BIODIVERSITAS
Volume 22, Number 4, April 2021
Pages: 2142-2149

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d220464

Carbon emissions as impact of mangrove degradation: A case study on the Air Telang Protected Forest, South Sumatra, Indonesia (2000-2020)

SYAIFUL EDDY[1], NORIL MILANTARA[2], MOHAMMAD BASYUNI[3,♥]

[1]Department of Biology, Faculty of Natural Sciences and Technology, Universitas PGRI Palembang. Jl. Jend. A. Yani, 9/10 Ulu, Palembang 30251, South Sumatra, Indonesia

[2]Faculty of Forestry, Universitas Muhammadiyah Sumatera Barat. Jl. Pasir Kandang No. 4, Koto Tangah, Padang 25172, West Sumatra, Indonesia

[3]Department of Forestry, Faculty of Forestry, Universitas Sumatera Utara. Jl. Tri Dharma Ujung No. 1, Medan 20155, North Sumatra, Indonesia. Tel./fax: +62-61-8201920, ♥email: m.basyuni@usu.ac.id

Manuscript received: 27 February 2021. Revision accepted: 31 March 2021.

Abstract. *Eddy S, Milantara N, Basyuni M. 2021. Carbon emissions as impact of mangrove degradation: A case study on the Air Telang Protected Forest, South Sumatra, Indonesia (2000-2020). Biodiversitas 22: 2142-2149.* Massive degradation in ATPF occurs due to anthropogenic activities that have converted this area into a coconut plantation, fishpond, settlement, and agriculture. The purpose of this study was to describe changes in land cover and the amount of CO_2 emission in ATPF and its causes during the 2000-2020 period using remote sensing data. Data from remote sensing were used to obtain area, classification and land cover change in each period; meanwhile, carbon stock, emissions, and CO_2 sequestration were obtained from the analysis using LUMENS software. The results showed that the emissions resulting from land conversion in ATPF during the 2000-2020 period were much greater than sequestration. Net emissions of 1,928,076.56 tons of CO_2-eq with an annual emission rate of 96,403.83 tons of CO_2-eq/year. The largest source of emissions came from the conversion of primary forest, coconut plantation and secondary forest to open areas; while the source of sequestration comes from the formation of primary and secondary forests. There need to be restoration and conservation efforts in this area by the government and the community to restore the function of ATPF as a coastal protection forest. This research is the first study to examine land cover changes in mangrove forests using data analysis methods with LUMENS.

Keywords: Air Telang Protected Forest, carbon emission, mangrove forest degradation, remote sensing

Abbreviations: ATPF: Air Telang Protected Forest. LUMENS: using Land Use Planning for Multiple Environmental Services

INTRODUCTION

Mangrove forests grow along the muddy coasts that undulate weakly around the mouths of large rivers and deltas in the intertidal regions of tropical and subtropical countries. Mangrove plant species have different levels of tolerance to salinity and are strongly influenced by geophysical, geographic, geological, hydrographic, biogeographic, climatic and edaphic factors spatially and temporally (Ellison 2002; Linares et al. 2007; Feller et al. 2010; Basyuni et al. 2019, 2014). They provide a variety of environmental services for life and can reduce the impact of global climate change from their ability to store carbon stocks (Lee et al. 2006; Fatoyinbo et al. 2008; Nagelkerken et al. 2008; Koch et al. 2009; Mukherjee et al. 2014; Eddy et al. 2016; Atwood et al. 2017; Ouyang et al. 2018; Hochard et al. 2019; Kusmana et al. 2019). They store up to three times more carbon than inland tropical forests and five times more than upland forests (Donato et al. 2011; Murdiyarso et al. 2015). On the other hand, the reduced quality and quantity of mangrove forests will increase the rate of greenhouse gas emissions in nature, which in turn creates problems in mangrove forest conservation, especially in the context of climate change (Mai et al. 2019).

