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5CR: A Conceptual Model of Collaborative Carbon Credit Initiatives for Coastal Community Resilience and Sustainable Economy in Makassar, South Sulawesi

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ABSTRAK

Penelitian ini bertujuan untuk mengukur penyerapan karbon biru, menganalisis nilai ekonomi kredit karbon, dan merumuskan model konseptual 5CR. Penelitian ini dilakukan di kawasan konservasi mangrove Lantebung dan Untia. Pengukuran dilakukan di enam titik menggunakan petak berukuran 10 × 10 meter dengan jarak transek 25 meter. Hasil Biomassa di Atas Permukaan Tanah atau Above Ground Biomass (AGB), yang dinyatakan dalam Mg C ha^{-1}, adalah sebagai berikut: Titik 1 memiliki total AGB sebesar 6,883.12 dan karbon organik sebesar 22.99%; Titik 2 memiliki total AGB sebesar 7.425,41 dan karbon organik sebesar 22.86%; Titik 3 memiliki total AGB sebesar 2.577,16 dan karbon organik sebesar 23.97%; Titik 4 memiliki total AGB sebesar 1.335,79 dan karbon organik sebesar 21.26%; Titik 5 memiliki total AGB sebesar 8.809,60 dan karbon organik sebesar 19.89%; dan Titik 6 memiliki AGB sebesar total 3.697,80 dan karbon tanah sebesar 19.29%. Total nilai ekonomi karbon biru di kedua lokasi, berdasarkan konversi karbon, diperkirakan sebesar USD 2.01 juta per tahun (IDR 33.45 miliar/tahun) atau USD 33.48 ribu per hektar per tahun (IDR 55.80 juta/ha/tahun). Konsep 5CR berfungsi sebagai kerangka kerja konseptual yang terdiri dari jaringan kolaborasi karbon biru, manajemen pengetahuan, dan penggerak. Kerangka kerja 5CR didukung oleh lima kegiatan utama untuk meningkatkan ketahanan masyarakat pesisir: kesadaran dan pendidikan kredit karbon, penguatan kolaborasi masyarakat pesisir, ketahanan mangrove dan peningkatan karbon biru, sistem pemantauan digital dan pelacakan karbon, serta ketahanan masyarakat pesisir yang berkelanjutan dan ekonomi kredit karbon. Untuk saat ini, konsep ini merupakan tawaran dari para penulis dan belum diimplementasikan.

***Kata kunci**:* Karbon Kredit, Lantebung, Mangrove, Pesisir, Untia

ABSTRACT

This study aims to measure blue carbon absorption, analyze the economic value of carbon credits, and formulate a conceptual 5CR model. The research was conducted in the mangrove conservation areas of Lantebung and Untia. Measurements were carried out at six points using 10 × 10 meter plots with 25 meter transect spacing. The results of Above Ground Biomass (AGB), expressed in Mg C ha^{-1}, were as follows: Point 1 had an AGB of 6,883.12 and organic carbon of 22,99%; Point 2 had an AGB of 7.425,41 and organic carbon of 22.86%; Point 3 had an AGB of 2.577,16 and organic carbon of 23.97%; Point 4 had an AGB of 1,335.79 and organic carbon of 21.26%; Point 5 had an AGB of 8,809.60 and organic carbon of 19.89%; and Point 6 had an AGB of 2.697,80 and soil carbon of 19.39%. The total economic value of blue carbon in both locations, based on carbon conversion, was estimated at USD 2.01 million per year (IDR 33.45 billion/year) or USD 33.48 thousand per hectare per year (IDR 55.80 million/ha/year). The 5CR concept serves as a conceptual framework consisting of blue carbon collaboration networks, knowledge management, and an enabler. The 5CR framework is supported by five key activities to enhance coastal community resilience: carbon credit awareness and education, strengthening collaborative coastal communities, mangrove resilience and blue carbon enhancement, digital monitoring and carbon tracking systems, and sustainable coastal community resilience and carbon credit economy. As for now, the concept is offered by the writers and has not yet been implemented.

Keywords: Carbon Credit, Coastal, Lantebung, Mangrove, Untia

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1. INTRODUCTION

Carbon dioxide (CO_2) gas emissions in the atmosphere are produced from industrial activities through the process of burning fossil fuels over a long period of time, thus causing global warming (IPCC, 2022). Industrial sectors such as power plants and manufacturing collectively release CO_2 into the air in large quantities, thereby not only exacerbating the effects of global warming but also triggering climate change (Yang *et al*., 2023). According to research from (Pangestu & Ayuningsasi, 2024), the energy and industrial sectors are responsible for more than 70% of total CO_2 emissions in the world.

Research from (Fitria 2021) states that mangrove forests can absorb 3 to 5 times CO_2 compared to tropical forests. Mangroves have an important role in reducing the impact of global climate change through the process of photosynthesis, by absorbing CO_2 and then releasing oxygen (O_2) into the atmosphere. The absorbed CO_2 is converted into organic carbon that is stored in the soil, leaves, and stems of mangroves (Boone Kauffman *et al*., 2017). Mangrove sediments even have the ability to store carbon (C) in large quantities for thousands of years, making mangrove forests an appropriate choice to reduce the impact of climate change (Macreadie *et al*., 2021).

