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Potential Carbon Uptake by Meranti Ecotourism Area in Balikpapan City: Implications for Emission Reduction

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ABSTRAK

Pohon meranti dapat menangkap dan menyimpan karbon dari atmosfer, sehingga membantu mitigasi emisi gas rumah kaca. Pemerintah Kota Balikpapan harus menyadari dan memaksimalkan potensi tersebut. Penelitian ini bertujuan untuk menghitung biomassa, cadangan karbon, dan serapan CO2 di kawasan ekowisata Meranti di Kota Balikpapan untuk membantu target pengurangan emisi di kota tersebut. Biomassa tanaman meranti ditentukan dengan menggunakan sebuah persamaan. Biomassa setiap tanaman meranti bagian atas ditentukan dengan menggunakan rumus ln(AGB) = -1,533 + 2,294 x ln(DBH) + 0,56 x ln(WD). Bagian bawah menggunakan persamaan BGB = AGB x 0,2. Analisis cadangan karbon dilakukan dengan menggunakan rumus C = 0,47x (AGB+BGB). Menentukan jumlah karbon dalam limbah daun dengan mengalikan biomassa daun dengan persentase karbon yang ada. Hasil penelitian menunjukkan bahwa kawasan ekowisata Meranti di Kota Balikpapan memiliki biomassa sebesar 7.731 g dan cadangan karbon sebesar 7.092 g. Kedua nilai tersebut dapat mengurangi emisi CO_2 di atmosfer sebesar 10.711 gCO2 per hektar. Kawasan ekowisata Meranti berpotensi untuk mempercepat upaya Pemerintah Kota Balikpapan dalam mencapai tujuan penurunan emisi gas rumah kaca.

Kata kunci: Cadangan karbon; perubahan iklim; emisi CO_2; gas rumah kaca; sampah

ABSTRACT

Meranti trees can capture and store carbon from the atmosphere, helping in the mitigation of greenhouse gas emissions. The Balikpapan City government has to realize and maximize its potential. This study intends to calculate biomass, carbon stock, and CO2 uptake in the Meranti ecotourism area in Balikpapan City to help the city's emission reduction target. The biomass of meranti plants was determined using an equation. The biomass of each upper meranti plant was determined using the formula ln(AGB) = -1.533 + 2.294 x ln(DBH) + 0.56 x ln(WD). The lower part uses the equation BGB = AGB x 0.2. The analysis of carbon stocks was conducted using formula C = 0.47x (AGB+BGB). Determine the amount of carbon in leaf waste by multiplying the leaf biomass by the percentage of carbon present. The study revealed that the Meranti ecotourism area in Balikpapan City has a biomass of 7,731 g and a carbon stock of 7,092 g. Both values can decrease CO2 emissions in the atmosphere by 10,711 grams of CO_2 per hectare. The Meranti ecotourism region has the potential to expedite the Balikpapan City Government's efforts to reach the aim of lowering greenhouse gas emissions.

Keywords: Carbon stocks; climate change; CO2 emission; greenhouse gas; waste.

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1. INTRODUCTION

Trees and forests play an integral role in climate change mitigation efforts, especially in the context of carbon sequestration (Moomaw et al., 2020; Ontl et al., 2020). This process plays a vital role in balancing the concentration of CO_2 in the atmosphere through the mechanism of photosynthesis (Ryu et al., 2019), where trees and other plants absorb CO_2, convert it into organic matter, and store it in the form of biomass. In the context of ecotourism areas, the Meranti ecotourism area, nestled within the Balikpapan Forest conservation area, serves as a poignant testament to the vital need for preserving diverse ecosystems. Enveloped by towering Meranti trees (*Shorea spp.*) covering an area of 77 hectares, this locale not only carries profound cultural and economic significance but also assumes a pivotal role in environmental stewardship. Meranti, celebrated for its timber production and economic value across Indonesia, embodies a duality of prosperity and resilience. However, its intrinsic prowess as a formidable carbon sink, capable of sequestering vast amounts of atmospheric carbon dioxide, transcends its tangible benefits. Urban forests serve as crucial carbon sinks, effectively mitigating the impacts of climate change by absorbing atmospheric CO_2. The dense canopy structure of tree species like Meranti offers significant potential for carbon uptake through the storage of biomass (Jo & Ahn, 2012). Therefore, Meranti trees can capture and store carbon dioxide from the atmosphere within their living tissues. Tropical tree species such as Meranti are especially adept at this task due to their rapid growth rates and dense wood composition. Their fast growth allows them to accumulate biomass, which in turn enables them to store more carbon over relatively short periods compared to slower-growing species. Additionally, the dense wood composition of these trees means that they can hold a considerable amount of carbon within their structure.