Air Telang Protected Forest (ATPF) is one of the mangrove protected forests in South Sumatra Province, Indonesia. This protected forest has an area of approximately 12,660.87 ha. Degradation that occurs due to anthropogenic activities such as coconut and oil palm plantations, fishponds, agricultural land, ports, and settlements in this area has resulted in decreased species diversity in it (Eddy et al. 2017, 2019, 2021). One of the indicators of disturbed ATPF mangrove forest is *Nypa fruticans* invasion in almost all zones, from tidal zone to near land zone (Eddy and Basyuni 2020). Recently it has been reported that one of the anthropogenic drivers of mangrove loss in ATPF was coconut plantation (Eddy et al. 2021).

This study describes changes in land cover and the amount of CO_2 emissions in ATPF and their causes during the 2000-2020 period. Data obtained through remote sensing to determine land cover changes that have occurred. In addition, the determination of carbon stocks and CO_2 emissions and sequestration were determined using Land Use Planning for Multiple Environmental Services (LUMENS) software (van Noordwijk et al. 2016). This software can help analyze carbon emissions by entering data on changes in land cover over a certain period in an area (Nguyen et al. 2016; Untari et al. 2018; Do et al. 2020). The results of this analysis are expected to be a reference for the government in determining policies to reduce carbon emissions as one of the efforts to mitigate global climate change.

MATERIALS AND METHODS

Study area

Air Telang Protected Forest (ATPF) is a mangrove forest with an area of approximately 12,660.87 ha which is directly adjacent to the east with Banyuasin II and Muara Telang Districts; in the west by the Banyuasin River; in the north by the Bangka Strait; and in the south with Muara Telang District. Many communities and companies have converted this protected forest into coconut plantations, oil palm plantations and fishponds. Plants in this region are dominated by Nypa fruticans for the tree level, Rhizophora apiculata for saplings and Acrostichum aureum for understorey/seedling levels (Eddy et al. 2019).

Methodology

The data used in this study are spatial data of land cover in 2000 and 2020 in the form of raster data and administrative data in the form of vector data. The supporting data used are the reference map of land use types and the carbon density reference tabular data for each land cover type. Land cover data was obtained based on the results of remote sensing data from Landsat imagery for 2000 and 2020 with specs obtained from USGS glovis (Table 1). We used Landsat 5 TM data types in 2000 and Sentinel-2 in 2020. Although there are differences in spatial resolution between the two, we have minimized errors through our supervised classification method. In addition, we also used Landsat 8 imagery data to adjust and correct the land cover type generated from the Sentinel-2 imagery in 2020. Forestry thematic maps and relevant land cover maps obtained from the South Sumatra Provincial Forestry Service are also used to support land cover classification and to improve the accuracy of classification results.

Land cover data were analyzed using a Geographic Information System (GIS) using ArcGIS 10.5 software. Land cover classification based on land use type and tree canopy cover density. The land cover type classification consists of primary forest, secondary forest, coconut plantation, open area, fishpond and water body. Several field survey locations were determined using the Geographical Positioning System (GPS). The field survey points we used (Table 2) were the same as those we used in our previous research (Eddy et al. 2021).