Mangroves have an important role for coastal communities as natural protectors from sea waves by reducing the strength of waves that hit the coast, as occurred in several locations after the Aceh tsunami (Taillardat, Friess, and Lupascu 2018). Mangrove roots also function as natural nets that slow down water currents and prevent abrasion (Menéndez *et al*., 2020). In addition, mangroves serve as a source of livelihood for many fishermen and fishpond farmers (Lukman *et al*., 2022). The mangrove ecosystem becomes a breeding ground for fish, shrimp, and crabs, which are then caught by local fishermen (Nagelkerken *et al*., 2008). Furthermore, shrimp and crab ponds that are well-managed around mangrove forests provide income for coastal communities (Bryan-Brown *et al*., 2020).

Human activities have a significant impact on the mangrove ecosystem through the conversion of mangrove forests into pond areas, thus contributing to global climate change (Donato *et al*., 2011). In addition, the mangrove ecosystem plays an important role in protecting coastal areas and supporting marine biodiversity (Ward *et al*., 2016). Two main factors causing the decline of mangrove forest area worldwide are deforestation and land conversion into aquaculture areas, such as shrimp ponds (Bhowmik *et al*., 2022). Moreover, domestic and industrial waste can damage the productivity and health of mangroves, disrupt nutrient cycles, and endanger the living organisms within them (Alongi 2008). As a result, the degradation of this ecosystem threatens the lives of coastal communities and increases their vulnerability to natural disasters and coastal erosion (Marois and Mitsch 2015).

One of the efforts to ensure the sustainability of mangrove ecosystems is through the Ecosystem Services Payment (ESP) scheme. Companies or industries that produce CO_2 emissions are obliged to pay ecosystem service fees to countries that possess mangrove forests in the form of environmental compensation (Malik *et al*., 2025). In Indonesia, this scheme is regulated under the (Law of the Republic of Indonesia No. 32/2009) each ton of carbon absorbed by mangroves has a tangible economic value in the global market. The price of carbon in the voluntary carbon market ranges from US$5 to US$50 per ton or equivalent to Rp80,000–Rp800,000 per ton of CO_2, depending on the quality and location of the project. Several studies estimate that the economic value of mangrove carbon in Indonesia reaches US$1,355–5,775 per hectare or equivalent to Rp 24,200,000-Rp103,100,000 per year (van Zanten *et al*., 2025). This value can have a significant impact on coastal communities if managed properly. The greatest challenge lies in developing an accurate measurement system and a benefit distribution mechanism that can be felt by all coastal communities.

The development of research on mangrove ecosystems thus far has focused on two main aspects, namely the carbon content in mangroves and the economic value of blue carbon. For instance, the study conducted by (Khan *et al*., 2025) focuses on the carbon storage capacity of mangroves in Malaysia. In addition, another study conducted by (Lu and Wang 2021) developed an automatic mangrove sample collection method. Furthermore, the study conducted by (Jupin *et al*., 2025) discusses the evaluation of temporal changes in sediments and the accumulation of organic carbon in urban mangrove forests in Mexico. Next, the study conducted by (Yang *et al*., 2025) discusses vegetation structure and mangrove carbon stocks in China. Lastly, the study by (Zanvo *et al*., 2023) examines the impact of mangrove tree harvesting intensity on carbon allocation and carbon stock. Based on the synthesis of the above studies, the focus has only been on measuring carbon stocks and economic value without discussing the mechanism of the relationship between carbon content and the economic value of mangrove blue carbon with the resilience system of coastal communities. Additionally, a sustainability concept of mangrove ecosystems, as well as strategies for ecological and economic resilience, is required.

Makassar, as a city experiencing rapid industrial development in the eastern region of Indonesia, faces serious environmental pressures due to industrial activities such as carbon gas emissions from factories, industrial waste, and land-use conversion in coastal areas driven by a high rate of urbanization. These issues have led to the degradation of coastal ecosystems. The coastal areas of Makassar contain mangrove forests in several locations, including the Lantebung and Untia mangrove areas. Both locations are designated as conservation areas. Several

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mangrove species are found in these locations, such as *Rhizophora mucronata*, *Rhizophora apiculata*, and *Avicennia marina*, which dominate the Lantebung mangrove area, while *Bruguiera gymnorrhiza* and *Sonneratia alba* are more commonly found in the Untia mangrove area.

Based on the findings from field observations and interviews with coastal communities and relevant stakeholders, it was revealed that mangrove ecosystems in these two areas face significant pressures from industrial activities, land conversion into aquaculture ponds, and residential development in coastal zones. In addition, the lack of public awareness among coastal communities regarding the ecological and economic functions of mangroves as coastal protectors, habitats for various marine species, and sources of income exacerbates the problem. If left unaddressed over time, this situation could lead to the collapse of coastal ecosystems, increased CO_2 emissions harmful to human health, greenhouse effects, and the loss of community livelihoods. These issues require serious attention and comprehensive assessment through collaboration among various stakeholders.

This research aims to measure the carbon absorption capacity of mangroves in the Lantebung and Untia mangrove areas and analyze the economic value of the blue carbon stored within them. Furthermore, this study intends to propose a concept called 5CR (Collaborative Carbon Credit Coastal Community Resilience) to design a more effective coastal ecosystem protection scheme. Through this scheme, blue carbon economic incentives are directed toward enhancing the economic resilience of coastal communities by providing alternative, sustainable sources of income. Consequently, coastal communities will gain greater awareness and refrain from environmentally damaging practices. The findings of this study are expected to serve as a foundation for governments and industry sectors to formulate conservation policies that drive sustainable business practices, while realizing the 5CR model for replication in other regions.

Therefore, this research investigates the carbon stock valuation and economic value of blue carbon in the Lantebung and Untia mangrove ecosystems, as well as how this valuation can be allocated through the 5CR model to enhance sustainable coastal economic and ecological resilience.