Various studies bolster the potential of Meranti trees in mitigating CO_2 emissions through carbon storage. Raihan (2021) underscores the economic value of forest carbon stocks in Malaysia, emphasizing forests' role in curbing greenhouse gas emissions (Raihan et al., 2021), while Liu (2012) provides a case study on the carbon storage and sequestration by urban forests, which can include Meranti trees (Liu & Li, 2012). Rijal (2022) describes the community of *Shorea robusta* forests as a priority institution for the implementation of Local Adaptation Plans for Action to combat climate impacts (Rijal et al., 2022). Additionally, Superales (2016) highlights the high carbon storage potential of Mahogany saplings, a species akin to Meranti (Superales, 2016). The red meranti (*Shorea macrophylla*) had a high carbon biomass potential in both litter and soil, with the latter having a particularly high percentage of soil organic carbon (Kooch et al., 2017). Collectively, these studies affirm that the dense Meranti canopy, with its extensive biomass, holds a critical role in reducing atmospheric CO_2 through carbon storage.

In light of the Balikpapan City Government's initiative to slash GHG emissions by 4.3% by 2025, this study seeks to quantify the current carbon uptake of the local Meranti ecotourism forest. This study provides support to the city's emission reduction target by explaining the potential for carbon emission mitigation through forest carbon storage in Balikpapan. This pioneering study is the first attempt to address the important role of local forests, particularly the Meranti ecotourism area, in achieving the emission reduction target at Balikpapan city level. Therefore, the purpose of this study is to estimate and analyze the potential biomass, carbon stock, and CO_2 sequestration in Meranti ecotourism area in Balikpapan City.

2. METHODS

2.1. Research Location and Time

The research site is located at Jalan Giri Rejo 2, Kampung Banyumas, Karang Joang Village. The Meranti Tourism Area has an area of about 17 hectares out of a total of 77 hectares that are allowed to be utilized. The research area is only limited to four areas, namely locations A, B, C, and D, which can be seen in Fig.1 and Fig.2. The area of each Meranti area is 1,191 m^2, 9,755 m^2, 6,110 m^2, and 7,234 m^2, respectively. The study was carried out in January 2023 over a period of approximately 10 days.

2.2. Data Collection

The data collection method used in this research is done by collecting primary and secondary data. Primary data that will be used in this research includes data related to the existing conditions of the research area. This primary data collection will be carried out by survey or direct observation to the research location. Data taken in the form of location data or coordinate points of the meranti area, data on the area of meranti plants, data on the distance between trees, tree diameter at chest height or tree diameter at a height of 130 cm.

While the secondary data needed in this research is in the form of maps of administrative areas, land use, regional development plans, similar case studies, and so on. The secondary data is obtained by conducting a literature study.

2.3. Data Analysis

2.3.1. Estimated Number of Trees and Leaf Litter

The amount of leaf litter can be estimated using the approach of calculating the number of trees and the average leaf fall. Calculation of the number of trees using the formula (Coder, 2023):

$$M = \frac{A}{Jp}$$

Where M is the number of trees, A is the area (m^2) and Jp is the distance between trees (m^2). Meanwhile, the value of the amount of leaf waste in this study uses a previous research approach that has similar environmental and tree characteristics as in the Meranti ecotourism area. The total production of Meranti Tree leaves per week is 10.22 g/m^2/week for trees with a diameter of ± 20 cm and 19.275 g/m^2/week for trees with a diameter of ± 40 cm (Irawan et al., 2016). So, the amount of leaf waste can be calculated by this formula.

$$W = M \times Gd$$

Where W is the amount of leaf litter (g/m^2), M is the number of trees, Gd is the amount of leaf drop (g/m^2/week).

