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Optimization of Mangrove Ecosystem Services Based on Comparison of Stand Carbon Stock Estimates in Climate Change Mitigation

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ABSTRACT

One form of mangrove ecosystem service is carbon sequestration. The issue of carbon is an important concern for the climate change response. The purpose of this study is to determine the comparison of stand carbon stock estimates in mangrove ecosystems on the coast of East Lampung Regency (Kuala Penet Resort Mangrove Forest, Lampung Mangrove Center (LMC) Mangrove Forest, and Register 15 Mangrove Forest). The stages of research include: determination of data collection based on purposive sampling and Forest Health Monitoring (FHM) techniques; stand biomass and carbon calculations using allometric equations and the Intergovernmental Panel on Climate Change (IPCC); descriptive data analysis; and a literature study. Based on the results of the study, the highest stand carbon was in LMC (144.56 tons per ha), and the lowest was in Kuala Penet Resort (19.19 tons/ha). These conditions are influenced by stand structure factors (growing conditions, tree age, and microclimate conditions) and management schemes. The partnership is a form of stakeholder commitment as a way to maintain mangrove ecosystem services. Thus, carbon stands in coastal mangrove ecosystems of East Lampung Regency, namely Kuala Penet Resort (19.19 tons/ha), Register 15 (9.66 tons/ha), and LMC (144.56 tons/ha).

1. INTRODUCTION

Mangrove ecosystems have the characteristics of Common Pool Resource (CPR) [1], which are open access to management and utilization, so there is a need for strong institutions and legislation to regulate restrictions on the use of mangrove ecosystem resources. Mangrove ecosystems are directly adjacent to the sea, so they are dynamic and quite vulnerable to damage due to changes in land cover [1] and the quality of natural resources. This condition is also directly related to the physical, biological, climate, land, and human resources aspects of mangrove ecosystems [2]. Mangrove ecosystems need to be managed very wisely so that ecosystem health conditions are maintained. According to the study [3], damage to mangrove ecosystems reached 5.3 million hectares.

Asia is the region with the largest mangrove ecosystem, which is about 38% of the total area of 15.2 million hectares [4, 5]. Around 23% of the coastal area in Indonesia is the coastal ecosystem of East Lampung Regency, Lampung Province [6]. This mangrove ecosystem has a trend of forest health conditions in the medium category, so optimization of ecosystem functions is needed [7]. Mangrove ecosystems located on the coast of East Lampung Regency are managed by several stakeholders, including the Provincial Government, Regency Government, and the community.

As an implementation management unit, government agencies have the task of monitoring and assessing the implementation of community-based mangrove ecosystem management activities [8]. Community activities affect the dynamic conditions of mangrove ecosystem forest management [9]. Through community empowerment schemes, it can support optimizing the operation of potential natural resources (SDA) in the form of wood, non-timber forest products, and ecosystem services [8]. One form of ecosystem service is carbon potential.

Currently, carbon is a hot issue that is being discussed by stakeholders in various countries. Since the 2009 climate conference held in Copenhagen, various regulations and policies have emerged to reduce emissions as a form of response to climate change [10]. Carbon can be obtained from the biomass of living stands, the biomass of dead trees, litter, and soil [11], so that it can describe the growth conditions of tree stands and become one of the indicators of mangrove ecosystem health [7].

Based on research by Salsabilli Rh et al. [12], there was a decrease in carbon content over a 4-year period (2016-2020) by 26% in the coastal mangrove ecosystem of East Lampung Regency. This is of particular concern because it is caused by degradation and damage to ecosystems. In addition, natural factors and the ability of vegetation to survive can also be influential. This condition can be overcome with rehabilitation activities. This activity is able to improve the arrangement of mangrove vegetation stands and soil fertility [13]. Mangrove stands have the highest carbon content compared to other parts [14]. In addition to rehabilitation efforts, there is a need for strengthening between institutions and communities as conflict resolution, as well as binding regulations for stakeholders as an effort to preserve and prevent ecosystem damage in terms of maintaining the potential to support climate change response [2]. Based on the results of the study, there are differences in carbon stock content at several research sites. These results can be used as considerations and studies to formulate policies for mangrove ecosystem management based on carbon content.

Information and data on the potential of carbon in mangrove ecosystems along the coast of East Lampung Regency are still very minimal. Even though this information is very important for stakeholders in managing and utilizing mangrove ecosystems, In addition, there is still little research that considers optimizing ecosystem services through comparative carbon estimation of mangrove stands as a policy for climate change mitigation efforts. Therefore, to ensure the sustainability of mangrove forests and optimize the function of ecosystem services in mitigating climate change in Coastal East Lampung Regency, it is necessary to measure and calculate stand carbon stock estimates as the basis for mangrove forest management policies. This study aims to determine the comparison of stand carbon stock estimates in several mangrove forest areas in Coastal East Lampung Regency. This study was conducted to obtain standing carbon values at three study sites. The estimation of carbon value is obtained based on the calculation of allometric formulas and IPPC. Then, a qualitative descriptive analysis and literature study were carried out to obtain a study on optimizing mangrove ecosystem services based on carbon estimation.

2. LITERATUR REVIEW

Based on the total mangroves in Southeast Asia, the area of mangrove forest ecosystems in Indonesia reaches 75% of the total area. This shows that Indonesia has potential and natural wealth in the form of abundant mangrove ecosystems. There are two dominant types of mangroves commonly found in coastal areas of Indonesia, namely *Avicennia marina* and *Rhizophora mucronata*. The type of *Avicennia marina* is a pioneer type whose vegetation arrangement is directly by the sea. This type has more significant growth than the type of *Rhizophora* because the type of *Avicennia* absorbs more minerals contained in seawater. However, compared to the *Avicennia* type, the *Rhizophora* type has strong roots, so it serves as a shoreline stabilizer to protect coastal areas from strong sediments, abrasion, and seawater waves [15]. This is what causes a lot of damage to the vegetation of *Avicennia marina*. Damage to vegetation will also have an impact on the condition of mangrove ecosystems.