2. RESEARCH METHOD

2.1. Description of the Research Location

The research location is located in the Lantebung mangrove conservation area and in Untia mangrove conservation area, both areas are on the northern coast of Makassar City. Based on data from the Makassar City Government (Khairul *et al*., 2023), the mangroves in Lantebung cover an area of 12 hectares (Ha), dominated by mangrove species such as *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia marina,* and *Avicennia alba*. Meanwhile, the Untia mangrove area covers approximately 48.19 Ha (Arfan, Sanusi, and Rakib 2023). The dominant mangrove species in the Untia mangrove area is *Bruguiera gymnorrhiza*.

2.2. Interview

The method used is a qualitative method with an interview research approach. An interview is a method in which direct communication occurs between two or more people aimed at obtaining new information or clarifying a matter; this method is most commonly used to gather information from respondents or informants (Salsabila, B. *et al*., 2024). In this study, a total of 11 respondents were interviewed using a semi-structured interview method, which provides room for respondents to offer more varied answers (Kamaruddin, I. *et al*., 2023). Based on the interview results, it was found that Lantebung is an area currently facing pressure from industrial expansion, land conversion into aquaculture ponds, and coastal residential development. Furthermore, the community in Lantebung tends to overlook the economic and ecological functions provided by mangroves, such as serving as protection against abrasion, an ecosystem for various marine species, and a carbon absorber.

2.3. Data Collection Method

2.3.1. Plot Determination

Lantebung mangrove area, we established a total of 4 plots: 2 plots for *Avicennia marina* and 2 other plots for *Rhizophora mucronata*. Meanwhile, in the Untia mangrove area, we established 2 plots for the mangrove species *Bruguiera gymnorrhiza*. So, the total number of plots at both locations is 6. Each plot has an area of 10 x 10 meters (m^2), with transect distances between plots of 25 meters. The method used in this study involves establishing 1 representative plot for every 10 hectares; thus, 6 plots are considered representative of 60.19 hectares. Each plot was measured using a measuring tape, and its position was marked using the global positioning system (GPS) (Kauffman JB and Donato DC, 2012).

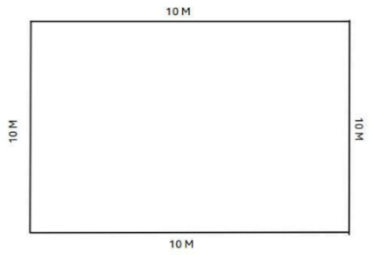


Figure 1. Plot Size

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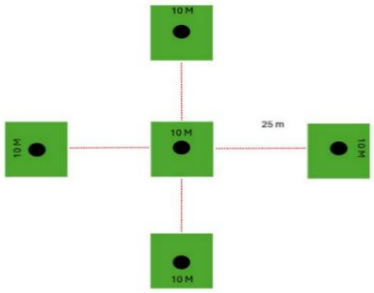


Figure 2. Plot Layout (Kauffman JB and Donato DC, 2012)

2.3.2. Soil Organic Carbon Sampling

In each plot, 7 sampling points were taken using the zig-zag method with a soil auger at a depth of 0-30 cm (as shown in Figure 4). We collected soil carbon samples at a depth of 0-30 cm because this layer contains the largest percentage of the total carbon stock stored in the first meter of sediment (Dali *et al*., 2023). Sampling was focused on soil collection because the proportion of carbon stored in the soil is highly dominant, accounting for 85-90% of the total ecosystem carbon stock (Donato *et al*., 2011).

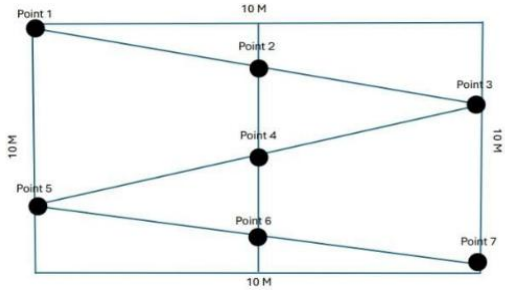


Figure 4. Soil Organic Carbon Sampling Points

2.3.3. Diameter at Breast Height (DBH) Sampling

The measurement of the main stem diameter of trees was conducted at a height of 1.37 m above the ground surface, commonly referred to as Diameter at Breast Height (DBH). For trees with roots exceeding 1.37 m above the ground surface, the stem diameter was measured directly above the roots. DBH was measured using a diameter tape. The criteria for including trees were as follows: Trees numbered 1-5 were considered absolutely inside the plot, No. 6 was considered inside the plot because most of the trees were within the plot area, while trees numbered 7-9 were clearly outside and not counted (Ahmed *et al*., 2023).