2.3.2. Estimation Carbon Stock

In this study, only two parameters were calculated, namely carbon in above and below-ground biomass (AGB) and litter biomass (LB). Above-ground biomass (AGB) is the total amount of biomass from plant parts located above the ground. It includes parts such as stems, branches, leaves, flowers, and fruits of the plant. AGB is one of the important parameters in measuring ecosystem productivity and carbon storage potential (Shen et al., 2018). The calculation formula used to calculate carbon in Above Ground Biomass is as follows (Dallinga, 2013).

$$\ln(AGB) = -1.533 + 2.294 \times \ln(DBH) + 0.56 \times \ln(WD)$$

Where AGB is above ground biomass, DBH is diameter at breast height (20 cm dan 40 cm) dan WD is wood specific gravity (0.55). After obtaining the AGB value, then calculate the below ground biomass (BGB).

$$BGB = AGB \times 0.2$$

Where BGB is below ground biomass, 0.2 is the conversion factor (Agonafir et al., 2017). To calculate carbon stock, use the following formula (Santosa et al., 2020).

$$C = 0.47 \times B$$

Where C is carbon stock (g), B is biomass (AGB + BGB). Meanwhile, to determine the carbon in leaf litter, first calculate the litter biomass. Litter Biomass (LB) is the amount of organic biomass accumulated on the soil surface, which consists of organic materials such as leaves, twigs, and other organic materials that have died or decomposed (Achmad, 2017; Gao et al., 2014).

$$CL = LB \times \%C$$

Where CL is carbon stock in litter biomass, LB is litter biomass which is the amount of leaf litter divided by the distance between trees, %C is organic C (35% for coarse litter and 14% for fine litter) (Achmad, 2017).

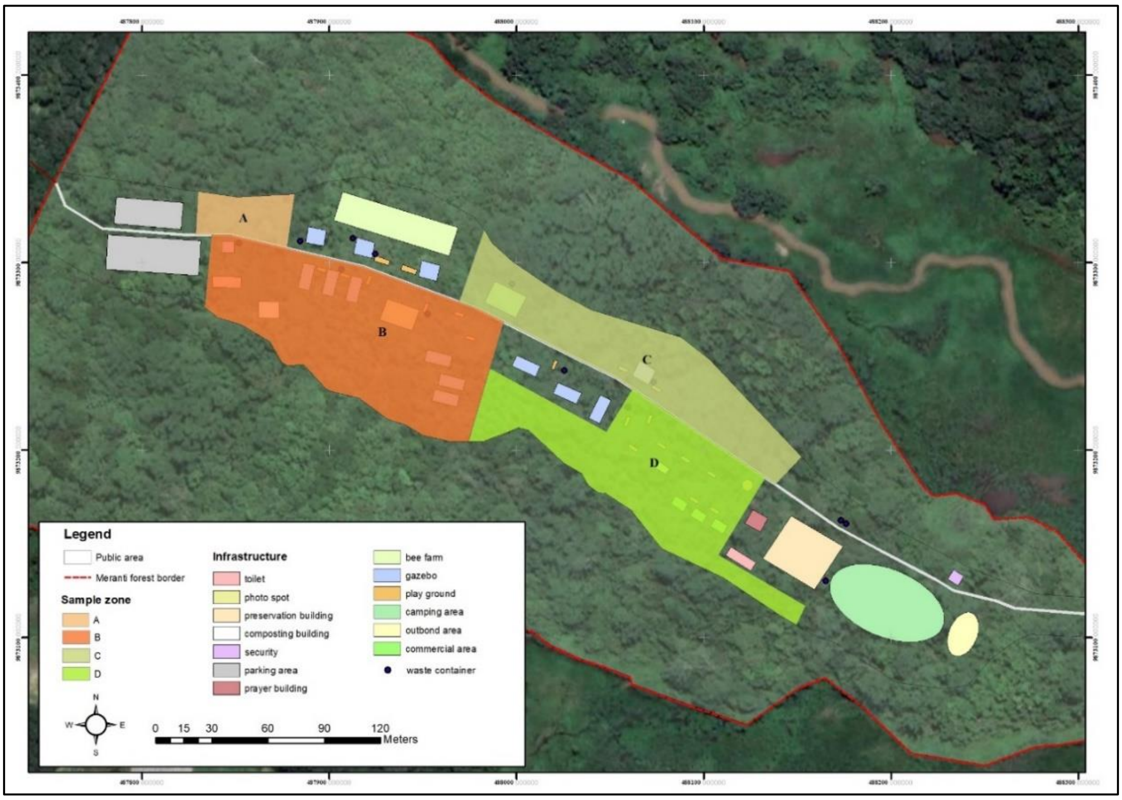

Figure 1. Research Location

Figure 2. Meranti Plants in Meranti Ecotourism

3. RESULT AND DISCUSSION

The results of observations of meranti plants show a planting distance of 6 m and 9 m between trees and almost the same diameter. The following in Table 1 is a profile of each of these areas.