Based on the results of research [3], mangrove ecosystems that have been damaged reached 5.3 million hectares, where damage occurred in forest areas as much as 3.7 hectares (69.8%) and outside forest areas as much as 1.6 hectares (30.2%). Mangrove ecosystems are unique and different from all other rainforest ecosystems because they are near the sea, making them vulnerable to ecosystem damage [1]. Therefore, it is necessary to optimize mangrove ecosystem services as a scheme to anticipate these conditions.

One of the provinces in Indonesia that has mangrove ecosystem potential is Lampung Province, precisely on the coast of East Lampung Regency. The coast of East Lampung Regency has an area of mangrove ecosystems (Labuhan Maringgai and Pasir Sakti areas) reaching 2,228.44 hectares [14]. The health trend of the coastal mangrove ecosystem of East Lampung Regency, based on the research [7], is in the medium category, so it is necessary to optimize the function of the ecosystem. To maintain the sustainability of mangrove ecosystems, there is a need for community-based forest management efforts and the involvement of multi-stakeholders in supporting the management and supervision of mangrove ecosystems [1]. Community-based mangrove ecosystem management attracts attention because there are variations and differences in management practices. This condition has direct implications for differences in vegetation structure, vegetation diversity, and carbon stock [11].

The determination of carbon estimation is based on the perspective of biomass estimation, which is an important component in studying the structure and function of mangrove ecosystems [16]. Based on research by Salsabilli Rh et al. [12], there was a decrease in carbon content by 26% in the LMC area from 2016 to 2020. According to the study [14], the carbon content in stands has greater value compared to other parts. This is because the carbon storage contained in stands is obtained from nutrients in organic matter through the decomposition process on the soil surface and the process of photosynthesis [17]. It can be said that the condition of the site or topography has implications for the size of the carbon content in mangrove stands. Topography affects the content of above-surface biomass (AGB), as shown in research [18], which shows that topographic conditions contribute to an increase in AGB of 87 mg/ha (48.6%) and 91.7 mg/ha (51.4%).

The value of carbon has direct implications for biomass estimation, where low biomass in mangrove stands will reduce the productivity ability of these coastal ecosystems [16]. The increase in CO_2 compounds in the atmosphere is caused by the degradation of mangrove stands as carbon sinks [14]. In line with research by Indrayani et al. [19], which states that "blue carbon" is an important parameter of mangrove ecosystems in reducing greenhouse gases, Mangrove ecosystems have high productivity, so they play an important role in carbon circulation and become important in the study of climate change mitigation in coastal areas [16].

In all types and types of forest areas (especially protected forests and conservation forests (national parks), NetZero emission efforts by 2050 can no longer be discussed as a sustainable development discourse [20]. This needs direct action by managers, considering the amount of ecosystem damage caused by greenhouse gas emissions. The government plays an important role as a regulator in anticipating this condition. There are already many countries that are aware of the issue of climate change. Like in Ethiopia, where the government there started the Climate Resilience Green Economy (CRGE) strategy. This strategy is focused on afforestation and restoration of land to increase forest land cover and reduce land degradation [21]. Indonesia has also begun to design and realize a similar strategy, namely Indonesia's Forestry and Other Land Use (FOLU) Net Sink 2023 strategy. This strategy is an initiative of the Indonesian government to reduce greenhouse gas emissions in the atmosphere through several activity targets.

Some information related to the research topic has been discussed and obtained based on research that has been done by other researchers. The aim of this research was to add information related to the content of carbon stocks in several activity locations, and which led to the optimization of the function of mangrove ecosystems as carbon sinks based on carbon stock estimates as databases and regulations for formulating climate change mitigation policies. This work is expected to be able to formulate information in an effort to suppress and reduce the rate of degradation of mangrove ecosystems.

3. METHODS

3.1 Study site

The study was conducted in June - August 2023 in three coastal mangrove ecosystems in East Lampung Regency. The determination of the location of the study was carried out based on purposive sampling techniques with several considerations from researchers, namely the status of the area and the management status of mangrove forest areas. The three research locations include Kuala Penet Resort Mangrove Forest, Lampung Mangrove Center (LMC) Mangrove Forest, and Register 15 Mangrove Forest.

The management status of the research site, among others: Kuala Penet Mangrove Forest is managed by the central government, namely the Ministry of Forestry; LMC Mangrove Forests are managed by the regional government (village) and the community; and the Mangrove Forest Register is managed by the provincial government, namely the Lampung Provincial Forestry Service. Determination of observation points was based on purposive sampling methods that consider the dominant types of mangrove vegetation, namely *Avicennia marina* and *Rhizophora mucronate.* There are 6 observation points at the research site, where in each mangrove ecosystem area there are 2 observation points (cluster plot) based on the dominant type, as presented in Table 1 and Figure 1.