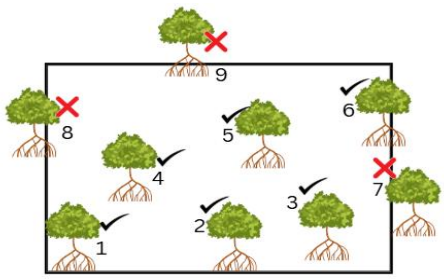


Figure 5. The Tree Selection Criteria (Ahmed *et al*., 2023)

2.3.4. Tree Density

Based on Malik *et al*., (2025), species density, individual tree basal area, and total tree basal area were calculated using equations (1-3):

$$D = \frac{ni}{A} \quad (1)$$

$$ba_1 = \pi\, x\, ((\frac{1}{2})DBH)^2 \quad (2)$$

$$BA = \sum ba_1 \quad (3)$$

where:

D = Individual species density (ind. m^{-2})
ba_1 = Individual tree basal area (m^2 ha^{-1})
BA = Total tree basal area per hectare (m^2 ha^{-1})
ni = Number of individual stand species
A = Total area of sample subplots per plot
DBH = Diameter at breast height (cm)

2.4. Data Analysis

2.4.1. Reserve Carbon and Biomass Stocks Above Ground and Soil

General allometric equation that is commonly used to estimate above-ground biomass (AGB) (Komiyama, Poungparn, and Kato 2005) (Komiyama, Ong, and Poungparn 2008):

$$AGB = 0.251 \times (DBH)^{2.46}$$

DBH is the diameter at breast height (cm), and AGB is the biomass (kg). Because species-specific models for local or regional species and appropriate wood densities for all species have not been developed and established, this general equation and wood density are used. To obtain biomass carbon stock per unit area (Mg C ha^{-1}), we multiplied the biomass by the commonly used carbon proportion of 0.47 per unit area.

2.4.2. Reserve Soil Carbon Stocks

Soil carbon was analysed using the Loss on Ignition (%LOI) method. Before weighing, the soil samples were allowed to cool to room temperature after being dried at 60°C for at least 72 hours to maintain a stable weight. Weighing the cooled samples allowed us to determine their bulk density. The mass (g) of the oven-dried soil samples was divided by their volume (cm^3) to calculate the bulk density (g cm^{-3}).

$$Soil\ bulk\ density\ (gcm^{-3}) = \frac{oven{-}dry\ sample\ mass\ (g)}{(ample\ volume\ (cm^3)}$$

Each sample contained 20 grams of subsample dried in an oven, which was burned for five hours at a temperature of 540°C in a muffle furnace (AAF 11/7, Wolf Laboratories Limited, UK). The organic matter content is expressed as a percentage (%LOI) based on the difference between the dry weight and the burned weight (loss on ignition, or LOI) as

$$\%LOI = \left[\frac{dry\ mass\ before\ combustion - dry\ mass\ after\ combustion}{dry\ mass\ before\ combustion}\right] \times 100$$

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Soil carbon density is calculated as

$$Soil\ carbon\ (Mg\ ha^{-1}) = bulk\ density\ (g\ cm^{-3}) \times soil\ depth\ interval\ (cm) \times \%C$$

The following formula, proposed by (Kauffman JB and Donato DC. 2012), is used to determine the percentage of organic carbon (% C):

Organic carbon concentration (% C) = 0.415 x % LOI + 2.89

2.4.3. Credit Carbon Price

Based on (Farahisah, Yulianda, and Effendi 2021), the Environmental Defense Fund determines the economic value of mangroves in estimating the carbon price, which is used to refer to the Social Cost of Carbon. With that said, 50 USD is the price that has been set per ton of carbon that we use for the calculation at the end. Now, the conversion of 1 USD to rupiah is Rp. 16,600. Meanwhile, the price of carbon that we use is based on the voluntary market price and the mandatory market price for the clean development mechanism are Rp. 84,000.00/tCO2e and Rp 219,520.00/tCO2e, which is referred to as the carbon price estimate.

3. RESULT AND DISCUSSION

3.1. Result

We have conducted research at a total of 6 points across 2 locations, namely Lantebung and Untia. The first to fourth points are in Lantebung with 2 different types of mangroves, while the fifth and sixth points are in Untia with the same type of mangrove. Therefore, the total number of mangrove types studied is 3. Description of the location of each point explained in Table 1.

Point 1, observed at 10:00 a.m., is located near the sea with fairly wet conditions due to low tide. The mangrove vegetation at this site reaches approximately 14 meters in height. Point 2, situated to the left of Point 1 and close to a residential area, was observed at 10:45 a.m. under drier conditions, with mangroves reaching around 20 meters in height. At Point 3, observations were made at 1:53 p.m., where the area was very wet and muddy. Point 4, observed at 2:32 p.m., showed similar conditions, with mangroves at both points reaching around 23 meters in height. At the next research location, namely the Untia area, Point 5 was observed at 4:43 p.m. under dry conditions with mangroves about 23 meters tall. Meanwhile, Point 6, located near the sea and observed at 5:00 p.m., also exhibited dry conditions. The results of Above Ground Biomass (AGB) Point 1 had an AGB of 6,883.12 Mg C ha^{-1}, Point 2 had an AGB of 7.425,41 Mg C ha^{-1}, Point 3 had an AGB of 2,577.16 Mg C ha^{-1}, Point 4 had an AGB of 1,335.79 Mg C ha^{-1}, Point 5 had an AGB of 8,809.60 Mg C ha^{-1}, Point 6 had an AGB of 3,697.80 Mg C ha^{-1}.

Point 1 had an organic carbon of 22.99%, Point 2 had an organic carbon of 22.86%, Point 3 had an organic carbon of 23.97%, Point 4 had an organic carbon of 21.26%, Point 5 had an organic carbon of 19.89%, and Point 6 had an organic carbon of 19%.

