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Analysis of Carbon Emission Levels in the SSH Forest Area Based on Land Cover Change

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ABSTRACT
The Sultan Syarif Hasyim (SSH) Forest Park (Tahura) area in Riau Province is a forest conservation area that has an important role in maintaining the balance of the ecosystem, especially in terms of carbon sequestration and carbon emission reduction. This study aims to measure the level of carbon emissions resulting from land cover changes and analyze the main causative factors of carbon emissions in the Tahura SSH area. The methods used include field analysis, measurement of carbon emissions based on land cover changes, and data processing using emission modeling software. The results show that carbon emissions in this region are mainly caused by deforestation and land clearing activities, which accelerate the release of carbon stored in forest biomass. In addition, this study provides recommendations for mitigation strategies that can be carried out, such as forest rehabilitation efforts, sustainable land management, and strengthening conservation policies. This research is expected to be an important reference in efforts to reduce carbon emissions in conservation forest areas and encourage policies that support environmental sustainability.

INTRODUCTION

The environmental phenomenon faced today is global warming caused by an increase in Greenhouse Gases (GHGs). One of the most abundant and long-lasting Greenhouse Gases (GHGs) is carbon dioxide (CO2). Based on the IPCC report (2006), the composition of CO2 is around 76.6% compared to other types of GHGs, such as Methane (CH4), Nitrogen Dioxide (N2O), Nitrogen Trifluoride (NF3), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur Hexafluoride (SF6). In Indonesia, total GHG emissions in 2020 amounted to 468,413 Gg CO2, of which 183,492 Gg CO2 (39.17%) came from Riau Province (MoEF, 2021).

Carbon emissions are the process of releasing carbon dioxide (CO2) and other greenhouse gases into the Earth's atmosphere. Carbon emissions can be caused by natural factors or human activities (Bar et al., 2022). The level of carbon emissions released into the atmosphere and the ability to absorb carbon affect the amount of GHG emissions in the atmosphere. Sources of carbon emissions come from various sectors, including the industrial, energy and transportation, agriculture, land use and forestry, and waste sectors, while the carbon absorption capacity comes from the existence of green vegetation covering land (Intergovernmental Panel on Climate Change, 2006). The excessive increase in carbon emissions coupled with the loss of land cover vegetation due to the continuous conversion of functions has increased the amount of carbon emissions.

Riau Province is one of the provinces that has diverse natural resources and biodiversity. One of its natural resources is the Sultan Syarif Hasyim Forest Park (hereinafter abbreviated as Tahura SSH). Based on Decree No. 178/KSDAE/RKK/KSA.0/9/2023 concerning the Determination of the SSH Tahura Management Block, it has an area of: (1) A protection block with an area of 962.62 ha; (2) Utilization block with an area of 410.13 ha; (3) Rehabilitation block with an area of 4,390.63 ha; (4) Special block with an area of 51.76 ha; (5) Collection block with an area of 356.85 ha. This conservation area has high ecological value and plays an important role for rare and endemic species. However, with many human activities such as building settlements, plantations, and mining in the area, the land cover has changed from forest to non-forest, causing carbon release into the atmosphere to increase (Biah et al., 2024).

Based on the results of the analysis of sentinel images coverage on May 22, 2022 and field ground checks carried out covering an area of ± 3,696 Ha, the Tahura SSH area has changed its function to an oil palm plantation, covering an area of ± 300 Ha in the form of shrubs and wild acacia plants, and the Tahura SSH area with natural vegetation cover only ± 2,176 Ha or one-third of the total area (Li et al., 2023). This condition causes an increase in carbon emissions through land degradation such as fires and decomposition. High carbon emissions can cause damage to forest ecosystems, reduce biodiversity, and accelerate climate change. Therefore, calculating the level of carbon emissions in this region is very important to understand the ongoing environmental impact and formulate effective mitigation strategies (Mya, 2020).

The environmental impacts of carbon emissions are becoming more apparent, contributing to the increasing frequency and intensity of climate-related events, such as flooding, droughts, and wildfires. Indonesia, with its vast tropical rainforests, holds a key position in the global fight against climate change (Agus et al., 2013). Forest conservation areas like the Sultan Syarif Hasyim (SSH) Forest Park play a critical role in reducing carbon emissions by acting as carbon sinks. However, changes in land cover due to human activities, such as agricultural expansion, illegal logging, and deforestation, disrupt this delicate balance. In particular, the loss of forested areas in the SSH Forest Park leads to significant carbon emissions, which, if left unchecked, could have severe consequences for both the local and global climate (Assede et al., 2023).