Table 1. Coordinates of the research location

No.	Location	Cluster-Plot (CL)	Coordinate Point
1	Mangrove Forest of Resort Kuala Penet	CL1	05°04'47.69"S 105°51'27.96"E
2		CL2	05°03'48.74"S 105°51'29.8"E
3	Mangrove Forest of LMC	CL3	05°16'10.98"S 105°51'21.15"E
4		CL4	05°16'36.98"S 105°50'53.64"E
5	Mangrove Forest of Register 15	CL5	05°32'32.60"S 105°49'15.65"E
6		CL6	05°32'21.75"S 105°49'6.12"E

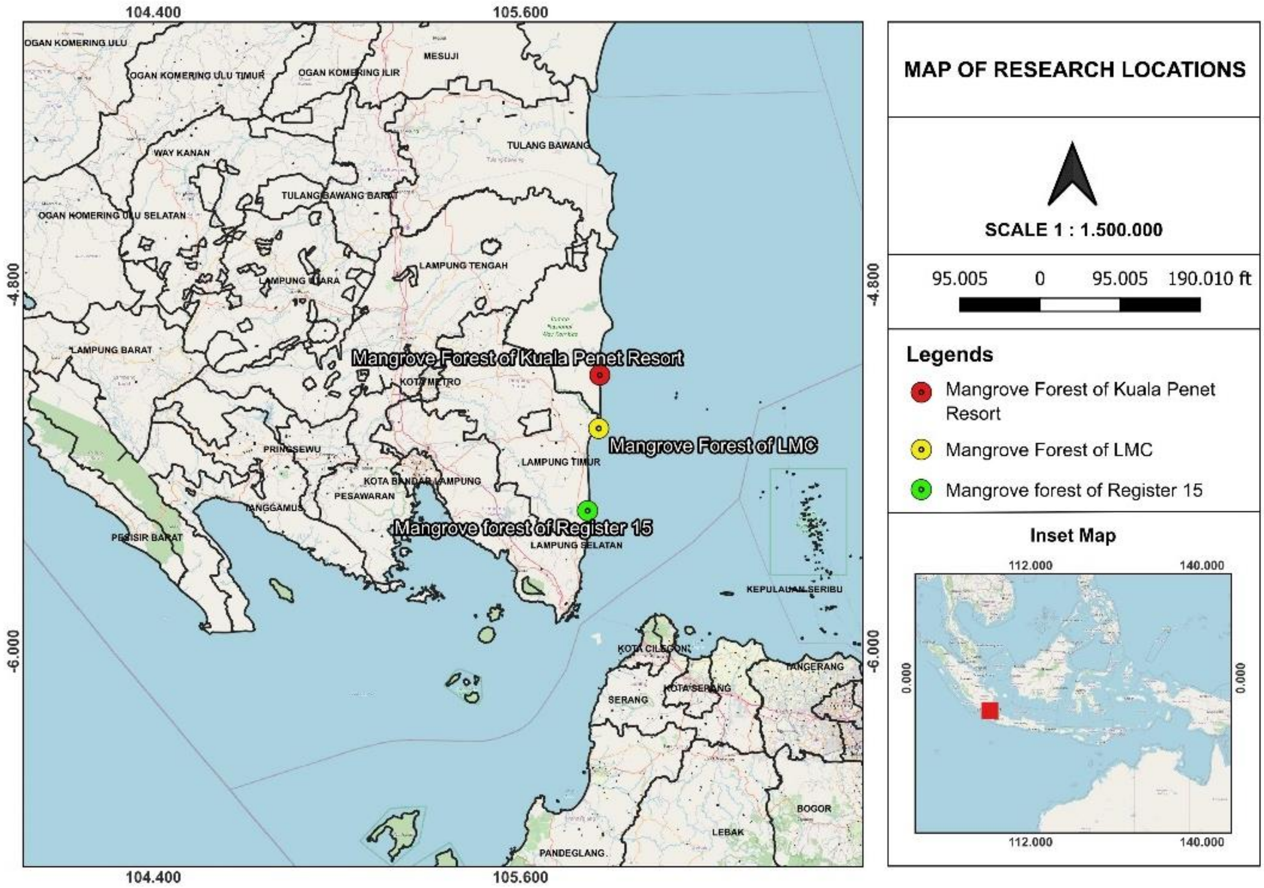

Figure 1. Research location

3.2 Data collection

The study was conducted in three locations of mangrove forests on the Coast of East Lampung Regency, Indonesia, with data collection based on purposive sampling techniques and Forest Health Monitoring (FHM) techniques. Purposive sampling technique is used to determine the number of observation points. The FHM technique is used for the determination of the shape of the observation plot and the distribution of data collection based on the vegetation phase. FHM is commonly used in assessing and monitoring forest health [22]. However, with various developments from researchers, FHM can be used in various conditions tailored to the needs of researchers. The FHM cluster-plot model can be seen in Figure 2.

The FHM technique is identical to an observation plot called a cluster plot with a circle shape, where in one cluster plot there are 4 observation plots [23]. Thus, this study was conducted with a total of 24 observation plots.

Stand carbon data collection is based on mangrove tree stand growth. The growth of mangrove trees is based on taking data on tree's dimensions, namely the diameter of the tree trunk. Diameter data collection was carried out on tree trunks at an altitude of 1.3 meters above ground level. Then, through the diameter data, stand carbon values are determined based on the allometric formula.

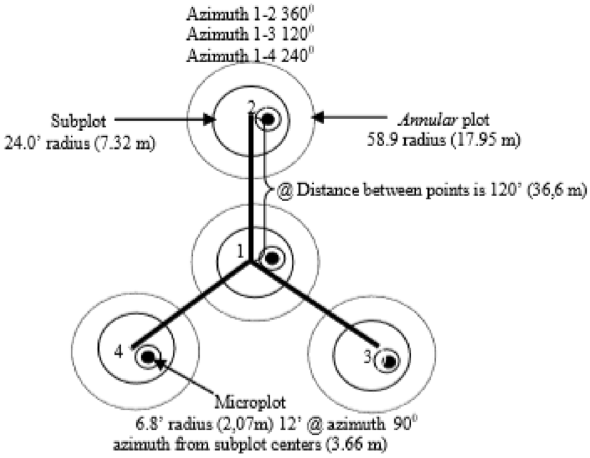

Figure 2. FHM cluster-plot design

3.3 Data analysis

3.3.1 Biomass

Stand carbon estimation is based on the mangrove stand biomass perspective approach. Biomass estimation is carried out by calculating the dimension measurement of tree trunk diameter (DBH), which is then calculated by an allometric equation formula [19]. Many studies have been conducted to determine allometric equations for estimating the biomass value of mangrove tree trunks, and this equation model is considered part of an environmentally friendly method because it does not require damaging or removing mangrove trees [15, 19]. Estimating biomass with allometric models can facilitate adjusting to regional geographical conditions in mangrove ecosystem management [16].