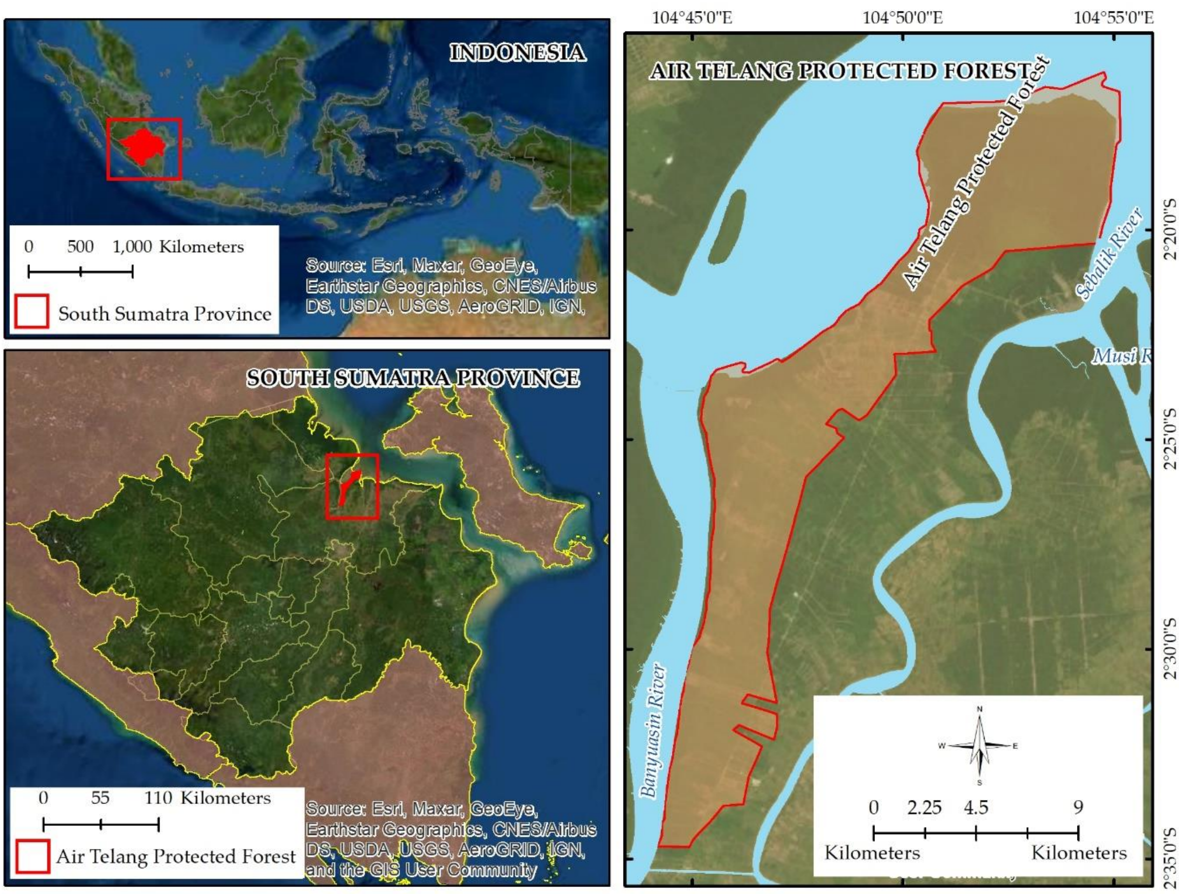

Figure 1. Map of ATPF locations in South Sumatra Province, Indonesia. Map coordinate system: UTM projection, zone 48 S, datum WGS 1984

Table 1. Specifications of Landsat Image data used

Data type	Bands kind	Resolution (m)	Date of acquisition	Source
Landsat 5 TM	RGB 543	250	19-08-2000	USGS Glovis
Sentinel-2	RGB 654	250	20-04-2020	USGS Glovis

Table 2. The coordinates of the field survey results using a Geographical Positioning System (GPS) (Eddy et al. 2021)

No	Latitude	Longitude	Actual_con
1	2º 32' 0.874" S	104º 45' 52.912" E	Secondary forest
2	2º 16' 42.162" S	104º 54' 22.317" E	Secondary forest
3	2º 20' 36.549" S	104º 51' 36.003" E	Secondary forest
4	2º 22' 31.778" S	104º 48' 15.035" E	Primary forest
5	2º 17' 20.364" S	104º 52' 15.878" E	Primary forest
6	2º 19' 55.811" S	104º 50' 45.469" E	Primary forest
7	2º 33' 15.545" S	104º 45' 39.05" E	Coconut plantation
8	2º 24' 21.234" S	104º 48' 54.87" E	Coconut plantation
9	2º 31' 0.584" S	104º 45' 58.816" E	Coconut plantation
10	2º 23' 23.353" S	104º 48' 21.203" E	Fishpond
11	2º 21' 59.763" S	104º 50' 28.207" E	Fishpond
12	2º 23' 35.178" S	104º 47' 53.384" E	Fishpond
13	2º 30' 15.817" S	104º 46' 23.389" E	Open area
14	2º 21' 17.159" S	104º 50' 30.569" E	Open area
15	2º 20' 2.949" S	104º 52' 41.706" E	Open area
16	2º 16' 36.561" S	104º 53' 59.572" E	Water body
17	2º 17' 1.211" S	104º 51' 59.945" E	Water body
18	2º 17' 4.611" S	104º 55' 2.086" E	Water body

The results of the analysis of land cover data were then processed with the open-source software LUMENS version 0.1 of 2016 (van Noordwijk et al. 2016; Nguyen et al. 2016; Untari et al. 2018; Do et al. 2020). This software was able to analyze changes in various types of land cover in an area at one time to see carbon stock (carbon density), emissions, and carbon sequestration. The method used is the Stock Difference method, where emissions were calculated as the amount of reduction in carbon stocks due to changes in land cover if the initial carbon stock was higher than the carbon stock after the change in land use.

