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RESEARCH ARTICLE

The Effect of C-Organic Sediment and Litter Carbon Estimation on Fertility and Site Health in Lampung Mangrove Center

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ABSTRACT

Subsurface carbon storage reflects the fertility of mangrove sites. Site fertility has implications for site health. The aims of this study, among others, are to determine the content of C-organic sediments, determine the litter carbon content, and understand the effect of C-organic and litter carbon on on-site health (soil pH and CEC). The stages of research, among others, are sediment and litter sampling on the observation plot, analysis of sediment and litter samples in the laboratory, calculation of litter carbon by dry weight, and fertility analysis of site health using multiple linear regression analysis with a significant threshold of 95%. Based on the results of the study, the highest C-organic content was observed in cluster plot 3 (CL3); the highest increase in litter carbon was at CL2, and there was a significant effect between site fertility (C-organic) and site health (pH). The pH and carbon play a role in the mobility of compounds that form organic materials. Factors influencing on-site carbon health conditions include waste production, organic material, temperature, tree species, pollution, and climate. Sediment conditions affect sigh in organic matter and the health of the site. The results of this research can illustrate the fertility and health conditions of sites in mangrove forests, so regulations can be formulated to prevent damage to mangroves.

Introduction

Approximately 23% of the mangrove ecosystems in Indonesia are spread in the coastal areas of the East Lampung Regency. One is the Lampung Mangrove Center (LMC), with dozens of administrative areas covering 700 ha in 2012 [1]. The LMC is a mangrove management ecosystem located on the coast of the East Lampung Regency in Margasari Village, Labuhan Maringgai District. The LMC was formed through cooperation between higher education agencies (Lampung University) and government agencies (Margasari Village Government and East Lampung Regency). This collaboration was ratified in Decree Number 170.07.02.2008/143/2005 concerning Support for integrated mangrove management to the University of Lampung and Regent Decree No. B.303/22/SK/2005 concerning Determination of Mangrove Forest Management Location in the Framework of Education, Environmental Conservation, and Community Empowerment covering an area of 700 ha in Margasari Village, Labuhan Maringgai District. Based on the cooperation and content of the agreement, the purpose of establishing the LMC is to preserve the ecosystem through the Tri Dharma of Higher Education concept, namely, education, research, and service.

Mangrove forests are transitional ecosystems with unique chemical-physical characteristics that are widespread in tropical and subtropical regions throughout coastal areas [2]. Therefore, they have a higher organic carbon content than terrestrial forests [3]. Organic carbon (C-organic) is stored in mangrove sites and in soil (sediments). Thus, the condition of a healthy site affects its stored organic content. Site health is part of the concept of forest health, and one of the indicators of forest health is site health or quality [4]. Soil pH and soil cation exchange capacity (CEC) can be used to describe the health of a site. Torres et al. [2] showed that the pH value was correlated with organic matter content, where the organic matter in question included sediment and mangrove litter.

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The potential of hydrogen (pH) is an essential factor for controlling the compounds, mobility, and availability of chemicals and minerals in sediments [5]. Thus, pH can be related to sedimentary organic ligands. The nutrient content, carbon content, and soil pH have also been associated [6]. Sediment is a part of mangroves, with a carbon content of 80% of the total carbon stock of mangrove ecosystems [7]. One factor affecting the value of CO_2 storage in mangrove sediments is litter productivity, which has been decomposed for years and becomes a carbon stock [8]. Litter decay also contributes to the production of dissolved organic matter (DOM) in soil [9]. This condition makes litter a critical factor in increasing fertility and site health.

However, the health of the site in the LMC decreased in quality. This is caused by natural conditions, one of which is the tide, which causes damage to vegetation and mangrove sites. The same is true in previous research, which shows that LMC mangrove forest health trends are in the medium-poor category [1,10]. Healthy mangrove forests can affect the stored carbon content. Based on research by Salsabilli et al. [11], shows a sediment C-organic content of 5.33% and an increase in litter carbon content by 8% from 1.25 tons ha^{-1} (in 2016) to 1.35 tons ha^{-1} (in 2019) [11,12]. Descriptively and conceptually, some of the above research results show no relationship, although some are unitary variables that indicate fertility and site health. Further research is needed to examine the relationship between site variables statistically and descriptively. Therefore, this study aimed to analyze the influence of sediment C-organic and litter carbon content on on-site health based on soil pH and soil CEC values.