Different types of mangroves have different allometric models for estimating biomass values. In this study, two dominant types of mangroves were found and used as the object of research, namely *Avicennia marina* and *Rhizophora mucronata*. Thus, the allometric models used in both types are as follows (Table 2).

Table 2. Allometric model of mangrove species

No.	Mangrove Species	Model Allometric	Source
1	*Avicennia marina*	$W=0.1848 (D)^{2.3524}$	[3]
2	*Rhizophora mucronata*	$W=0.1466 (D)^{2.3136}$	[24]

Notes: W= Total biomass (Kg); D= Diameter/DBH (meter)

3.3.2 Stock carbon estimation

The biomass value that has been obtained is then added to obtain the total value of biomass. Then, the stand carbon estimation value is calculated by binding the total biomass value with the percentage of carbon content fraction (%C) of 0.47 [25]. The formula for calculating the carbon value is as follows:

$$C=W\times\%C \quad (1)$$

3.3.3 Literature review

A literature review serves the purpose of gathering data and arguments on research topics from researchers who have conducted relevant studies in support of research results based on phenomena that have occurred. The literature review was carried out by collecting several papers or papers with criteria adjusted by researchers, in this case related to mangrove forests and mangrove carbon [26]. The results of the paper collection are then studied more deeply to identify the desired issues.

4. RESULTS

Global warming is a major concern that raises the concerns of the world community and has an impact on sustainable development in various sectors [10]. One of the sectors that has an impact is the forestry sector. The forestry sector plays an important role in mitigating climate change, especially in coastal areas, namely mangrove forests.

Indonesia has various forms of forest ecosystems, one of which is mangrove forests. Mangrove forests have great potential for binding and absorbing CO_2 [11, 21]. The part of Indonesia that has the potential for mangrove forest ecosystems is the coastal area in East Lampung Regency, Lampung Province. Mangrove vegetation can adapt to extreme ecological conditions, such as in case studies that have high waves and sea breezes, which has implications for conditions of severe vegetation damage [7]. This is caused by several factors, namely natural factors and human activities.

There needs to be an effort to anticipate this as a form of climate change mitigation while maintaining and optimizing the function of mangrove vegetation ecosystem services as carbon binders. Knowing the potential for estimating carbon stored in mangrove vegetation can be used as a policy reference in the preparation of coastal area management regulations. In this study, there were three mangrove forest locations that were used as research objects to determine their carbon potential, namely Kuala Penet Resort Mangrove Forest, Lampung Mangrove Center (LMC) Mangrove Forest, and Register 15 Mangrove Forest. The estimated value of carbon stocks stored in mangrove vegetation at the research site is explained in detail as follows.

4.1 Estimation of stand carbon stocks in Kuala Penet Resort Mangrove Forests

Kuala Penet Resort is part of the Kuala Penet National Park Management Section (SPTN), Way Kambas National Park, East Lampung Regency, Lampung Province, Indonesia. In this area, there is potential for mangrove forests on the side of the Kuala Penet River [27]. In the area, there are mangrove plants and piers, as well as abrasion prevention buildings built from rocks that extend far towards the Java Sea, making it crowded by the surrounding community. On the other hand, ecologically, there is potential for stand carbon estimation, with the estimated values obtained in this study presented in Table 3.

Table 3. Stand carbon stocks in Kuala Penet Resort's Mangrove Forests

Vegetation Type	No. Plot	Total Biomass (Kg)	Total Carbon (Ton/Ha)
Avicennia marina	Plot 1	492.93	2.29
	Plot 2	584.63	2.71
	Plot 3	415.79	1.93
	Plot 4	526.81	2.45
Rhizophora mucronata	Plot 1	554.44	2.57
	Plot 2	512.58	2.38
	Plot 3	421.09	1.95
	Plot 4	625.44	2.90

4.2 Estimation of stand carbon stocks in LMC Mangrove Forests

LMC is one of the mangrove forest areas located on the Coast of East Lampung Regency, precisely in Margasari Village, Labuhan Maringgai District. The determination of the LMC area was initiated based on the collaboration between the Margasari Village Government and the University of Lampung, Indonesia, which stated there was Decree No. 170.07.02.2008/143/2005 and Regent Decree No. B.303/22/SK/2005. The initial area of this area, based on the decree, is 700 ha and has diverse potential. The stand carbon potential contained in the LMC can be seen in Table 4.

Table 4. Stand carbon stocks in LMC Mangrove Forests

Vegetation Type	No. Plot	Total Biomass (Kg)	Total Carbon (Ton/Ha)
Avicennia marina	Plot 1	5191.57	24.10
	Plot 2	6934.47	32.19
	Plot 3	6833.61	31.72
	Plot 4	8207.88	38.10
Rhizophora mucronata	Plot 1	1041.16	4.83
	Plot 2	830.53	3.85
	Plot 3	1062.84	4.93
	Plot 4	1043.08	4.84

4.3 Estimation of stand carbon stocks in Mangrove Forest Register 15

Mangrove Register 15 is a protected forest area located at the mouth of Way Sekampung. This area is managed under the Gunung Balak protected forest management unit. This mangrove is located on the Coast of East Lampung Regency, precisely in Pasir Sakti District, Lampung Province. The stand carbon potential in Register 15 is listed in Table 5 below.