One of the primary concerns of land cover changes in forest conservation areas is their impact on carbon storage in vegetation and soil. Forests store carbon in both living biomass and in the soil, and when they are cleared or disturbed, this carbon is released back into the atmosphere, contributing to the greenhouse effect (Sambieni et al., 2024). The SSH Forest Park, once an area of lush green vegetation, has seen its fair share of land-use changes, many of which are driven by economic activities like logging, agriculture, and infrastructure development. Understanding the exact sources and extent of carbon emissions in this region is crucial for assessing the effectiveness of current conservation strategies and identifying new approaches to reduce emissions (Lozano-García et al., 2020).

In addition to land-use changes, forest fires pose another significant threat to the SSH Forest Park. During dry seasons, the combination of human activity and natural conditions can lead to forest fires, which not only destroy vegetation but also release large amounts of carbon stored in trees and soil (Buthelezi et al., 2024). The smoke and carbon emissions from these fires can spread to neighboring areas, further exacerbating the impacts of global warming. The region has already experienced numerous forest fires over the years, which have led to a dramatic increase in carbon emissions. Thus, monitoring and mitigating these fires is also a key component of reducing overall carbon emissions in the SSH Forest area (Biaou et al., 2021).

As global awareness of the importance of forest conservation grows, there is an increasing push for better land management practices and policies that encourage the protection

of forests and their ecosystems (Kusiima et al., 2022). Sustainable forestry practices, such as selective logging, agroforestry, and reforestation, have been promoted as viable solutions to minimize carbon emissions and promote environmental sustainability. However, the implementation of these practices often faces challenges, such as limited funding, lack of enforcement, and competing land-use interests. In this context, research on carbon emissions resulting from land cover changes in conservation areas like the SSH Forest Park is essential for informing policy and decision-making processes (Lu et al., 2021).

Research by Siregar et al. (2020) focused on the carbon emissions associated with deforestation in the Riau Province. The study used remote sensing and GIS data to map land cover changes and estimate the carbon released from deforested areas. The findings highlighted that significant amounts of carbon were emitted due to large-scale land conversion for agriculture and industrial activities. The study also discussed the effectiveness of reforestation efforts in sequestering carbon and mitigating emissions, providing a valuable insight into forest management strategies.

A study by Prasetyo et al. (2021) examined the impact of forest degradation and land cover change on carbon emissions in Sumatra. Using a combination of field measurements and remote sensing technologies, the research estimated the amount of carbon emitted from various land use types, including forests, plantations, and urban areas. The study concluded that forest degradation, particularly from illegal logging and land clearing, was one of the main contributors to carbon emissions in the region. It also emphasized the importance of effective forest conservation policies to curb carbon emissions and protect biodiversity.

Although previous studies have provided valuable insights into the impact of land cover changes on carbon emissions, there remains a lack of focused research on specific conservation areas such as the SSH Forest Park. Most studies have concentrated on larger regional areas, which do not capture the unique characteristics of smaller conservation areas. Furthermore, there is a limited understanding of how different land cover types within these parks contribute to carbon emissions over time. By focusing on the SSH Forest Park, this study aims to fill these gaps by providing more localized and detailed data on carbon emissions and their primary drivers.

This study is novel in its approach to directly measure the carbon emissions caused by land cover changes within the SSH Forest Park. Unlike many previous studies that rely on broad regional data, this research focuses on a specific conservation area, providing a detailed analysis of local carbon emissions. By using advanced emission modeling software and field-based measurements, this study offers a more precise and up-to-date assessment of the factors contributing to carbon emissions in the region. Additionally, it explores the effectiveness of mitigation strategies such as forest rehabilitation and sustainable land management practices in reducing emissions.

The purpose of this study is to measure and analyze the carbon emissions resulting from land cover changes in the SSH Forest Park. This research aims to identify the primary drivers of carbon emissions, such as deforestation, land clearing, and forest fires, and to assess the effectiveness of current mitigation strategies. The findings of this study will contribute to the development of more targeted conservation policies and strategies aimed at reducing carbon emissions and enhancing the role of the SSH Forest Park as a carbon sink. Moreover, the research will serve as a reference for future efforts to mitigate climate change in conservation areas across Indonesia and beyond, promoting the protection of vital ecosystems and supporting environmental sustainability.

RESEARCH METHOD

The research was conducted at the Sultan Syarif Hasim Forest Park (TAHURA SSH). The Tahura SSH area has an area of 6,172 ha, of which 2,323.33 ha is in the Siak Regency area; 3,041.81 ha of which are in the Kampar Regency area; and 806.86 ha in the Pekanbaru City area. The data that will be collected and analyzed in this study are primary data and secondary data. Sampling was carried out through field observation surveys, direct measurements, and interviews for primary data. Meanwhile, secondary data is carried out by literature study. The calculation of the amount of CO2 emissions is carried out to find out how much CO2 emissions are produced from forest areas. The amount of CO2 emissions was obtained based on *overlay* data on land cover conditions in 2000-2020. Changes in land cover in forest areas have had CO2 emission factors determined by the Ministry of Environment and Forestry and IPCC (2006).