Materials and Methods

Study Area

This study was conducted between July and August 2023. The research locations were the Lampung Mangrove Center (LMC), Margasari Village, Labuhan Maringgai District, and East Lampung Regency. Purposive sampling determined the location based on conditions at the research site. The location point, which is the observation area, was marked with a coordinate point. The research location map is shown in Figure 1 and the cluster plot coordinates are listed in Table 1.

Figure 1. Study area.

Table 1. Cluster plot coordinate points.

No.	Cluster plot (CL)	Coordinate points	
		Longitude	Latitude
1	CL1	105.8553290	–5.2705987
2	CL2	105.8565283	–5.2690886
3	CL3	105.8482057	–5.2765544
4	CL4	105.8474307	–5.2774205

Materials and Tools

Soil sediment and litter samples were used for the analysis. The tools used are polyvinyl chloride (PVC) rings, plastic samples, plant scissors, markers, soil shovels, ovens, digital scales, office stationery, and tally sheets.

Data Collection

Data collection was carried out by purposive sampling, using two types of data: primary and secondary. Preliminary data are obtained based on direct observations and surveys in the field, whereas secondary data use data from previous researchers. Data collection (sediment and litter) was performed by sampling each observational plot. Determination of observation plots based on the forest health monitoring (FHM) techniques. This technique uses the concept of a cluster plot in the form of a circle, wherein one cluster plot contains three types of plots: annular plots, subplots, and micro plots [13–15] (Figure 2).

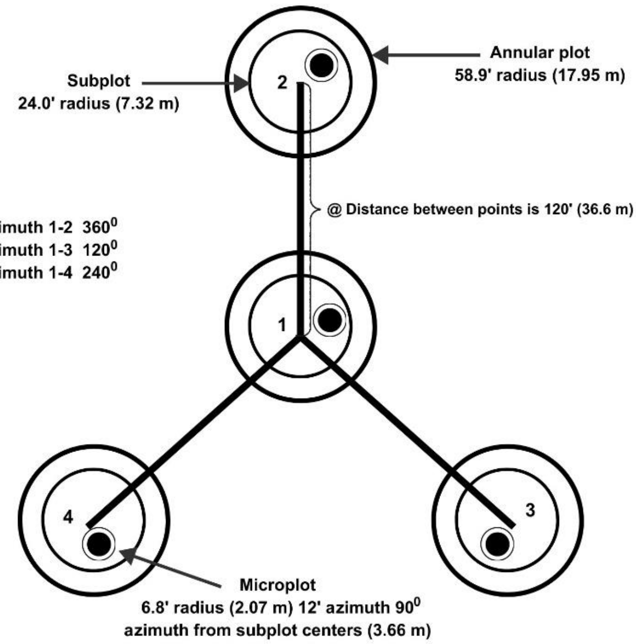

Figure 2. FHM cluster plot design.

Mangrove forests in the LMC have homogeneous vegetation characteristics and are dominated by certain types. Thus, the number of observation plots was determined based on the stratified sampling method, which targets several classes classified into specific categories [16]. The class and size used in determining the measuring plot were based on the type of dominant stand and dominant mangrove canopy stratum. At the research location, there were two predominant types of mangroves, namely *Avicennia marina* and *Rhizophora mucronata*, whereas there were two dominant header strata, namely strata B and strata C. Thus, four cluster plots with 16 observation plots were used in this study. Litter samples were obtained by collecting as much as ± 300 g litter above the soil surface in each observation plot, so that there were 16 litter samples. In contrast, soil sample data were obtained by taking soil at a depth of 10 cm using a ring PVC with a diameter of 15 cm. Three land points were considered in a cluster plot located between annular plots. Three samples were then taken in one cluster and combined (composited) to analyze the four soil samples.