Table 5. Stand carbon stocks in Register 15 Mangrove Forest

Vegetation Type	No. Plot	Total Biomassa (Kg)	Total Carbon (Ton/Ha)
Avicennia marina	Plot 1	404.06	1.88
	Plot 2	530.67	2.46
	Plot 3	408.5	1.90
	Plot 4	406.37	1.89
Rhizophora mucronata	Plot 1	56.72	0.26
	Plot 2	105.99	0.49
	Plot 3	93.89	0.44
	Plot 4	75.58	0.35

4.4 Optimization of mangrove ecosystem services based on comparison of stand carbon stock estimates

Mangrove stored carbon is a form of ecosystem service that is converted from free CO_2 products into biomass stored on trunks through the process of photosynthesis [17]. Stand carbon content is very good for plants, but it will be bad for the environment if the CO_2 content produced exceeds the tolerance threshold. Through the process of photosynthesis in mangrove trees, the increase in CO_2 in the atmosphere can be minimized. Each region and topological condition will affect the difference in stored carbon content. As conducted in this study, the estimation of stand carbon stocks stored in three mangrove forest ecosystems in East Lampung Regency can be seen in Figure 3.

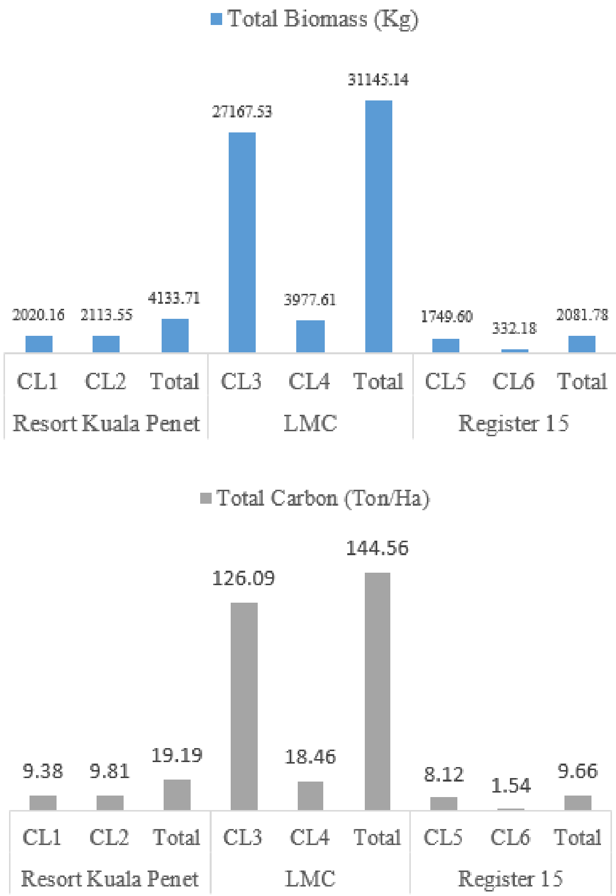

Figure 3. Estimation of stand carbon stocks in each cluster in each mangrove ecosystem site

Notes: CL1, CL3, CL5=*Avicennia marina* species; CL2, CL4, CL6=*Rhizophora mucronata* species

5. DISCUSSIONS

Mangrove forests play an important role in the world's carbon cycle because this is related to productivity, so it is important to study them in an effort to mitigate climate change in coastal areas [16]. In the research case study, there was a significant difference in the carbon stock estimates listed in Figure 3 above. This difference can be caused by the condition of the stand structure, such as age, site conditions, and plant type. There are three areas based on management status that are used as research locations, namely Kuala Penet Resort

Mangrove Forest, LMC Mangrove Forest, and Register 15 Mangrove Forest.

Kuala Penet is part of TNWK, which has the status of a conservation area. Conservation areas play an important role in the conservation of natural resources and as a global ecosystem service [28]. The form of an ecosystem that can be conserved and optimized is the content of stand carbon stocks. Based on Table 3, the stand carbon stock content of the dominant species, *Rhizophora mucronata*, has a greater value than that of the *Avicennia marina* species. This difference can be caused by age, number of species, and plant ripening. As a conservation area, optimizing natural resources, including environmental services, is an important obligation of managers, especially TNWK managers.

Table 4 above shows the differences in stand carbon stocks of each type in each observation plot. There are significant differences, especially in the type of differences. The type of *Avicennia marina* shows a greater carbon content compared to the type of *Rhizophora mucronata*. According to the research [29], the species *Avicennia marina* is a fast-growing plant species, a pioneer in mangrove forest ecosystems, and has the ability to adapt to extreme conditions. However, besides being a fast-growing plant, this type of *Avicennia* is also a plant that quickly experiences damage when exposed to pathogens and disturbing factors.

In addition, differences in carbon values in each species are found in differences in tree trunks and tree age. Carbon is influenced by biomass, and biomass is influenced by tree diameter, so the larger the diameter of the tree, the more biomass content and more CO_2 that can be absorbed [14]. Another factor that causes differences in carbon values is damage to vegetation, which affects the reduction of carbon levels in mangrove ecosystems [12].

Table 5 above shows the results of stand carbon stocks in mangrove register 15 in two dominant species. Similar to the stand carbon potential in the LMC, the carbon potential of the *Avicennia marina* species is greater than that of the *Rhizophora mucronata* species. This is due to differences in site conditions that affect stand carbon stocks, such as soil conditions, plant water absorption, and the quantity of plant species in each observation plot. In addition, in stands at the study site, the species *Rhizophora* sp. is younger compared to *Avicennia* sp., where the average diameter of *Rhizophora* species is only <5 cm [17]. Based on brief interviews with managers, *Rhizophora* stands are a type of plant that has just been planted (aged <2 years), where previous *Rhizophora* stands experienced mass death of stands caused by inability to adapt to local site conditions and exposure to several diseases.

