sediment, hydrology, and restoration management. Hence, management efforts can help in determining practices that can store the highest carbon. Mangroves in Southeast Asia can be stored as much as much as $544 \pm 29 \text{ Mg C ha}^{-1}$ on average, higher than many other tropical regions (Rahman et al., 2024). With such comparison of mangrove carbon sequestration across Philippines, Indonesia, and

Vietnam, stakeholders can determine which mangrove species can sequester more carbon, plan on how a site can efficiently store more carbon, and identify the most effective strategy for long-term carbon storing. Despite large mangrove areas covered in Southeast Asia, it was also subjected to high anthropogenic threats such as deforestation, aquaculture, and coastal development. With such pressures, restoration efforts should focus on budget allocation for protection, prioritize high impact restoration sites, and integrate mangrove conservation in climate strategies of local government units.

Soil analysis for carbon sequestration was not included in the study but some studies discussed on how the soil also contributed to the total carbon stored within a mangrove forest. In the findings of Ucat and Tampus (2024), the mean soil carbon estimated across the three sites was 917.23 Mg ha⁻¹. Camiguin recorded the highest soil carbon content (491.78 Mg ha⁻¹), accounting for more than half of the total average across all sites, followed by Cagayan de Oro City (224.85 Mg ha⁻¹) and, least Laguindingan (200.60 Mg ha⁻¹). Study from Soccoro, Surigao Del Norte also showed a large amount of carbon stored on the mangrove soil with 489 Mg ha⁻¹ within its 100 cm top layer. The carbon stored in this mangrove area was higher compared to a terrestrial forest (Salvador et al., 2022). The two mentioned studies reflected the additional capacity of mangrove soil in carbon sequestration giving the idea of the power of a mangrove forest to store carbon, thus protection from land conversion should be considered to prevent release of large carbon to the environment.

Interview Responses of the Residents and Bantay Bakawan on the Mangrove Plantation of Barangay Old Caaluan, Tinambac.

(A. Palaad, personal communication, May 3, 2026)

According to Mr. Palaad, barangay captain, the El Verde program of the Provincial Government of Camarines Sur started last 2011. Before that year, typhoons washed out their houses because of the lack of protection from mangroves, serving as barriers from strong wind and waves. He highlighted the results of the El Verde program which were:

- Add livelihood to constituents
- Protection in coastal flood and storm surge
- Good for their fishing harvest and shell collection
- Supported their livelihood where they had supported their children for the education
- Food for work program of the province in where they can already sell propagules for 2 pesos from 1 peso.

The mangrove plantation also served as an educational area for students with research focusing on mangroves. There was already a barangay ordinance for strict prohibition of cutting of mangroves for house fences.

E. Bolasa Peña, personal communication, May 3, 2026

Ms. Peña, a mangrove planter, mentioned that the mangrove plantation was a big help for the residences specially it served as nursery to crabs and fishes. With the increase in mangrove stands, their fish catch also increases. Such livelihood of mangrove planting helped them in sending their children to school and for their daily expenses.

A. Arnata, personal communication, May 3, 2026

Mr. Anata, a bantay bakawan and fishermen, stated that before El Verde program, there was a low catch of fish and crabs but after the start of the program, an increase in crab catch was recorded with almost 10 – 20 kgs catch every week, averaging of income of 300 to 1,000 pesos per week.

J. Medina, personal communication, May 3, 2026

Mr. Medina, a honeybee collector, stated that mangrove pollen served as the honey for his bee farm. He can sell 10 – 15 bottles and earned at least 1,000 – 3,000 per month. Therefore, he was positive on the improvement of his livelihood from the mangrove plantation.

J. Abanicutos, personal communication, May 3, 2026

Mr. Abanicutos, a fisherman, planter, and beekeeper, stated that their livelihood improved through the mangrove plantation. He explained that shell collection increased, and he was able to sell about 18–20 bottles of honey per day, with an additional 150 bottles produced from mangrove flowers.