Soil pH and CEC Data

Soil pH and cation exchange capacity (CEC) data were obtained from secondary data collected by previous researchers at the study site (LMC). Secondary data were used because the location and data collection points in this study were the same as those used in previous studies. Soil pH data were obtained using the data from Syahiib [17], and soil CEC data were obtained using the data from Maulana et al. [10].

Data Analysis

Analysis of C-Organic Sediment Data

Three soil or sediment samples taken from one cluster were collected into one sample for analysis; therefore, four soil samples were analyzed in this study. Soil and sediment analyses were performed to determine sediment organic carbon (C-organic) test parameters. These parameters were analyzed at the Lampung State Polytechnic Analysis Laboratory. The method used in this analysis was based on the instructional and technical methods of edition 2 [18]. The carbon-hydrogen-nitrogen-sulfur (CHNS) analysis method was used to determine the concentrations of soil carbon and C-organic [19,20].

Litter Carbon Data Analysis

The collected litter was a cover crop consisting of twigs and leaves that had decomposed above the soil surface. Litter samples of as much as ± 300 g were collected from each observation plot. The samples were weighed wet and then oven-dried at 80 °C for 24 hour or until the weight was constant. The dry weight and carbon content stored in the litter were calculated when the weight was stable. The determination of litter carbon content was based on the Intergovernmental Panel on Climate Change (IPCC) method by multiplying the dry weight of the litter by the carbon fraction (0.47). The dry weight calculation formula for the sample was as follows [21]:

$$Total\ Dry\ Weight = \frac{DW\ sub\ sample\ (g)}{WW\ sub\ sampel\ (g)}\ X\ Total\ Dry\ Weight\ (g) \quad (1)$$

where:

DW= Dry weight, WW= Wet weight

Multiple Linear Regression Analysis

Analysis of site health and fertility parameters and variables using multiple linear regression models. This model aims to explain the spatial distribution of a dependent variable using a linear combination of predictors [22]. Before the regression analysis, an initial analysis was carried out, namely, a correlation analysis, to determine the correlation or relationship between the parameters. In this case study, site health parameters were considered as dependent variables, whereas carbon parameters (C-organic and litter carbon) were assumed to be predictor variables (independent variables). Based on this statement, the following regression model was obtained:

$$y_i = a + b_1x_1 + b_2x_2 + \varepsilon \quad (2)$$

Based on the equation model above, "y" is the bound variable (soil pH and CEC), "x" is the predictor variable (C-organic and litter carbon), "a" is the intercept, "b" is the partial regression coefficient, and "ε" is the error standard. In this study, regression analysis was performed using the help of MS Excel software with a 95% confidence interval and 5% standard error. The assumptions and hypotheses of this study are as follows:

H0 = No influence between predictor variable and bound variable

H1 = There is at least one influential variable between the predictor variable and the dependent variable

Results and Discussion

Mangrove forests are effective in storing carbon. Through the results of the photosynthesis process, carbon compounds, such as stems, leaves, and sediments, are stored in the stands in the form of carbon stocks. Several factors can affect the amount of carbon stored, including the density and number of trees, solar lighting, tree species, temperature, moisture content, and fertility of sediments or sites [11]. Thus, the fertility of sediments and mangrove ecosystem sites needs to be considered for healthy conditions because all materials and nutrients required for photosynthesis begin with absorption in the roots of trees. This study was conducted to determine the potential of carbon in soil fertility variables (sediment and litter) and its relationship with site health (pH and sediment CEC).

C-Organic Content of Mangrove Sediments

Sediment is one of the most sensitive indicators [6]. Internal and external factors impact sediment dynamics, including tides and the contamination of hazardous materials. Sediment is one part that stores carbon stocks through the decomposition and metabolism of organic matter [23]. Usually, the carbon in sediments is known as organic carbon (C-organic). The carbon contents of the LMC ecosystem are presented in Table 2.

Table 2. Results of C-organic sediments in mangrove ecosystems.