The analysis of carbon emission levels is calculated with Tier-1 accuracy. Based on the IPCC (2006), the accuracy of calculating GHG emissions is grouped into 3 levels of accuracy known as the term "Tier. In Indonesia, GHG emission sources use Tier-1. Estimate tier 1 GHG emissions using the following equation:

Tier 1 Umun Equation

Carbon Emissions (Tons CO2/ha/year) = Activity Data (ha/year) x Emission Factors (Tons CO2/ha)

Activity data is data on the amount of activity associated with the amount of carbon emissions released. Data on emissions-producing activities in forest areas is a change in land cover. Meanwhile, the emission factor (FE) is a coefficient that shows the number of emissions per unit of activity.

RESULTS AND DISCUSSION

Existing Conditions of Tahura SSH

Based on the analysis of the existing conditions of land cover in the Tahura SSH conservation forest area, the land cover consists of Secondary Dryland Forest covering an area of 1,717.33 ha, Secondary Swamp Forest covering an area of 28.26 ha, Open Land covering an area of 11.23 ha, Plantation covering an area of 3,172 ha, Mixed Dryland Agriculture covering an area of 973.38 ha, and swamp bush covering an area of 269.80 ha. The land cover area is presented in Table 1.

Table 1. Existing Conditions of SSH Tahura Land Cover

Land Cover	Area (Ha)	Percentage (%)
Secondary Dryland Forests	1.717,33	27,82
Secondary Swamp Forest	28,26	0,46
Open Land	11,23	0,18
Plantation	3.172	51,39
Mixed Dryland Agriculture	973,38	15,77
Swamp Bush	269,80	4,37
Total	**6.172**	**100,00**

Source: Processed from the Results of the Analysis of the Land Cover Map of BPKHTL XIX 2024

The plantation area in the Tahura SSH conservation forest area reaches 3,172 ha or 51.39% of the total forest area. The majority of plantation commodities are oil palm plantations. This condition shows that there has been deforestation and forest conversion activities that have the potential to cause an increase in carbon emissions released into the atmosphere.

B. SSH Tahura Land Cover

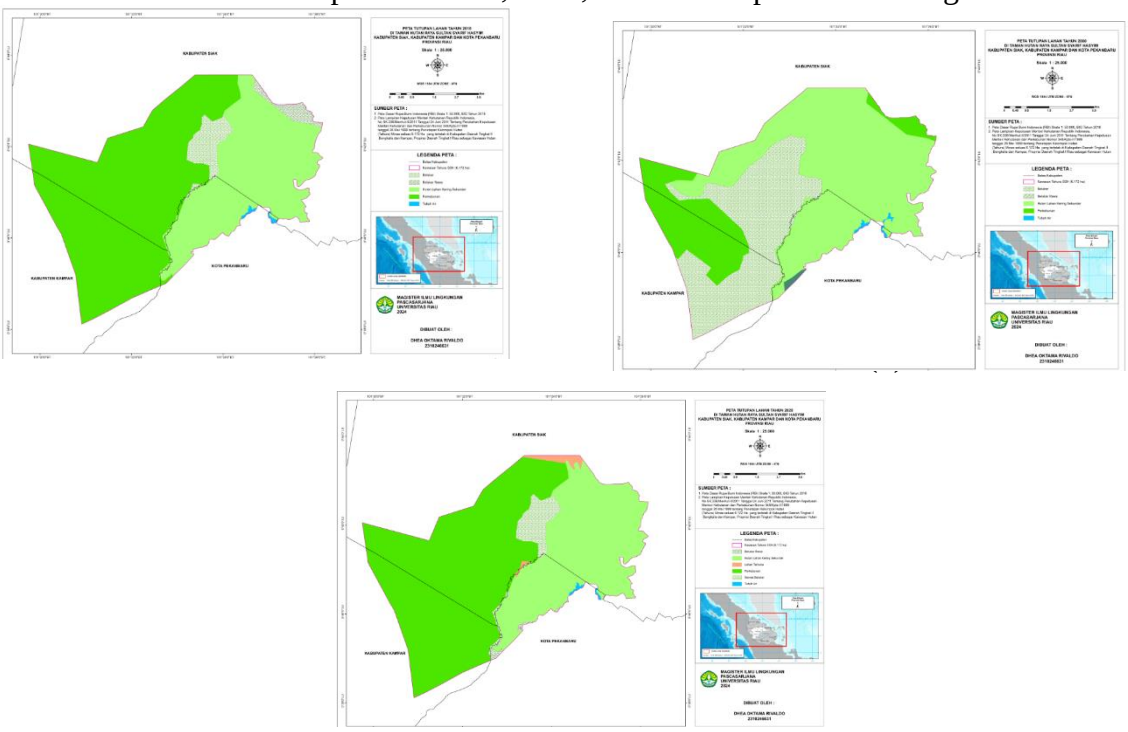
The utilization of forest areas that occur in the Tahura SSH area can be analyzed based on changes in land cover. The results of spatial analysis show that there has been a decline in the Tahura SSH forest area during the period from 2000 to 2020. The full analysis data is presented in Table 2.