Land cover data was in the form of raster data from image interpretation, while the carbon stock constant was obtained from secondary data in the form of tabular data on all types of land cover originating from direct field measurements. Conversely, sequestration was calculated as the amount of additional carbon stock due to changes in land cover, where the carbon stock in the initial land use was lower than the carbon stock after the change in land use. The carbon stock for each land cover derived from the multiplication of the area of land cover and the reference data for the carbon density of South Sumatra Province. The underlying assumption of this study from the rate of change in emissions and carbon sequestration was obtained from changes in land cover types that occur in the same area of the unit area (pixel)

RESULTS AND DISCUSSION

Land cover conditions 2000 and 2020

The annual land cover in ATPF for 2000 and 2020 is shown in Figure 2. The land cover in the ATPF area can be classified into primary forest, secondary forest, coconut plantation, open area, fishpond and water body. According to Eddy (Eddy et al. 2017), primary forest in this area is dominated by true mangrove stands, such as *Nypa fruticans*, *Rhizophora apiculata*, *Avicennia alba*, *Bruguiera cylindrica*, *Excoecaria agallocha*, and *Xylocarpus granatum*, while secondary forest contains a mixture of shrubs and mangroves.

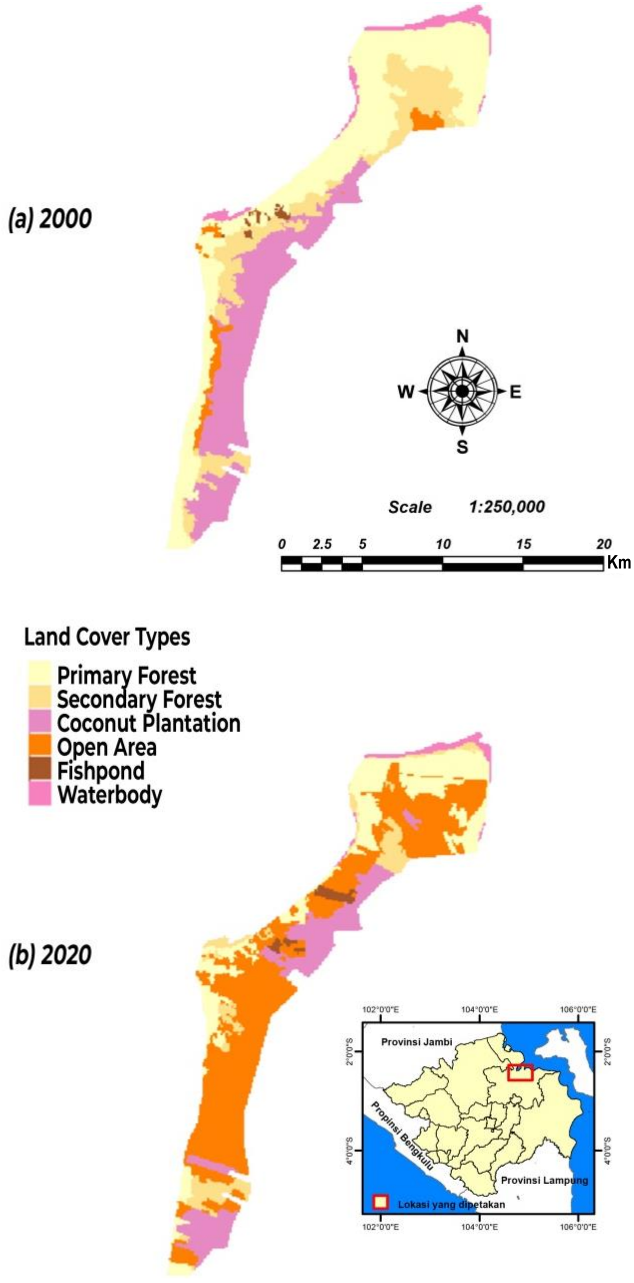

Figure 2. Map of existing land cover types at ATPF 2000 and 2020. The map output is obtained from the analysis using LUMENS