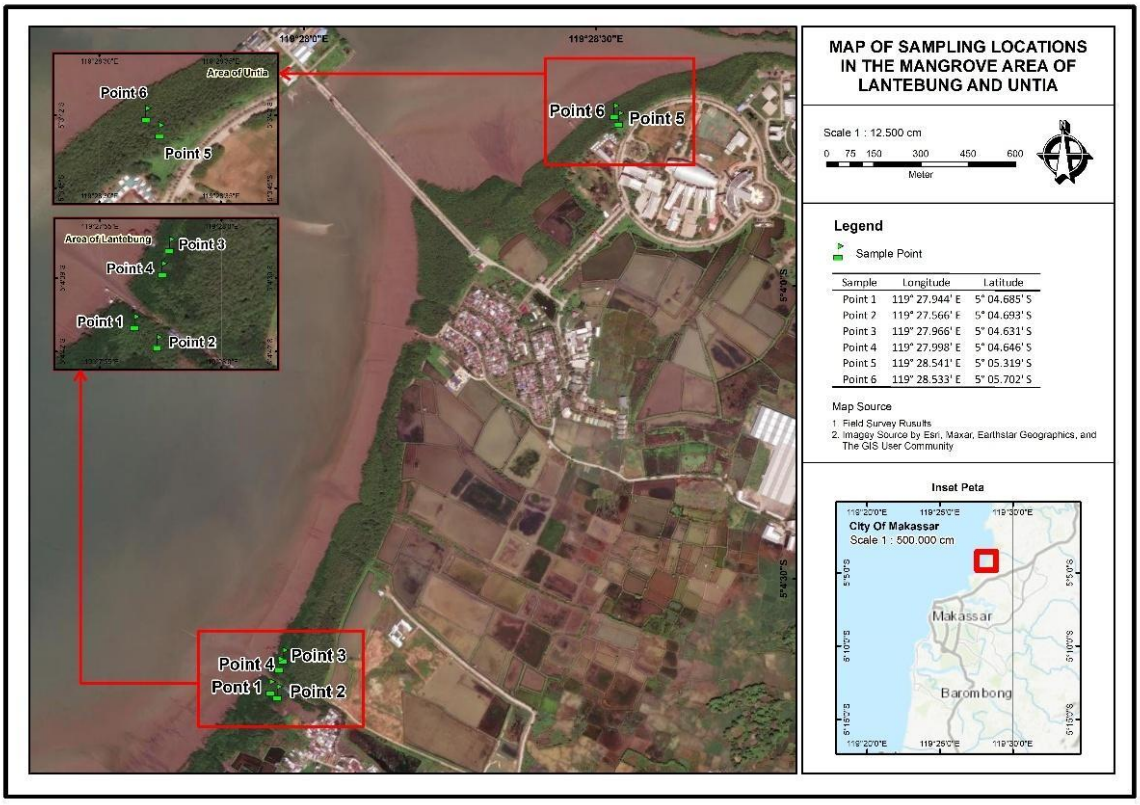


Figure 3. Research Location

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Table 1. Structure and Composition of Mangrove Forests

Plot	Species	n	Number of trees (tree ha-1)	D (ind. m-2)	DBH (cm)	H(m)	Ba (m2ha-1)	AGB (Mg C ha^{-1})
Point 1 05° 04.685' S 119° 27.944' E	AvM	48	480	0.48	28.24	14	67.83	152.9
Subtotal		**48**	**-**	**21.6**	**1271**	**-**	**3050.23**	**6883.12**
Point 2 05° 04.693' S 119° 27.956' E	AvM	22	220	0.22	39.36	20	129.89	337.51
Subtotal		**22**	**-**	**4.84**	**3408**	**-**	**8958.11**	**7425.41**
Point 3 05° 04.631' S 119° 27.966' E	RaM	33	330	0.33	25	23.26	50.54	78.09
Subtotal		**33**	**-**	**10.89**	**825**	**-**	**1667.79**	**2577.16**
Point 4 05° 04.646' S 119° 27.959 E	RaM	28	280	0.28	19.6	23.26	32.97	47.70
Subtotal		**28**	**-**	**7.84**	**549**	**-**	**923.20**	**1335.79**
Point 5 05° 03.715' S 119° 28.541 E	BrG	23	230	0.23	46.82	23	182.31	383.02
Subtotal		**23**	**-**	**5.29**	**1077**	**-**	**4193.18**	**8809.60**
Point 6 05° 03.702' S 119° 28.533' E	BrG	29	290	0.29	29.92	23	75.88	132.06
Subtotal		**29**	**-**	**8.12**	**838**	**-**	**2124.71**	**3697.80**

Source: Authors

AvM: Avicennia marina. RaM: Rhizophora mucronata. BrG: Bruguiera gymnorrhiza. n: individual number of species. D: density of species. DBH: diameter of breast height. H: height. Ba: basal area. AGB: above-ground biomass.

Table 2. Soil Organic Carbon

	Sampels							Subtotal
	1	2	3	4	5	6	7	
Point 1 (AvM) 05° 04.685' S 119° 27.944' E	20,51%	18,76%	27,27%	25,02%	25,02%	24,26%	20,01%	22,98%
Point 2 (AvM) 05° 04.693' S 119° 27.956' E	26,27%	20,51%	23,26%	24,26%	23,01%	22,01%	20,76%	22,87%
Point 3 (RaM) 05° 04.631' S 119° 27.966' E	20,76%	23,52%	25,77%	25.02%	22,76%	22,01%	28.01%	22,96%
Point 4 (RaM) 05° 04.646' S 119° 27.959 E	22,51%	19,01%	20,23%	20,62%	22,95%	21,78%	21,78%	21,27%
Point 5 (BrG) 05° 03.715' S E119° 28.541 E	19,84%	23,34%	12,45%	23,34%	21,01%	21,78%	17,50%	19,89%
Point 6 (BrG) 05° 03.702' S 119° 28.533' E	18,67%	18,67%	17,50%	20,23%	17,89%	23,34%	19,45%	19,39%
Subtotal								**21,56%**