Table 2. Area of Changes in Tahura SSH Land Cover

It	Year	Forest Area (ha)	Decline in Forest Area (ha)	Percentage (%)	Rate of Decline in Forested Areas (ha/Year)
		a	***b***	***c***	***b / 10 Years***
1	2000	3236,40	2935,60	47,56	293,56
2	2010	2116,15	4055,85	65,71	405,585
3	2020	1745,59	4426,41	71,72	442,641
		Average		**61,66**	**380,60**

Source: Analysis results, 2024

The decrease in the area of forested areas is evidenced by changes in land cover conditions. This change can be illustrated spatially, where most of the land cover in the Tahura SSH area has been turned into plantations (non-forests). A comparison of the distribution of Tahura SSH land cover maps from 2000, 2010, and 2020 is presented in Figure 1.



(c)

Figure 1. Changes in Land Cover in the Tahura SSH Area, (a) Year 2000; (b) Year 2010; (c) Year 2020

The decline in forest area is triggered by several factors, namely deforestation, conversion of forest areas, and occupation of forest areas in the Tahura SSH area. In the Tahura SSH area, there are also residential areas that make community activities in the forest area difficult to supervise. This condition causes an increase in land cover changes that continue to increase.

The change in land cover that occurred in the Tahura SSH area was caused by an increase in forest conversion activities into oil palm plantations. This leads to the loss of ecological and hydrological functions of forest areas. Potential impacts include (a) loss of vegetation and

animal diversity, (b) loss of water catchment areas, (c) increased CO2 emissions, (d) land degradation, and (e) loss of carbon stocks from forest areas. Land clearing from forests to plantations will eliminate the diversity of vegetation that turns into monoculture. Land clearing has reduced the amount of vegetation as a producer in the life chain of the biological structures that make up the ecosystem. The extinction of vegetation will put pressure on various types of fauna as consumers on it. This triggered the extinction of fauna that were unable to adapt to changes in their environment. The loss of vegetation also affects the constituent and retaining structures of water and causes an increase in carbon emissions in these forest areas (Fischer et al., 2016).

Analysis of Carbon Emissions in the Tahura SSH Area

The analysis of carbon emission levels is calculated based on the approach of changing the value of carbon stocks lost due to changes in land cover from forest areas to non-forests. The results of the analysis of changes in carbon stocks based on land cover are presented in Table 3.

Table 3. Carbon Stock Value Based on Land Cover Class Changes

It	Types of Land Cover Tahura SSH	Area of Land Cover Change in 2000 (ha)	Area of Land Cover Change Year 2020 (ha)	Carbon Reserves Year 2000 (Tons)	Carbon Reserves Year 2020 (Tons)	Total Carbon Stock Change (Tons)	Changes in Carbon Stocks (Corrugated iron C/ha)
			a	***b***	***c***	***(C-B)***	***(c-b)/a***
1	Secondary Dryland Forests	3.236,40	1.717,33	290.228,77	56.446,80	-256.722,83	-149,49
2	Open Land	0,00	11,23	0,00	28,075	28,075	2,50
3	Plantation	1.016,49	3.172	6.098,94	29.201,40	12.933,06	4,08
4	Mixed Dryland Agriculture	20,44	973,38	613,20	19.032	28.588,2	29,37
5	Secondary Swamp Forest	0,00	28,26	0,00	5.652,00	5.652	2,50
6	Shrub	1.881,56	0,00	0,00	0,00	-56.446,8	0,00
7	Swamp Bush	0,00	269,80	0,00	809,40	809,4	3,00
	Sum			610.110,54	344.951,65	-265.158,90	89,46
	CO2 emissions from forest areas become non-forested					**16.42 tons of CO2/ha/year**	

Source: Analysis results, 2024

CONCLUSION

Carbon emissions resulting from deforestation and forest conversion activities cause land cover changes. Based on the land cover map from 2000 to 2020, there has been a decrease in carbon reserves of 265,158.90 tons/C in the Tahura SSH area with a CO2 emission rate of 16.42 tons/ha/year due to the land conversion. The rate of increase in CO2 emissions is due to the decline of forested areas that have been converted into non-forest areas in the Tahura SSH area.

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