The results of measuring trunk diameter obtained an average diameter of location A of 20 cm, location B of 30 cm, location C of 35 cm, and location D of 40 cm. The diameter of the tree trunk is an important indicator in determining the amount of biomass contained in it. Therefore, the diameter of the trunk is closely related to the volume and mass of wood in the tree. The larger the trunk diameter, the greater the probability that there is more biomass in the tree. In addition, trunk diameter also correlates with the amount of carbon stock in the tree. Carbon is absorbed by trees through photosynthesis and stored in the form of woody biomass. Therefore, by using trunk diameter data, we can estimate the amount of carbon stock each meranti tree has in the location. Based on Table 1, it can be seen that the amount of leaf litter varied across sites, with Site B producing the highest amount of leaf litter compared to the other sites.

In contrast, Site A produced the least amount of leaf litter, only 2,029 grams per square meter. This variation can be explained by the difference in the number of meranti trees in each site, where the more trees there are, the more leaf litter is produced. This leaf litter data was then used to estimate the amount of biomass contained in the leaf litter.

3.1. Biomass and Carbon in Above Ground and Leaf Litter

Before calculating carbon stocks, we first need to know the biomass. Biomass is the amount of organic matter stored in the tree. The distribution of biomass in each tree component shows how much photosynthesis is stored by the plant. Biomass and carbon increase because plants absorb CO_2 from the air and convert it into organic compounds through the process of photosynthesis by plants. Biomass estimation is very important for assessing carbon stocks. The results of biomass estimation in the Meranti ecotourism area can be seen in Fig. 3.

Based on the data presented in Fig. 3, the analysis showed that Site B had a higher total above-ground biomass than Site A, indicating a potentially denser vegetation cover. However, there was a significant difference in the amount of litter biomass between the two sites, as well as when compared to the amount of litter biomass at Sites C and D. This could be due to factors such as differences in environmental conditions, including climate and soil, as well as different land management practices. The amount of litter biomass at Site B tended to be close to its total above-ground biomass, indicating a significant accumulation of organic matter on the soil surface, signaling active organic matter turnover or efficient decomposition (Chen et al., 2014). Site C, while having higher total above-ground biomass than Sites A and B, was lower than Site D. Meanwhile, Site D showed the highest total above-ground biomass among all observed sites.

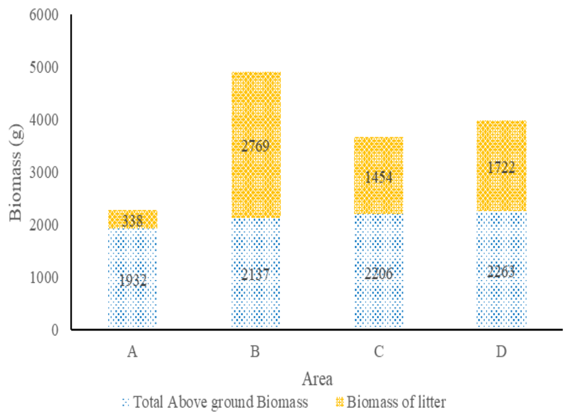

Figure 3. Total Biomass in Above Ground and Litter

Figure 4 shows the different carbon distribution patterns between the sites. Site B shows a higher proportion of carbon stock in litter biomass compared to above ground, indicating different ecological processes in this area. In contrast, sites C and D showed an almost equal distribution between above-ground carbon and litter biomass. Site A showed a higher proportion of above-ground carbon compared to carbon stock in litter biomass. The increase in carbon is in line with the increase in biomass. The higher the amount of biomass, the higher the amount of carbon stock. Figure 4 shows the different carbon distribution patterns between the sites. Site B shows a higher proportion of carbon stock in litter biomass compared to above ground, indicating different ecological processes in this area. In contrast, sites C and D showed an almost equal distribution between above-ground carbon and litter biomass. Site A showed a higher proportion of above-ground carbon compared to carbon stock in litter biomass. The increase in carbon is in line with the increase in biomass. The higher the amount of biomass, the higher the amount of carbon stock.