Source: Authors

AvM: Avicennia marina. RaM: Rhizophora mucronata. BrG: Bruguiera gymnorrhiza

Table 3. Mangrove Economic Value

Mangrove forest area (ha)	Economic value of carbon stock mangrove (USD/year)	Economic value of carbon stock mangrove (IDR/year)	Economic value of carbon stock mangrove (IDR/year/ha)	Economic value of carbon stock in mangrove (USD/year/ha)
60.19	2.015.311,68	33.454.173.805	55.809.500	33.482,50

Source: Authors

Conversion 1 USD = 16,600 rupiah

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Based on the tested organic carbon and carbon stock in tree trunks, the carbon value can be converted into an economic value. The total blue carbon stock in tree trunks and soil reaches 2,486.98 Mg C ha^{-1}. Furthermore, the carbon stock value for the two areas is 149,671.29 Mg C with a mangrove area of 60.19 ha. Therefore, the total economic value collection in the two locations, Lantebung and Untia, based on carbon conversion, is 2.01 million USD/year (33.45 billion rupiah/year) or 55.80 million rupiah per year/ha (33.48 thousand USD/year/ha).

3.2. Discussion

3.2.1. Mangrove Blue Carbon Stock and the Economic Exchange Value

Based on the research results, a total of 183 mangrove trees were identified, consisting of three different mangrove species: *Avicennia marina* (AvM), *Rhizophora mucronata* (RaM), and *Bruguiera gymnorrhiza* (BrG). One of these three species, *Avicennia marin*a (AvM), has the largest number of trees, with a total of 70 trees. This species was also recorded as dominant at the first point in our research area, indicating that *Avicennia marina* (AvM) has a higher level of adaptation and distribution than other species at the site.

However, the research results of (Asbar and Yunus 2022) shows that *Rhizophora mucronata* is the most dominant species in their study area, with a total of 70 trees, while only 29 *Avicennia marina* trees were recorded. This difference in results may be due to variations in environmental conditions, differences in sampling points, and the timing of the study, which can affect the growth and distribution of mangrove vegetation in the area.

In contrast, (Asbar and Yunus 2022) studied in the same region, which is the Lantebung region, with the findings of just two species of mangroves, *Avicennia marina* (AvM) and *Rhizophora apiculata* (RaA), out of a total of 100 trees. These results show that our study differed from earlier research in terms of the quantity of mangrove species and individuals.

Additionally, (Asbar and Yunus 2022) also concluded that the higher the mangrove density, the greater the total carbon stored, indicating a positive correlation between density and total carbon stocks. However, our analysis did not find any significant correlation between total carbon stocks and mangrove density in our study area. This suggests that other factors, such as mangrove species, DBH, or substrate conditions, likely play a role in determining the amount of carbon stocks in the mangrove ecosystem in Lantebung. Nonetheless, the sample size is limited hence these findings describe the observed outcomes within the study sample and should not be generalized to a broader population.

A graph illustrating the relationship between depth and total gas absorption, which was greater than 0.09 tons of CO2/ha that was presented in the study by (Asbar and Yunus 2022). Although we tested carbon at a depth of 21–30 cm in our own study, the findings were greater.

Moreover, our research results show a pattern of increasing and then decreasing carbon uptake values in areas closer to the sea, particularly at points 1, 3, and 6. This pattern shows the variation in environmental conditions that influence the mangrove's ability to absorb carbon at each location point. This contrasts with the research results that showed that carbon uptake values tended to increase with closeness to the sea. This could be due to the decrease in our study of (Goll *et al*., 2012) due to the availability of nutrients such as nitrogen and phosphorus from river flow. Nevertheless, research of (Rahman, Effendi, and Rusmana 2016) found that *Rhizophora mucronata* had less biomass potential in the Tallo River than in our findings. This suggests variability in the environmental factors that affect the growth and biomass accumulation of mangroves.

The carbon credit price we used was 50 USD per ton (Farahisah *et al*., 2021). Meanwhile, research (Malik and Rahim 2022) in South Sulawesi, specifically in Barru Regency, used the 2021 carbon value of 35 USD per Mg CO_2e with an exchange rate of Rp 14,000. The study obtained an estimate of 8.62 million USD/year (Rp 122.43 billion/year) or 335.14 million rupiah/year/ha (23.60 thousand USD/year/ha) with an area of 365.30 ha, while the results of our study showed a value of 7.48 million USD/year (Rp 124.22 billion/year) or 2.06 billion rupiah/year/ha (124.34 thousand USD/year/ha). Then, in other areas such as the Karang Gading wildlife sanctuary mangrove, North Sumatra, it is IDR 83,187,215,641.00 with an area of 15,765 ha using the assumption of a carbon price of USD 10/ton and a rupiah exchange rate against the dollar of IDR 12,000 (Barus and Kuswanda 2016).

The 5CR (Collaborative Carbon Credit Coastal Community Resilience) concept diagram presents a conceptual framework proposed to achieve the sustainability of ecological and economic resilience for carbon credit projects within mangrove ecosystems. This model addresses the limitations of previous studies, which tended to focus narrowly on either carbon sequestration (Sasmito *et al*., 2020) or a restricted discussion of economic potential (Hanifa, Nurmilah, and Indrawan 2025), without integrating economic schemes that directly benefit coastal communities. Given the complexity of mangrove challenges, which necessitate a multi-stakeholder approach, the 5CR places the carbon credit collaboration network as its central element. The economic value of mangrove carbon stock is estimated at IDR 33.454.173.805 per year, highlighting its significant potential to support both conservation efforts and community-based economic development.