S. Brazal, personal communication, May 3, 2026

Ms. Brazal, a planter, shell collector, and wife of a Bantay Bakawan member, shared that they planted 60 sacks of propagules across the mangrove plantation area. With the support of the El Verde program, her family was able to harvest clams, mussels, krill, and fish, noting an increased yield in seafood catches. She emphasized that this livelihood helped her children graduate from college.

P. Eligoyos, personal communication, May 3, 2026

Mr. Eligoyos, a fisherman and planter, explained that before the mangrove program, fish catches were scarce. After the program began, he observed a notable increase in fish harvests. He also emphasized the importance of mangroves in providing coastal protection during typhoons.

Integrating mangrove carbon stock into local climate change strategies

A) Translate carbon data into strategic action

Use the carbon baseline and projections to identify priority actions and quantify expected mitigation (tCO₂ avoided or sequestered) and adaptation benefits:

- Protection (avoid emissions from conversion) — often highest near-term mitigation. There is no more conversion of mangrove to fishpond and continuous protection by the Bantay Bakawan. A barangay ordinance also strengthened this protection from illegal loggers.
- Restoration / reforestation — longer term carbon gains + coastal protection. There is a continuous mangrove plantation specially on those abandoned fishponds by the planters and Bantay Bakawan.
- Sustainable management (harvest rules, fisheries integration). A policy on catch control like close season fishing can help in a yield increase of fish catch as the fishes have time to repopulate ensuring sustainability.

B) Embed into local planning & budgets

- Add mangrove actions into Local Climate Action Plans / Land Use Plans / Disaster Risk Reduction (DRR) plans. Bigger budget can be used for

additional Bantay Bakawan or increase in their honorarium as well as for their equipment used for roving.

- Align with existing agencies (forestry, coastal resource management, municipal planning office and environmental office of LGU Tinambac). Use national guidance if available (e.g., DENR/Forest Management Bureau guidance where relevant).

C) Community and Governance

- Engage local communities from design through monitoring -they're often the rights-holders and can help with field data and enforcement. Co-design livelihood alternatives where protection restricts extractive use. Strengthening Bantay Bakawan by adding members can help in monitoring specially on violators apprehension against illegal loggers. They can also be trained on how to assess the community structure of the mangrove plantation with the help of the DENR and Academe.

Policy Development Framework for Livelihood and Incentives in Mangrove

Management Programs

Table 10.4.

Proposed Framework Linking Mangrove Management Zones to Livelihood Opportunities and Incentive Mechanisms

Mangrove Zone	Management Goal	Allowable Livelihood Activities	Policy Incentives
Zone A: Strict Protection Zone	Conservation of primary growth forest, biodiversity, and carbon storage	(Non-Extractive Use) Ecotourism Researches Activities Beekeeping	Performance-based cash incentives for Bantay Bakawan stewards engaged in

Mangrove Zone	Management Goal	Allowable Livelihood Activities	Policy Incentives
			mangrove protection and monitoring
Zone B: Sustainable Use	Sustainable Fisheries Management	(Extractive) Mud Crab Culture Shellfish Collection Sustainable Nipa Harvesting	Issuance of long-term Mangrove Stewardship Contracts to qualified and compliant community members, subject to applicable environmental regulations
Zone C: Restoration Zone	Reforestation efforts	(Paid Labor) Nursery Management Mangrove Out-Planting Activities	Cash-for-work incentives for nursery management, mangrove planting, and site maintenance activities

Note. The proposed framework is adapted from principles of community-based forest management, mangrove zonation, and ecosystem-based livelihood development. Incentive mechanisms are presented as policy options for consideration by local government units and relevant management agencies.

The table above outlines a zoning-based management framework for mangrove areas, designed to balance environmental conservation, sustainable livelihoods, and community incentives. The mangrove ecosystem is divided into three zones, each with specific goals, allowable activities, and policy support mechanisms.