As a response to climate change, synergy needs to be strengthened in conservation partnership schemes in Way Kambas National Park [20]. This triggered the goal of a development project aimed at energy conservation. National parks are very vulnerable, so they need to be considered and reviewed regarding climate change considerations and net zero emissions [20]. However, according to the research [30], many organizations, including national park authorities, find it difficult to manage ecosystem services such as carbon. This is due to a lack of resources and guidance in assessing the environmental services assets managed and the ecosystem services provided by the assets. This shows that the carbon stock content in the Kuala Penet Resort is very small compared to the LMC Mangrove Forest, but larger than Register 15.

Based on the results of research shown in Figure 3, the stand carbon in LMC is 144.55 tons/ha. Meanwhile, based on research [14], the total carbon obtained was 198.61 tons/ha and in research [12], the total value of carbon obtained was 144.14 tons/ha. In addition to being influenced by stand productivity, other influencing factors are the degradation of stands by tides and exposure to pollutants. The value of biomass and carbon can be taken into consideration to maintain the productivity of mangrove stands [16]. LMC has the most stand carbon potential compared to the other two locations. This is because the lifespan of mangrove stands in LMC is much older compared to vegetation in other locations. However, the productivity of mangrove stands in the LMC has begun to be disrupted due to pathogens and ecosystem-damaging factors. As found at the research site, there are traces of oil and oil spills that have a major effect on damaging the condition of mangrove stands in the LMC. According to the study [31], pollutants from oil spills, air pollution, and economic growth are the causes of damage to the function of mangrove stands. Damage to LMC Mangrove Forests can affect stand carbon stock content because it will disrupt the sustainability of the photosynthesis process [7]. Unlike the LMC, Register 15 has a fairly good ecosystem health condition.

Based on Figure 3 above, the total estimated stand carbon obtained in this study in the Register 15 Mangrove Forest is 9.66 tons/ha, which is greater than the results of calculations that have been done by previous researchers at the research site. In a previous study conducted by Kusuma et al. [17], the potential stand carbon stock in mangrove Register 15 was 29.92 kg C/m^2 or 6.98 tons/ha. This increase in value is influenced by the increasing diameter of the tree trunk over the course of a year. The diameter of the tree greatly affects the size of the carbon potential in the stand. According to the research [15], through photosynthesis, carbon is more bound and relatively high in the tree trunk. Differences in carbon stocks found in mangrove stands in various ecosystems may not only be caused by differences in stand structure but may also be caused by climatic factors and habitat characteristics [16].

The size of the tides also affects the quality of ecosystem services; in addition to causing damage to mangrove vegetation, they can also provide environmental benefits. There is a consistent relationship between high salinity and topography (including seawater conditions) and biomass values, where the better the topography and salinity, the better the condition of plant productivity [18]. This is shown directly in Figure 3. Of the three locations, the type *Avicennia* sp. has more carbon potential due to the fact that stands and zones of *Avicennia* sp. are right on the edge of the sea water, so they interact directly with the tides. Basically, all successes in mangrove forest management go back to the management schemes and concepts carried out by managers and stakeholders. Stakeholders need to be firm in terms of finding illegal factors that damage the environment in order to maintain the potential of ecosystem services and the success of sustainable management. There need to be efforts and direction to protect and regenerate mangrove vegetation through community empowerment and conservation activities [32]. Excessive use of natural resources contributes to sustainability issues, including pollution and greenhouse gases [33]. The community needs to be actively involved in the management of mangrove forest ecosystem services. Interventions and management success problems arise when communities do not benefit from ecosystem services and access [32]. In line with UUCK 2020 and Law No. 1 of 2014, mangrove ecosystems need to be maintained so that diversity in them is sustainable. In addition, the government, as a regulator, plays a role in community empowerment. There are two strategies that can be implemented by the government that underlie a community-based coastal resource management (CBCRM) approach that empowers communities to manage mangrove resources while securing ownership of their resources [32].

To implement partnerships globally, governments contribute to technical progress and natural capital calculations. The reference that can be taken from the government order is to the Philippines, where the policies made must be transparent and in accordance with scientific facts or science, so that they can be in line with governance reform [32]. On the other hand, technological progress is very supportive of the success of sustainable development. In the current era of globalization and the industrial revolution, technological advances play an important role in the management and monitoring of sustainable development in the forestry sector. As in measuring carbon stock estimates in mangrove forests, many tools have been developed to facilitate this. As in the research [26], biomass estimation has been carried out using satellites and remote sensing. Therefore, further studies and research need to be carried out on the conservation and management of mangrove forests related to ecosystem services, including carbon estimation as a decision-making step and efforts to mitigate climate change.

6. CONCLUSIONS

This study tried to conduct a descriptive study and a literature study based on the results of carbon stock estimates in three mangrove ecosystem locations on the coast of East Lampung Regency. The selection of research site points is based on purposive sampling techniques, which consider ecosystem management status and the dominant type of mangrove vegetation. We perform carbon calculations with allometric formula calculations and IPCC based on vegetation type. Then we compared the carbon values of the three locations (Kuala Penet, LMC, and Register 15, LMC).