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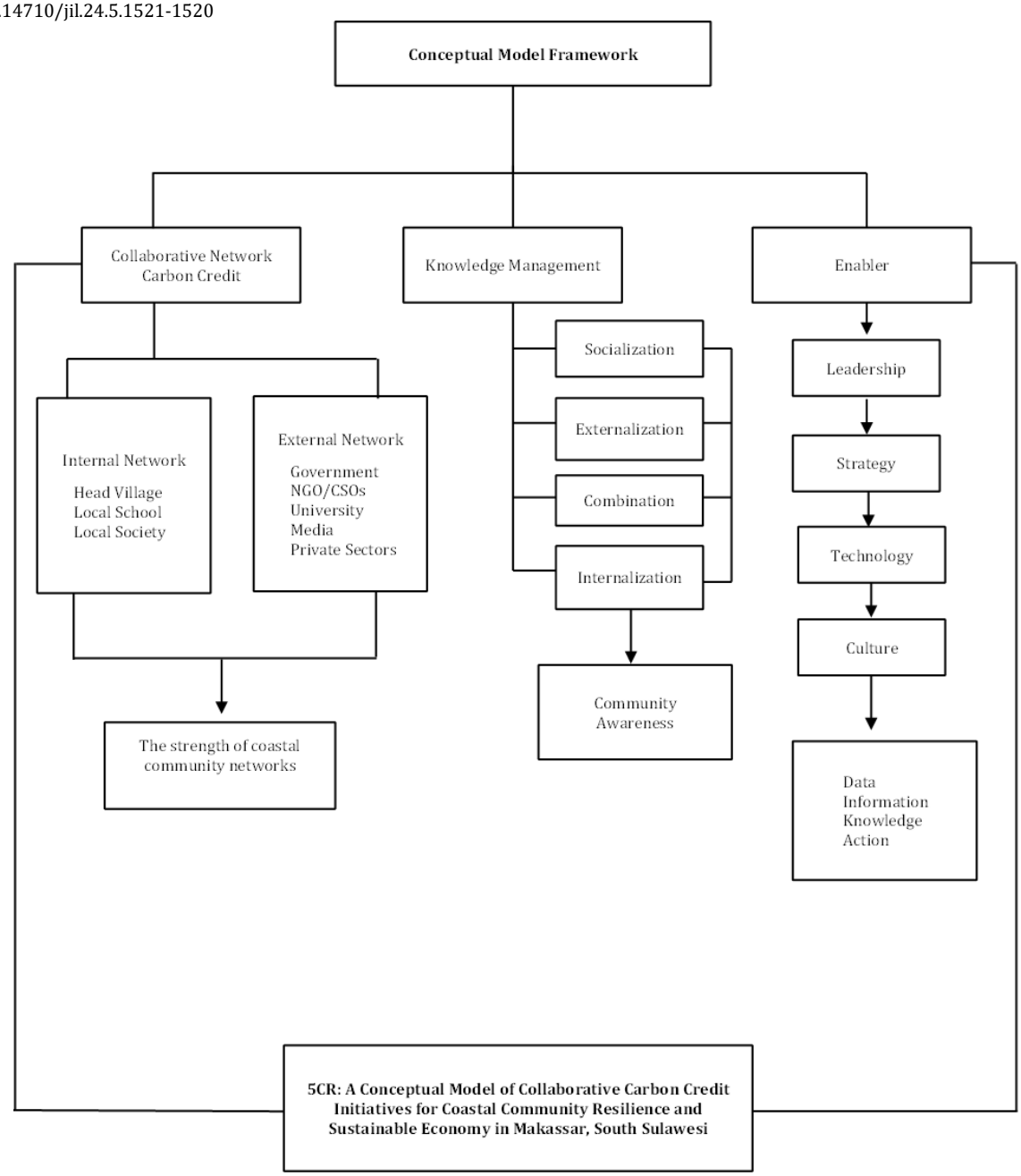


Figure 6. Conceptual Model of 5CR Flowchart

3.3. Collaborative Network Carbon Credit

The 5CR concept focuses on internal collaboration as the base for all external partnerships. It involves key local stakeholders, schools, the village head, and the community. Schools serve as centres for education and knowledge transfer across generations, through both general and government-supported curriculum tailored for coastal areas, emphasizing mangrove ecosystem importance. The community acts as volunteers and main protectors of mangrove sustainability, while the village head leads social regulation. This synergy forms a strong foundation for coastal resilience and economic stability, especially with the mangrove carbon stock valued at around IDR 124 billion annually, motivating community participation and sustainable practices. External collaboration enhances this network with broader connections and resources.

The external network includes the government, NGO/CSOs, universities or research centres, media, and the private sector. The government acts as facilitator and policy-maker through regulations supporting ecological resilience and the carbon credit economy, supported by the amount of IDR 33 billion in funding. NGO/CSOs assist and distribute support to communities, while universities offer innovation and scientific knowledge. Media raise awareness of mangrove threats from climate change and land use, promoting model replication. The private sector invests to sustain the carbon credit economy.