No.	Cluster plot (CL)	Zonation	C-organic value (%)	Average value of C-organic (%)
1	CL1	*Avicennia marina*	4.33	3.55
2	CL2		2.77	
3	CL3	*Rhizophora mucronata*	5.94	5.72
4	CL4		5.48	

This research was conducted based on observations and measurements in each cluster plot that described the conditions of the site and type of mangrove vegetation. Table 2 shows that more C-organic matter was stored in CL3 and CL4. These two clusters are the dominant species of *Rhizophora mucronata*. The conditions of this type of site were influenced more by seawater logging and sedimentation. Mangrove forest vegetation has different characteristics and adaptability, including functions in transportation, sediment deposition, and biogeochemistry [24,25]. For example, at the research location, the *Rhizophora mucronata* zone had a better C-organic value than the *Avicennia marina* zone because the *Rhizophora* root form can spread widely on the surface to obtain organic material. The sediment type at the study site was mud, which resulted in high organic content [11].

Based on the above table, there were differences between several sediment types in the four plot clusters. Apart from being influenced by differences in sediment characteristics, they are also influenced by the frequency and density of species in the plots [24]. Sedimentary sludge results from dust, clay, and sand sedimentation and mixing. Soil acidity and sediment influence carbon content. For example, in peatlands with high acidity, the carbon fraction in the soil reaches 95% of the total carbon storage [21]. The CO_2 storage in sediments occurs indirectly. CO_2 absorbed by vegetation is held in the form of biomass, deposited into sediments, and becomes carbon stocks stored in sediments [8]. Mangrove sedimentation estimates can also estimate damage to mangrove vegetation [26]. The results obtained were still quite good, but attention needs to be paid to avoid damage to the ecosystem.

Tides and river flow influence mangrove vegetation. This could have implications for carbon storage, especially in mangrove sediments. As stated by Torres et al. [2], this can be attributed to the contribution of sediment to the high organic matter content of river flow. Each cluster had different flow conditions at the research location, such as in the CL1 and CL2 areas, where small river flows influenced it, whereas in the CL3 and CL4 locations, it was influenced by small river flows originating from the pond area. Sediment parameters affect the value of C-organics. High C-organic content can be caused by differences between specific mangrove litter types, which has implications for nutrient decomposition at mangrove sites[9]. Each CL at the study location had different litter characteristics; some CLs contained only leaf litter, and there were CLs whose litter composition consisted of leaves and twigs.

This also influences the size of the C-organic value at the research location, such as CL2, which has a small carbon value because less organic material is decomposed compared with other CL locations. High aliphatic carbon content characterizes C-organics in mangrove sediments, indicating that the soil has not undergone humification and is susceptible to decomposition [3]. The soil organic matter content in sediments increases the concentration of Cu in sediment organic matter [5] and contains dissolved C-organic via a ligand-exchange mechanism [27,28]. At this research location, it can be seen from the CL2 results that the location has low vegetation density and is exposed to pollution from industrial waste. Thus, fertile sites have a high C-organic content because they store and bind a large amount of organic matter needed for mangrove stand growth.

Litter Carbon Content

Litter is part of the plant above the mangrove site's surface. This litter usually consists of dry leaves and twigs that decompose the bacteria on the soil surface. This decomposition results in organic compounds suitable for mangrove soil conditions. This litter decomposition also contributes to the soil organic matter content, including C-organic matter. The carbon content of mangrove litter in the LMC is shown in Table 3.

Table 3. Carbon analysis results for mangrove ecosystems.

No.	Cluster plot (CL)	Zonation	Litter carbon storage value (ton ha^{-1})	Average value of litter carbon storage (ton ha^{-1})
1	CL1	*Avicennia marina*	1.01	1.19
2	CL2		1.38	
3	CL3	*Rhizophora mucronata*	1.07	0.94
4	CL4		0.80	

Based on the above table, the carbon content is stored in CL2, which is dominated by the stands of *Avicennia marina*. *Api-api* (local name of *Avicennia marina*) stands are dominant and have higher growth rates than the *Bakau* (local name of *Rhizophora mucronata*) stands. However, the *api-api* stands suffered considerable damage due to broken branches (Figure 3). This contributes to the large amount of litter produced in the *api-api* stands.

Figure 3. Branch damage broken stand of *Avicennia marina*.