Zone A: Strict Protection Zone focuses on the conservation of primary mangrove forests, biodiversity protection, and carbon storage. Only non-extractive activities are allowed, such as ecotourism, scientific research, and bee-keeping. To

encourage community participation in protection, incentives include direct cash transfers to mangrove stewards (Bantay Bakawan).

Zone B: Sustainable Use Zone allows regulated extractive activities while ensuring long-term resource sustainability. Livelihoods include mud crab culture, shellfish collection, and nipa harvesting, all subject to fish catch regulation. A key incentive is the issuance of 25-year Mangrove Stewardship Contracts, granting exclusive harvest rights to compliant families, promoting accountability and stewardship.

Zone C: Restoration Zone is dedicated to reforestation and rehabilitation of degraded mangrove areas. Activities are labor-based and include nursery management and mangrove out-planting. Communities are incentivized through paid labor and wages for planting saplings, supporting both ecosystem recovery and local employment.

Overall, the framework emphasizes ecosystem protection, sustainable resource use, and community-based management, ensuring that conservation efforts are socially inclusive and economically viable.

Government Perspective for the Zoning Framework

The Five-Point Environment and Natural Resources Management Agenda of the Provincial Government of Camarines Sur (CamSur) has the following components:

1. Rehabilitation of disturbed and denuded ecosystems
2. Establishment of conservation sites and strengthening of the management of key ecosystems
3. Effective implementation of environmental laws and related policies
4. Genuine grass roots engagement in environmental governance

5. Development of multiple use production forest and coastal resource-based enterprises

Implementing Strategies

1. Use of native and endemic tree species only in forest rehabilitation activities.
2. Entering into co-management agreement and strengthening partnership with the Department of Environment and Natural Resources (DENR)
3. Strengthening and mobilization of community volunteer teams to assist in biodiversity conservation activities
4. Giving of priority to local, non-governmental, and people's organizations with genuine conservation and developmental agenda in undertaking various projects.

The agenda and strategy mentioned above was lifted from the DENR Book- Climate Change Adaptation Best Practices in the Philippines with key highlights on the implementation of policies regarding environmental protection. The strategy mentioned the partnership with DENR and local community to strengthened the implementing capacity and monitoring of conservation efforts to different ecosystems such as the mangrove forest in Barangay Caaluan.

In relation to the vision of Camarines Sur to be an Environment friendly province, the provincial government launched the El Verde Program. This large-scale environmental and socio-economic initiative launched in 2011 by the provincial government. It is widely recognized as one of the most ambitious local reforestation and climate adaptation programs in the Philippines. The program has four schemes so that it will also help the local community while protecting the environment. The said schemes were Food for Tree, Plant a Tree Study for Free, Building Communi-Trees, and Back Tree School Project.

Below are the details of each scheme under the El Verde Program.

- A. Food for Tree Package Partnership - Availled by families who are keeping nurseries, planting and maintaining their plantation of indigenous and native species in identified El Verde site in a food-for-work scheme. These families receive payment in the form of rice.
- B. Plant a Tree Study for Free - Entitles the participating youth members to college scholarship grants to both public and private universities and colleges. The tuition fee subsidy that the participants receive depends on the number of trees they planted.
- C. Building Communi-Tress - Corporate sponsors are invited to invest in communi-trees by giving a donation corresponding to the number of trees to be planted. Maintenance and supervision of the El Verde site is undertaken by the El Verde Program.
- D. Back Tree School Project - Sponsorship packages offered to individual and corporate donors willing to sponsor a drop-out student to go back to school via the El Verde Program. The only requirement is for the student to plant a certain number of trees.

The El Verde Program of Camarines Sur is a holistic environmental and development initiative that goes beyond tree planting. By combining reforestation, community engagement, and livelihood support, it addresses key issues such as deforestation, climate change, and rural poverty. Its success especially in mangrove restoration highlights the effectiveness of nature-based solutions in building resilient and sustainable communities.