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Table 4. 5CR Activities for Coastal Community Resilience

Activity	Impact	Contributors
Carbon Credit Awareness and Education The transfer of knowledge and education to communities and stakeholders about the concept of carbon credits is essential to help them understand its importance and impacts. This understanding can promote the sustainability of ecological and economic resilience through mangrove ecosystem reforestation.	The increasing awareness of the importance of carbon credits, along with the rising demand in the global market and public support for conservation projects, demonstrates the growing potential of carbon credit initiatives.	University, research institution, school community, and government (the Ministry of Forestry)
Strengthening Collaborative Coastal Communities The strengthening of collaborative networks among multiple stakeholders enhances the capacity of coastal communities to sustain both economic and ecological resilience through carbon credit initiatives.	Increasing effective collaborative participation among various parties to strengthen coastal communities.	NGOs, CSOs, government, coastal community, head village, university, and stakeholders.
Mangrove Resilience and Blue Carbon Enhancement The restoration and conservation of mangrove forest ecosystems aim to enhance mangrove expansion and strengthen the resilience of coastal communities in both economic and ecological aspects.	The enhancement of blue carbon stocks in mangroves, along with coastal protection and improved biodiversity, contributes significantly to strengthening the ecological and economic resilience of coastal communities.	NGOs, government, stakeholders, university, and research institutions.
Digital Monitoring and Carbon Tracking System The application of digital technology in mangrove ecosystems, such as drones and other tools, enables efficient monitoring and tracking of mangrove growth in coastal areas.	Transparent and verifiable carbon data, as well as the efficiency of digitally monitoring mangrove ecosystems.	Technology startup, university research institution, carbon certification agency, government, NGOs, CSOs.
Sustainable Coastal Community Resilience and Carbon Credit Economy The integration of conceptual models is essential to strengthen the sustainability of carbon credit initiatives by reinforcing both ecological and economic resilience within coastal mangrove ecosystems.	Improving the sustainability of coastal community resilience and the carbon credit economy for the community, as well as resilience to the impacts of intensive climate change.	Investors, international NGOs, CSOs, the central government, the private sector, stakeholders, and the coastal community.

3.4. Knowledge Management

A collaborative network requires strong knowledge management using the SECI (Socialization, Externalization, Combination, Internalization) model (Bandera *et al*., 2017). Tacit knowledge, inherent in individuals, such as mangrove maintenance techniques, is obtained through socialization in informal community discussions. This tacit knowledge is transformed into documented knowledge (externalization) when universities help communities create written rules and learning materials. Explicit knowledge from various networks, such as research results, is then combined (Combination) to produce new knowledge, like applying the blue carbon economy for coastal communities in Makassar City and its business model. The analysed explicit knowledge is re-internalized through training and practice, increasing the network's tacit knowledge capacity. The SECI model ensures that academic and local cultural knowledge are managed to build community awareness. The significant economic value of mangrove carbon stocks further motivates effective knowledge sharing and innovation to maximize benefits.

3.5. Enabler

The success of this concept depends on several key enablers that support effective collaboration and sustainable mangrove ecosystem management. These factors are interconnected and collectively ensure that ecological conservation and economic development can be achieved in a balanced and integrated manner. First, leadership is a crucial supporting factor. Innovative and inclusive leadership is not only the responsibility of the village head but also involves community leaders and representatives from each stakeholder group within the collaboration network. Strong leadership builds trust, ensures coordination, and aligns all parties toward a shared vision of sustainability. It also plays an important role in resolving conflicts, mobilizing resources, and maintaining accountability in implementing programs and policies. Second, a clear strategy provides direction and structure. A well-designed strategy defines goals, roles, responsibilities, and measurable outcomes. It guides both short-term and long-term actions, ensuring that conservation efforts, community empowerment, and economic initiatives are carried out systematically and efficiently.

Third, technology serves as an enabling tool that enhances monitoring and decision-making. Through remote sensing, digital platforms, and data management systems, mangrove growth and environmental changes can be observed more accurately. This improves data reliability, transparency, and evidence-based planning. Finally, culture strengthens collaboration by fostering shared knowledge, mutual responsibility, and environmental awareness. A strong collaborative culture ensures sustained commitment from all stakeholders. Together, leadership, strategy, technology, and culture produce accurate information and coordinated actions, helping to realize the economic potential of mangrove ecosystems valued at IDR 33 billion annually while maintaining ecological resilience.

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4. CONCLUSION

The measurement of blue carbon stock estimation and economic exchange value in the mangrove areas of Lantebung and Untia consists of 6 plots. For the Lantebung mangrove area, there are 4 plots consisting of 2 plots of *Avicennia marina* species and 2 plots of *Rhizophora mucronata*. Meanwhile, for the Untia mangrove area, there are 2 plots with the *Bruguiera gymnorrhiza* mangrove species. In addition, the economic value of the mangrove is known to be IDR 33.454.173.805 per year.

The 5CR (Collaborative Carbon Credit Coastal Community Resilience) concept plays a role in enhancing the sustainability of the ecological and economic resilience of coastal communities. With the mangrove economic value of IDR 33.454.173.805 per year, it is expected to encourage the success of the 5CR conceptual model in realizing the sustainability of ecological and economic resilience of coastal communities. As of now, 5CR is a conceptual model that is offered by the writers for the future, but it has not yet been implemented. The 5CR model has the potential to be adapted in other mangrove areas; however, further testing and validation by local communities and stakeholders are still required. The limitation of this study is that it focuses solely on measuring the economic valuation of carbon and is restricted to the Lantebung and Untia areas. Additionally, this study utilizes only 6 sample plots, allowing future researchers to expand upon this work by using a larger number of plots and broadening the study area to obtain more accurate results.

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