Table 1. Profile Each Area in Meranti Ecotourism

Location	Area (m^2)	Distance between trees (m)	DBH (cm)	Number of trees	Number of leaves fallen (g/m^2/week)	Amount of leaf litter (g/m^2)
A	1,191	6	20	199	10	2,029
B	9,755	6	30	1,626	10	16,616
C	6,110	9	35	679	19	13,089
D	7,234	9	40	804	19	15,497

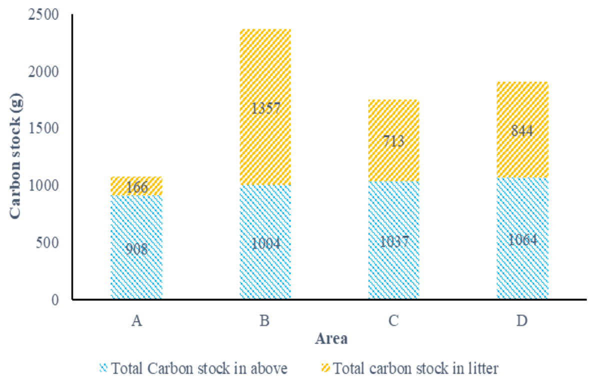

Figure 4. Amount of Above Ground Carbon and Litter

3.2. Carbon Uptake

Meranti plants in four locations with an area of 2.429 ha can absorb 26,029 gCO_2. Meranti plantations have the potential to reduce CO_2 content in the atmosphere, which is quite large, with an average of every hectare (ha) of meranti plants in the ecotourism area absorbing around 10,711 g CO_2. If the area is 77 ha, then the CO_2 absorbed reaches 824,794 gCO_2/ha with the assumption that CO_2 absorption is proportional to land area. However, the Meranti leaf area index is not greater than the leaf area of other trees. However, meranti trees still have productivity in absorbing carbon. Leaf area affects the speed of photosynthesis; the wider the leaves are, the faster the photosynthesis process will be. Through the process of photosynthesis, CO_2 in the air is absorbed by plants and, with the help of sunlight, is then converted into carbohydrates to be distributed throughout the plant body and stockpiled in the form of leaves, trunks, twigs, fruits, and flowers. Although photosynthetic activity occurs in the leaves, the largest distribution of the photosynthetic products is used for trunk growth. The trunk generally has a larger wood volume compared to other parts of the tree, so it has a significant role in CO_2 uptake and carbon stock.

Carbon dioxide (CO_2) is one of the greenhouse gases that causes global warming and climate change. One of the natural ways to reduce the concentration of CO_2 in the atmosphere is through carbon uptake and storage by forest ecosystems, in this case, the Meranti ecotourism area. Differences in carbon stocks between forest sites can be caused by a number of ecological factors, such as tree diameter at breast height (DBH); trees with larger DBH tend to have more biomass and, therefore, can store more carbon in their tissues (Lutz et al., 2018). Tree density also influences the amount of carbon stock in an area; the denser the trees, the more carbon is stored as there is more total biomass in the area (Stephenson et al., 2014). Furthermore, the number of trees directly affects the total amount of biomass and, therefore, the amount of carbon stock in a forest ecosystem. Areas with a greater number of trees have the potential to store more carbon (Naeem et al., 2009). The amount of leaf litter is an important source of organic matter for decomposition and carbon storage in the soil. High amounts of leaf litter can increase soil organic matter content, which in turn can increase soil carbon stocks (García-Palacios et al., 2013).

From Table 2, there is a close relationship between the increase in carbon and the increase in biomass in the Meranti forest ecosystem. The higher the amount of biomass, the higher the amount of carbon stock in the ecosystem. The main carbon in forest ecosystems is stored in living plant tissues, such as trunks, branches, and leaves (Luyssaert et al., 2018). For example, increased tree growth and biomass accumulation in the form of wood are key indicators of increased carbon stocks in forests (Bastin et al., 2019).

The performance of Meranti Trees depends on region and site characteristics. Faster growth as well as higher biomass accumulation was attributed to a contains of soil nutrients and microclimate (Mun et al, 2018). Despite being the smallest area with the least number of trees, Site A showed relatively high performance in terms of biomass, carbon stock and CO_2 sequestration. Microclimatic factors are likely the main reason, where environmental conditions favor optimal tree growth despite the limited number of trees. Positive microclimate effects, such as sufficient sun exposure, maintained humidity, allowed the trees in Site A to grow well and produce significant biomass.

As the largest area with the largest number of trees, Site B has the highest biomass, carbon stock and CO_2 sequestration values compared to other sites. This is consistent with the size and number of trees present, where a large area allows for a higher density of trees and results in optimal carbon sequestration.