Litter production on the soil surface correlates with organic matter content [2]. This shows that litter is part of the organic matter that stores the nutrients needed for the growth of mangrove trees. Higher litter production in stands increases organic matter production, including carbon stocks, below the soil surface. Litter production in the plot clusters varied depending on the amount of litter on the ground surface. More litter was produced at the study location in the *Avicennia marina* zone because of the large number of dry twigs and leaves that fell to the ground surface. This is because many mangrove trees experience drought because of damage.

Litter production was lower in the *Rhizophora mucronata* zone than in the *Avicennia marina* zone because there was less loss of foliage. Litter production is also influenced by the growth of tree canopy areas, which is directly correlated with an increase in tree age [29]. Litter carbon is a part of the carbon storage in mangrove ecosystems. Environmental factors affecting mangrove carbon stocks include temperature and climate gradients, which can reflect organic matter production [9,30]. Based on the research hypothesis of Torres et al. [2], it has been proven that the rainy season with a high rainfall intensity produces higher litter production than the summer season [31]. Thus, litter production can be associated with the response of mangroves to the environment, indirectly affecting the sediment, organic matter, and litter production.

pH and CEC Value of Mangrove Sediments and Their Effects on Soil Fertility

The high and low pH and CEC values in sediments depend on soil fertility conditions. These two variables are soil chemical properties that describe the conditions of mangrove sediment sites. Mangrove soil and sediments are productive parts of an ecosystem with high organic matter storage characteristics [6]. The pH and CEC values describe the health conditions of mangrove ecosystems. The pH and CEC values of the LMC are listed in Table 4.

Table 4. pH and CEC results for mangrove sediments.

No.	Cluster plot (CL)	pH	CEC (me 200 gram-1)
1	CL1	6.6	15.79
2	CL2	6.2	16.76
3	CL3	7.1	16.68
4	CL4	7.3	13.39

Source: Maulana et al. [10], Syahiib [17].

Based on the above table, the pH of mangrove sites had values in the acidic range (CL1 and CL2), basic range (CL3 and CL4), and CEC in the medium category. pH and CEC play important roles in treating the organic matter and minerals contained in sediments, including organic matter in the form of C-organics. Based on a previous study by Syahiib et al. [15], the pH value at the study location was in the medium category, which was neither too acidic nor alkaline. This indicates that the pH conditions were sufficient for the growth of the mangrove stands. Changes in pH can illustrate the capacity of organic materials to play a role in the carbon and nutrient cycles. Meanwhile, the CEC value at the research location has a low capacity, which has implications for the potential availability and absorption of nutrients [10]. The relationship between organic matter and site health parameters can illustrate the coherence of mangrove management based on the site. This study was conducted to obtain this linkage based on statistical analysis (Table 5).

Table 5. Analysis of the effects of site fertility on site health.

	pH (y1)		Cation Exchange Capacity (COC) (me 200 gram-1) (y2)	
	Coefficient	P-value	Coefficient	P-value
Intercept	5.44	6.94E-12	15.41	4.89E-06
C-organic (x1)	0.34	3.30E-7*	-0.27	0.38
Litter Carbon (x2)	–427.13	0.36	5526.83	0.18

*There is an influence between variables.

The table above shows the results of multiple linear regression analyses using MS Excel software with a confidence interval of 95%. The data were processed such that the table was produced. As shown in Table 5, the C-organic content significantly influences sediment pH. These results were supported by a correlation analysis performed before regression analysis. Table 6 shows the correlation results.

Table 6. Results of correlation analysis.

	Coefficient Correlation	
	pH	COC
C-organic (x1)	0.95	–0.40
Litter Carbon (x2)	–0.49	0.48

Based on the above results, the relationship between the C-organic content and pH was very strong, with a value of 0.95. Meanwhile, the relationships between the other parameters were negative and weak. Therefore, the equation used was based on the effect of C-organic on pH value. The resulting equation model based on the above table is as follows:

$$y_i = 5.44 + 0.34x_1 - 427.13x_2 + \varepsilon \quad (3)$$

Sediment conditions that produce litter and high organic matter can describe the high and low pH and CEC of the sediments [1]. The pH and organic C content contribute 53% to the growth of mangrove stands [32]. According to Pratama et al. [4], state forests have pH values below 7, which tends to be the base. In contrast, mangrove ecosystems are more acidic. The pH gradient is essential for the mobility of chemical elements that affect C-organic storage [3]. The organic matter content in sediments opens new binding opportunities for metal complexation at higher pH values [5]. According to Maulana et al. [10], the CEC value can describe the success of mangrove forest management based on site conditions and stand productivity.