The land cover in the form of open area in 2020 is an open area but there are also undergrowth and shrubs that dominate this area with an area of up to half of the area of the ATPF. The existence of this open area is due to the clearing of primary and secondary forest for new land by the community and also the area prepared by the community for coconut replanting. Although insignificant, the area of land cover in the form of fishpond was increasing in 2020. The identified coconut plantation area in 2000 was 3,713.43 ha, but decreased in 2020 to 1,834.56 ha.

Open areas which are open areas overgrown by undergrowth in the form of shrubs (shrubs) dominate this area in 2020 where the area is half of the area of the ATPF. The existence of this open area is due to the clearing of primary and secondary forest for new land by the community and also the area prepared by the community for coconut replanting. Ponds were identified in 2000 and are increasing in size in 2020 although not significant. The decrease in water body area occurred due to intensive sedimentation at the mouth of the Banyuasin River, causing the formation of new lands. The identified coconut plantation area in 2000 was 3,713.43 ha, but decreased in 2020 to 1,834.56 ha.

Table 3. Area of each land cover type in ATPF in 2000 and 2020

Land cover type	2000		2020	
	ha	%	ha	%
Primary Forest	5,321.36	42.03	2,936.06	23.19
Secondary Forest	2,563.83	20.25	1,123.02	8.87
Coconut Plantation	3,713.43	29.33	1,834.56	14.49
Open Area	495.04	3.91	6,334.23	50.03
Fishpond	93.69	0.74	189.91	1.50
Waterbody	473.52	3.74	243.09	1.92
Total	12,660.87	100.00	12,660.87	100.00

Carbon Stock, Emissions and Sequestration 2000-2020

The condition of carbon stock in ATPF in 2000 and 2020 can be seen in Figure 3. Overall carbon density in 2000 was higher than in 2020. Areas with carbon density in the range of 50-100 ton CO_2-eq are still widely distributed, especially in to the north and west in 2000. However, in 2020 the carbon density in this area was dominated in the range of 0-20 tons CO_2-eq. This is due to the wider open area opened by the community and the decreasing area of primary and secondary forests.

The emissions generated in ATPF were higher than sequestration during the 2000 and 2020 periods (Figure 4). Almost all regions in the ATPF produced emissions of more than 100 tons CO_2-eq, there were even some areas that produced emissions of more than 300 tons CO_2-eq in this period. However, the magnitude of emissions is not matched by sequestration. Almost all areas in ATPF did not produce sequestration (0 ton CO_2-eq), only a few areas produced sequestration in the range above 200 ton CO_2-eq. This is due to the rampant clearing of primary and secondary forests by the community to be used as plantation land.