Of the three research sites, namely Kuala Penet Resort, LMC, and Register 15, LMC has the greatest stand carbon potential compared to other locations, with a total stand carbon stock of 144.56 tons/ha. Then followed Register 15 with a total stand carbon of 9.66 tons/ha and Kuala Penet Resort Mangrove Forest with a total stand carbon of 19.19 tons/ha. The size of the stand's carbon value is influenced by the condition of the vegetation structure, such as tree age, site conditions, and climate. In addition, stakeholders play an important role in maintaining ecosystem services in the form of carbon potential in mangrove forests. Community empowerment regulation is the optimal way that the government can apply it as a form of climate change response.

Please note that this study exclusively examines the comparison of carbon stocks in several mangrove areas. Thus, in the future, it is important to expand the scope that includes ecological, social, and economic variables of mangrove forests on carbon stocks. In addition, the allometric models that we use are still based on references to other people's research; thus, it is also important for future research to formulate separate allometric models for the types contained in the research location conducted. This aims to increase the accuracy of the study and minimize the magnitude of errors. Given the large amount of data on estimating carbon stocks in various regions, this research model is enriched by estimating carbon stocks in more than one location so that they can be compared with each other, and it is also supported by secondary data related to carbon potential for ecosystem services.

Based on our results, this study is expected to provide information related to the potential of ecosystem services in the form of carbon on the coast of East Lampung Regency. For this reason, synergy between various stakeholders is needed to fulfill climate change mitigation efforts based on carbon potential. Therefore, as researchers, we can only provide information and recommendations based on research results and related issues. Furthermore, beyond our limits, the preparation of policy regulations in mangrove ecosystem management is fully carried out by the government as a regulator. In addition, it will be useful that future research be continued by enriching variables so that it can formulate tools related to carbon estimation and greenhouse gas emissions.

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REFERENCES

[1] Kustanti, A., Purnomo, M., Nurrochmat, D.R., Fitriana, Y.R. (2023). Sustaining mangrove and rainforests: Land rights and collective action in Indonesia. International Journal of Sustainable Development & Planning, 18(5): 1545-1552, https://doi.org/10.18280/ijsdp.180525

[2] Wang, Y.S., Gu, J.D. (2021). Ecological responses, adaptation and mechanisms of mangrove wetland ecosystem to global climate change and anthropogenic activities. International Biodeterioration & Biodegradation, 162: 105248. https://doi.org/10.1016/j.ibiod.2021.105248

[3] Dharmawan, I.W.S., Siregar, C.A. (2008). Karbon tanah dan pendugaan karbon tegakan Avicennia marina (Forsk.) Vierh. di Ciasem, Purwakarta. Jurnal Penelitian Hutan dan Konservasi Alam, 5(4): 317-328. https://doi.org/10.20886/jphka.2008.5.4.317-328

[4] Food and Agriculture Organization of the United Nations. (2007). The World's Mangroves 1980-2005. Rome, Italy.

[5] Ali, M.I., Malik, A., Rahim, A. (2022). Environmental knowledge and attitude of coastal community in decision making to participate in Mangrove Rehabilitation in Sinjai District South Sulawesi Indonesia. International Journal of Sustainable Development and Planning, 17(8): 2579-2584. https://doi.org/10.18280/ijsdp.170826

[6] Maulana, I.R., Safe'i, R., Febryano, I.G., Kaskoyo, H., Rahmat, A. (2022). The relationship between the health of mangrove forests and the level of community welfare. IOP Conference Series: Earth and Environmental Science, 1027(1): 012033. https://doi.org/10.1088/1755-1315/1027/1/012033