XI. RECOMMENDATION AND CONCLUSION

Mangrove ecosystems are increasingly recognized for their critical role in climate change mitigation, coastal protection, and livelihood support. They served as a carbon sink storage that can mitigate climate change impact. Old Caaluan in Tinambac Camarines Sur served as the site of El Verde Mangrove Plantation program where such program helps ecologically and economically specially for the barangay community of Old Caaluan. This study focuses on the: 1) measurement of biomass and carbon sequestration capacity of the Old Caaluan Mangrove Forest; 2) establishment of scientific baseline for integrating Old Caaluan's carbon stock data into local climate action strategies and forest management planning; 3) policy development by identifying conservation-linked livelihood opportunities and incentive mechanisms for communities dependent on mangrove resources. Biomass and carbon stock were computed from the measurement of planted *Rhizophora sp.* taken from different age groups. Data showed that the sampling sites in Plot 3 in P-15 has the largest biomass estimates with 85.94 ton^{-1} and carbon stock with 38.67 ton^{-1} . This data displayed the capacity of the mangrove forest to carbon sequestration that can help in climate mitigation. Local climate strategies highlighted the ways in which mangrove carbon stock can be integrated such as translating carbon data into strategic action, embedding into local planning and budget, and engaging community in governance. Interviews were also conducted among the local stakeholders and it surfaced that the El Verde Mangrove plantation has uplifted the livelihood status of the fisherman because of the increase in seafood catch. They also added that their barangay was protected from strong waves and wind decreasing damages to their properties. A framework was also drafted for livelihood and incentives in Mangrove

Management Programs where it emphasizes ecosystem protection, sustainable resource use, and community-based management, ensuring that conservation efforts are socially inclusive and economically viable.

Conclusion

The Old Caaluan mangrove forest plantation has the capacity to store carbon and mitigate impact of climate change specially the 15-year-old plantation. Mangrove plantation also helped the local community ecologically and economically. They are protected from strong wind and waves during strong typhoon and it also provides additional income for them from the increased seafood catch. Integration of the carbon stock assessment to local climate change strategies were very important as the mangrove forest contributes to the resiliency of the Old Caaluan community specially during strong typhoons. Establishing zonation in mangrove forest enables the community to maximize the resources they can acquired from it maintaining sustainability and continuous fish resource harvest. Strict implementation on policies from the local government and barangay level are important to ensure the protection of the mangrove forest.

Recommendations

While this study provides a valuable baseline of biomass and carbon stocks for *Rhizophora stylosa* plantations in Old Caaluan, several limitations and recommendations must be acknowledged to guide future research and strengthen policy relevance:

- **Stand Age Verification:** Reliance on oral histories and community records introduces uncertainty in classifying plantation ages. Although triangulated with DENR permits, LGU archives, and photo documentation, gaps remain.

Incorporating GIS mapping and more detailed LGU records in future phases would enhance spatial precision and strengthen stand age verification.

- Carbon Pool Coverage: This phase assessed aboveground and root biomass only. Since a substantial portion of mangrove carbon is stored underground, sediment and soil organic carbon sampling should be included in subsequent studies to capture the full “Blue Carbon” potential of Old Caaluan.
- Species Scope: Focusing on *Rhizophora stylosa* strengthens regional comparability but does not capture the dynamics of natural multi-species mangrove stands. Comparative analyses with nearby natural stands would contextualize *Rhizophora* performance within broader ecosystem functions and provide insights into biodiversity-carbon linkages.
- Institutional Bridging: While community and LGU participation were central, stronger alignment with DENR and provincial government programs is recommended. Formal integration with national forestry laws and climate policy frameworks will ensure that findings are not only locally grounded but also institutionally recognized and scalable.

By addressing these limitations, future research can deliver a more comprehensive estimate of carbon sequestration, reinforce methodological rigor, and expand the relevance of findings for climate policy, education, and long-term mangrove stewardship.

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