Mangrove soils and sediments in the LMC belong to illite and chlorite clay (16.53–20.19 me 100 g^{-1}), which are included in the low-capacity class. High and low CEC values indicate the ability of the soil to absorb nutrients, whereas high CEC values indicate the ability to absorb nutrients well, and vice versa. Net primary production can provide inputs for carbon stability to produce high CEC [22]. This illustrates that the condition of the site must be maintained to remain fertile and healthy. Based on the CEC values in Table 4, the sediment fertility level was relatively low, because this value was outside the medium category range [10]. However, many external factors disrupt the mangrove sediments. Apart from pollution, the ebb and flow of seawater, which is a characteristic of coastal areas, is a significant concern in efforts to preserve mangrove areas against potential damage.

Anthropogenic pollution from power plant waste (hot water streams), heavy metals, pesticides, polychlorinated biphenyls, industrial pollutants, eutrophication (fertilizers and sewage), and oil spills are major concerns affecting mangrove sediments and ecosystems [6]. Many toxic substances in oil spills can inhibit the growth of microbes in the soil and sediments [9]. This directly inhibits the function of mangroves as carbon sinks and binders. Carbon emissions are closely associated with climate change. Indonesia has made various efforts to mitigate climate change by conducting an inventory of carbon stocks to reduce the effects of greenhouse gases [33]. These pollution conditions occur at the study site.

Field observations showed that the LMC area has experienced ecosystem damage caused by oil spills. This condition is hazardous to ecosystems and living organisms in coastal areas, particularly mangrove forests. Therefore, an assessment of the risks and impact of oil spills on the environment is required. This incident occurred in the eastern season (May to July), when oil spills impacted the east coast of Lampung within a time range of 1 to 10 days and impacted for 2 to 5 days [34]. This oil spill occurred in 35% of the total area on the east coast of Lampung and impacted the LMC.

The risks posed by this include mangrove ecosystems, aquaculture, and tourism. In addition, oil spills hurt the productivity and growth of mangrove vegetation, and mangrove recovery from oil spills will only be seen ten years after the incident [35]. This indirectly affects the conditions of the site and the carbon storage in mangrove ecosystems. Regulation of organic matter and sediment pH is a way to solve the problem of oil spills. Sedimentary organic matter (complexed with Cu) can increase the mobility of Cu at higher pH levels in mangrove systems [5]. Thus, to maintain the potential of C-organic and mangrove litter, as well as overcome the problem of oil spills at mangrove sites, commitment and synergy between various parties need to be carried out so that there are actions to maintain and restore the ecosystem, especially communities that directly manage mangrove forests [36]. Knowing carbon and other potential is a form of forest inventory for monitoring forest health [37].

Conclusions

Based on calculations that have been carried out, the highest organic carbon (C-organic) content in sediment is found in the *Rhizophora mucronata* zone (CL3 and CL4), and the highest litter carbon is found in the *Avicennia marina* zone (CL2). The site carbon value has an influence on site health between C-organic and soil pH. The soil pH plays a role in the mobility of compounds that affect organic matter, including carbon. Therefore, the carbon content that describes the health condition of the site can be determined from the soil pH value. Environmental factors, such as tides and environmental pollution, can also affect the site health. For example, the LMC ecosystem is currently experiencing pollution owing to oil spills. This indirectly affects the fertility and health of the location. Therefore, it is necessary to maintain and restore ecosystems that are of concern to various stakeholders in order to synergistically preserve ecosystems and mangrove sites.

Author Contributions

ANS: Conceptualization, Methodology, Investigation, Formal Analysis, Visualization, Writing – original draft; **RS**: Conceptualization, Methodology, Formal Analysis, Visualization, Writing – original draft.

Conflicts of interest

There are no conflicts to declare.

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