With an intermediate area and a relatively small number of trees relative to its size, Site C produced a fairly high biomass and carbon stock, but not as high as Site B. This suggests that a lower density of trees relative to area may still allow for good carbon performance, although not as efficiently as an area with more trees. This shows that lower tree density relative to area still allows for good carbon performance, although not as efficiently as areas with more trees.

Table 2. Carbon Uptake in Each Location

Location	Area (m^2)	Number of trees	Total Biomass (g)	Total carbon stock (g)	Carbon uptake (gCO_2)
A	1,191	199	2,270	1,074	3,941
B	9,755	1,626	4,906	2,361	8,666
C	6,110	679	3,661	1,750	6,421
D	7,234	804	3,985	1,908	7,001
Total	24,290	3,307	7,731	7,092	26,029
Average	6,073	827	1,933	1,773	6,507

Site D occupies a middle position in carbon performance, with moderately high values of biomass, carbon stock and CO_2 sequestration. This site reflects the results of an intermediate area with moderate tree density, where the distribution of trees and availability of environmental resources are good enough to generate significant carbon sequestration. Differences in carbon storage in litter biomass at a given site, such as those observed in Site B, may indicate active decomposition processes or higher levels of organic matter input. These active decomposition processes indicate higher dynamics in ecosystem functioning at the site. It can have significant implications on nutrient cycling, soil fertility, and overall ecosystem health. For example, rapid decomposition can increase nutrient availability to plants and improve soil fertility (Powers et al., 2009; Santosa et al., 2020). In addition, positive microclimate effects, such as adequate sun exposure, retained moisture, protection from wind or pollution are favorable for generating significant carbon sequestration (Kotrla & Prčík, 2019).

The data showed that Meranti plants were able to absorb a significant amount of carbon across four sites, totaling 2,429 ha. This highlights the important role of plants in absorbing carbon from the atmosphere, helping to reduce CO_2 concentrations that cause global warming. Carbon uptake by plants, such as meranti, has a direct impact on reducing greenhouse gas emissions.

The revelation of the extraordinary capacity of Meranti plants to sequester carbon across multiple sites emphasizes the critical role of natural ecosystems in mitigating climate change. These data underscore the importance of conserving and restoring forests like Meranti, as they act as important carbon sinks, effectively reducing atmospheric CO_2 concentrations and helping to combat global warming. The findings advocate for more intensive conservation efforts and sustainable management practices aimed at protecting Meranti forests and other carbon-rich ecosystems. By increasing the planting of plants that are efficient in absorbing carbon, we can accelerate efforts to achieve greenhouse gas emission reduction targets, especially in Balikpapan City. Primary forests, where meranti plants often grow, are very important carbon reservoirs. Conservation of primary forests and reduction of deforestation, including proper waste management (Khoriah & Ulimaz, 2023), are important steps in maintaining the carbon reserves stored in them and preventing the release of carbon into the atmosphere.

In addition, the positive impact of promoting ecotourism activities that encourage visitors to appreciate and support conservation efforts in the Meranti area can contribute to its preservation and further increase its carbon sequestration potential (Hakim & Nakagoshi, 2014). Education and awareness campaigns can be launched to inform locals and tourists about the importance of protecting natural ecosystems to mitigate climate change (Graci & Van Vliet, 2020; Lanier, 2014). For instance, collaborate with schools to integrate environmental education into the curriculum, organizing field trips to ecotourism sites and inviting guest speakers to discuss conservation topics (Moseley et al., 2020). Another example is developing and implementing public awareness campaigns about the importance of conservation and sustainable tourism practices (Gani et al., 2017). These campaigns can use various tools such as social media, television, radio, and printed materials to reach a wide audience. Therefore, it is important for local governments and communities to work together to create policies and programs that support forest planting and preservation as a carbon sink strategy in Balikpapan.

4. CONCLUSIONS

Meranti ecotourism area in Balikpapan City has a total biomass of 7,731 g and carbon stock of 7,092 g. Both values are able to reduce CO_2 emissions in the atmosphere by 10,711 gCO_2 per unit hectare area. This shows that Meranti ecotourism area has the potential to accelerate the efforts of Balikpapan City Government in achieving the target of reducing greenhouse gas emissions. A comprehensive strategy that integrates forest conservation, ecotourism development, and community involvement can maximize the potential of areas such as the Meranti ecotourism area in reducing greenhouse gas emissions.

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