[7] Safe'i, R., Kaskoyo, H., Ardiansyah, F. (2022). Trend

analysis of mangrove forest health in east Lampung regency as community preparedness for natural disasters. International Journal of Design & Nature and Ecodynamics, 17(6): 943-949. https://doi.org/10.18280/ijdne.170616
[8] Golar, G. (2021). Can forest management units improve community access to the forest? International Journal of Design & Nature and Ecodynamics, 16(5): 565-571. https://doi.org/10.18280/ijdne.160511
[9] Syahiib, A.N., Safe'i, R., Febryano, I.G. (2023). The effect of community participation on forest health levels (Case study of Sekar Bahari mangrove forest tourism, Margasari village, Labuhan Maringgai district, East Lampung Regency). AIP Conference Proceedings, 2619(1): 060001. AIP Publishing. https://doi.org/10.18844/gjs.v7i2.2394
[10] Zhao, Y. (2019). Optimal decision-making for green supply chain based on overconfidence under the carbon emission constraint. Journal Européen des Systèmes Automatisés, 52(2): 199-204. https://doi.org/10.18280/jesa.520213
[11] Idris, M.H., Latifah, S., Setiawan, B., Mahakam Lesmono Aji, I., Permatasari, D. (2021). Vegetation and soil carbon under various forest management types: Case of Karang Sidemen community forest in Lombok, Eastern Indonesia. International Journal of Design & Nature and Ecodynamics, 16(6): 641-648. https://doi.org/10.18280/ijdne.160604
[12] Salsabilli Rh, C., Widiastuti, E.L., Wahyuningsih, S. (2021). Carbon stock estimation due to changes in mangrove Labuhan Maringgai District, East Lampung Regency. Advances in Engineering Research, 202: 6-10. https://doi.org/10.2991/aer.k.210603.002
[13] Ahmed, S., Sarker, S.K., Friess, D.A., Kamruzzaman, M., Jacobs, M., Islam, M.A., Alam, M.A., Suvo, M.J., Sani, M.H.N., Dey, T., Naabeh, C.S.S., Pretzsch, H. (2022). Salinity reduces site quality and mangrove forest functions. From monitoring to understanding. Science of the Total Environment, 853: 158662. https://doi.org/10.1016/j.scitotenv.2022.158662
[14] Windarni, C., Setiawan, A., Rusita, R. (2018). Carbon stock estimation of mangrove forest in Village Margasari Sub-District Labuhan Maringgai District East Lampung. Jurnal Sylva Lestari, 6(1): 66-74. https://doi.org/10.23960/jsl1667-75
[15] Wijeyaratne, W.M.D.N., Liyanage, P.M. (2020). Allometric modelling of the stem carbon content of rhizophora mucronata in a tropical mangrove ecosystem. International Journal of Forestry Research, 2020: 1-6. https://doi.org/10.1155/2020/8849413
[16] Kangkuso, A., Sharma, S., Jamili, J., Septiana, A., Sahidin, I., Rianse, U., Rahim, S., Nadaoka, K. (2018). Trends in allometric models and aboveground biomass of family Rhizophoraceae mangroves in the Coral Triangle ecoregion, Southeast Sulawesi, Indonesia. Journal of Sustainable Forestry, 37(7): 691-711. https://doi.org/10.1080/10549811.2018.1453843
[17] Kusuma, A.H., Effendi, E., Hidayatullah, M.S., Susanti, O. (2022). Estimasi serapan karbon pada vegetasi mangrove Register 15, Kecamatan Pasir Sakti, Kabupaten Lampung Timur, Provinsi Lampung. Journal of Marine Research, 11(4): 768-778. https://doi.org/10.14710/jmr.v11i4.35605
[18] Virgulino-Júnior, P.C.C., Carneiro, D.N., Nascimento Jr, W.R., Cougo, M.F., Fernandes, M.E.B. (2020). Biomass and carbon estimation for scrub mangrove forests and examination of their allometric associated uncertainties. PloS One, 15(3): e0230008. https://doi.org/10.1371/journal.pone.0230008
[19] Indrayani, E., Kalor, J.D., Warpur, M., Hamuna, B. (2021). Using allometric equations to estimate mangrove biomass and carbon stock in Demta Bay, Papua Province, Indonesia. Journal of Ecological Engineering, 22(5): 263-271. https://doi.org/10.12911/22998993/135945
[20] Nhamo, G., Dube, K., Chapungu, L., Chikodzi, D. (2023). Quest for NetZero emissions in South African national parks: A tourism perspective. Heliyon, 9(6): E16410. https://doi.org/10.1016/j.heliyon.2023.e16410
[21] Kendie, G., Addisu, S., Abiyu, A. (2021). Biomass and soil carbon stocks in different forest types, Northwestern Ethiopia. International Journal of River Basin Management, 19(1): 123-129. https://doi.org/10.1080/15715124.2019.1593183
[22] Safe'i, R., Upe, A. (2022). Mapping of tree health categories in community Forests in Lampung Province. In IOP Conference Series: Earth and Environmental Science, 995(1): 012004. https://doi.org/10.1088/1755-1315/995/1/012004
[23] Nurcahyani, A., Safe'i, R., Bintoro, A., Kaskoyo, H. (2022). Study of vitality change in teak community forest management (Case study on teak community forest in Natar Sub-district, South Lampung Regency, Lampung Province). IOP Conference Series: Earth and Environmental Science, 1115(1): 012054. https://doi.org/10.1088/1755-1315/1115/1/012054
[24] Dharmawan, I.W.S. (2010). Pendugaan biomasa karbon di atas tanah pada tegakan Rhizophora mucronata di Ciasem, Purwakarta. Jurnal Ilmu Pertanian Indonesia, 15(1): 50-56.
[25] The Intergovernmental Panel on Climate Change. (2006). 2006 IPCC Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, Forestry and Other Land Use. https://www.ipcc-nggip.iges.or.jp/public/2006gl/.
[26] Ahmad, A., Gilani, H., Ahmad, S.R. (2021). Forest aboveground biomass estimation and mapping through high-resolution optical satellite imagery-A literature review. Forests, 12(7): 914. https://doi.org/10.3390/f12070914
[27] Tentaang Tnwk. SPTN III Kuala Penet. https://waykambas.org/sptn-iii-kuala-penet/, accessed on Aug. 22, 2019.
[28] Dwiyahreni, A., Fuad, H.A., Sunaryo, Soesilo, T.E.B., Margules, C., Supriatna, J. (2021). Forest cover changes in Indonesia's terrestrial national parks between 2012 and 2017. Biodiversitas Journal of Biological Diversity, 22(3). https://doi.org/10.13057/biodiv/d220320
[29] Cahyo, A.T., Darmawan, A., Iswandaru, D., Setiawan, A. (2022). Pendugaan karbon stok di atas Permukaan Tanah Pada Hutan mangrove di Kabupaten Lampung Timur. Jurnal Hutan Tropis, 10(3): 268-276. https://doi.org/10.20527/jht.v10i3.14969
[30] Faccioli, M., Zonneveld, S., Tyler, C.R., Day, B. (2023). Does local Natural Capital Accounting deliver useful policy and management information? A case study of Dartmoor and Exmoor National Parks. Journal of Environmental Management, 327: 116272. https://doi.org/10.1016/j.jenvman.2022.116272

[31] Sharma, T., Sharma, M., Mehrotra, S., Grima, S. (2023). An econometric analysis of India's urbanization, energy consumption, economic growth and CO_2 emission. International Journal of Environmental Impacts, 6(2): 57-64. https://doi.org/10.18280/ijei.060201

[32] Song, A.M., Dressler, W.H., Satizábal, P., Fabinyi, M. (2021). From conversion to conservation to carbon: The changing policy discourse on mangrove governance and use in the Philippines. Journal of Rural Studies, 82: 184-195. https://doi.org/10.1016/j.jrurstud.2021.01.008

[33] Scapini, V., Berrios, P. (2022). Climate change in Chile, strategic plan and circular economy. International Journal of Environmental Impacts, 5(4): 306-315. https://doi.org/10.2495/EI-V5-N4-306-315