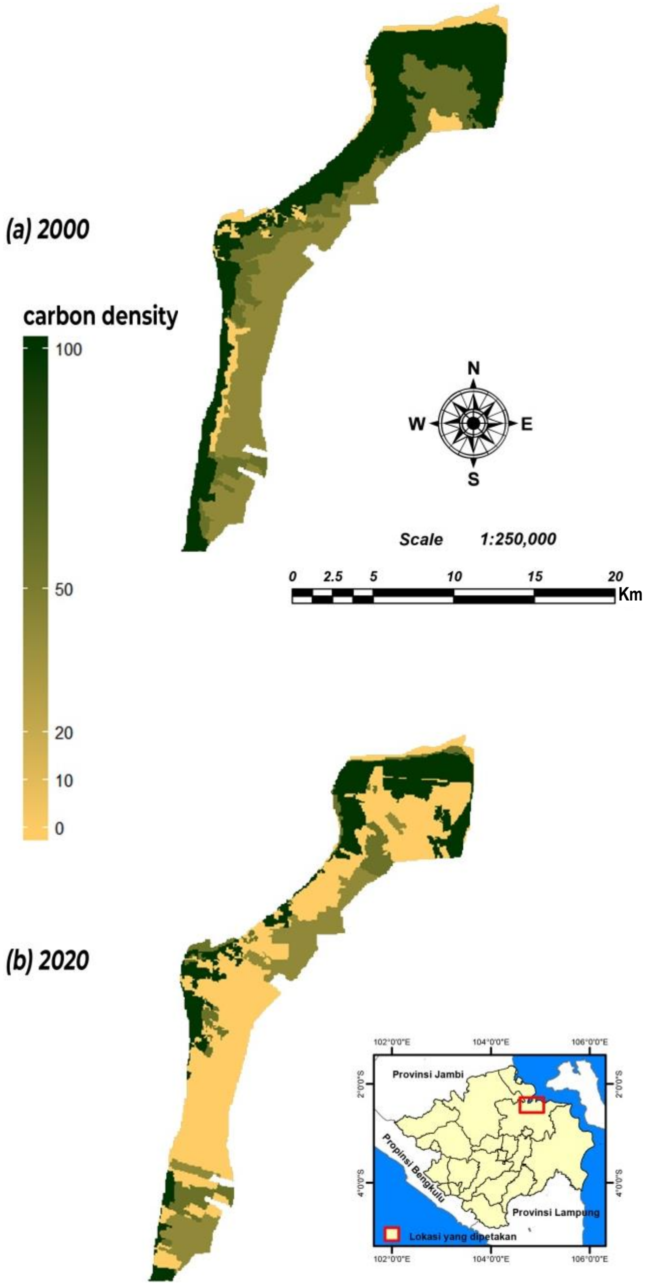

Figure 3. Carbon stock conditions in 2000 and 2020 at ATPF

Emissions resulting from land conversion in ATPF during the 2000-2020 period had a total emission of 1,981,392.08 tons CO_2-eq (Table 4). The highest emission resulted from the conversion of primary forest to open areas with an emission level of 873,853.31 tons CO_2-eq or 44.10% of total emissions. Primary forest is the most important part in nature which has a major role in absorbing carbon. However, with a reduction in the area of primary forest, carbon emissions in nature will increase.

High emissions are also generated from the conversion of coconut plantation into an open area, amounting to 503,865.75 tons of CO_2-eq or around 25.43% of total emissions. The coconut plantation land that was converted into an open area in 2020 is actually a community effort to rejuvenate old and less productive coconut plants.

Emissions also resulted from the conversion of secondary forests to open areas, amounting to 372,037.08 tons of CO_2-eq or around 18.78% of total emissions. The clearing of secondary forests is rife by the community to make land for coconut and oil palm plantations. Other sources of emissions are also generated from the conversion of primary forest to coconut plantation and fishpond and conversion of primary forest to secondary forest. In addition, emissions are also generated from the conversion of secondary forests to coconut plantations and fishponds.

The total sequestration produced in the ATPF during the 2000-2020 period was far below the total emissions, which was only 53,315.52 tons CO_2-eq or only around 2.7% of the total emissions (Table 5). This shows that the conversion that has occurred in this area is very massive and has not been matched by revegetation or reclamation processes. The highest sequestration resulted from the conversion of secondary forest to primary forest, amounting to 29,362.35 tons CO_2-eq or more than half of the total sequestration. The change of secondary forest to primary forest is a natural succession process that occurs especially in tidal zones.

Sequestration also occurred due to changes in water bodies to become secondary forests, which amounted to 13,294.58 tons of CO_2-eq or 24.94% of the total sequestration. This secondary forest was formed as a result of massive sedimentation at the mouth of the Banyuasin River which resulted in the formation of new lands. These new lands are then occupied by mangrove propagules which eventually grow and develop into secondary forests. In addition, sequestration also occurs due to changes in open areas to secondary forest, coconut plantation and primary forest, but the size is not too significant.

Table 6 shows the net emission value generated in ATPF during the 2000-2020 period, which is 1,928,076.56 tons of CO_2-eq (total emission value minus total sequestration value). The annual emission rate is 96,403.83 tons CO_2-eq/year and the average emission rate per unit area is 7.61 tons CO_2-eq/ha year.

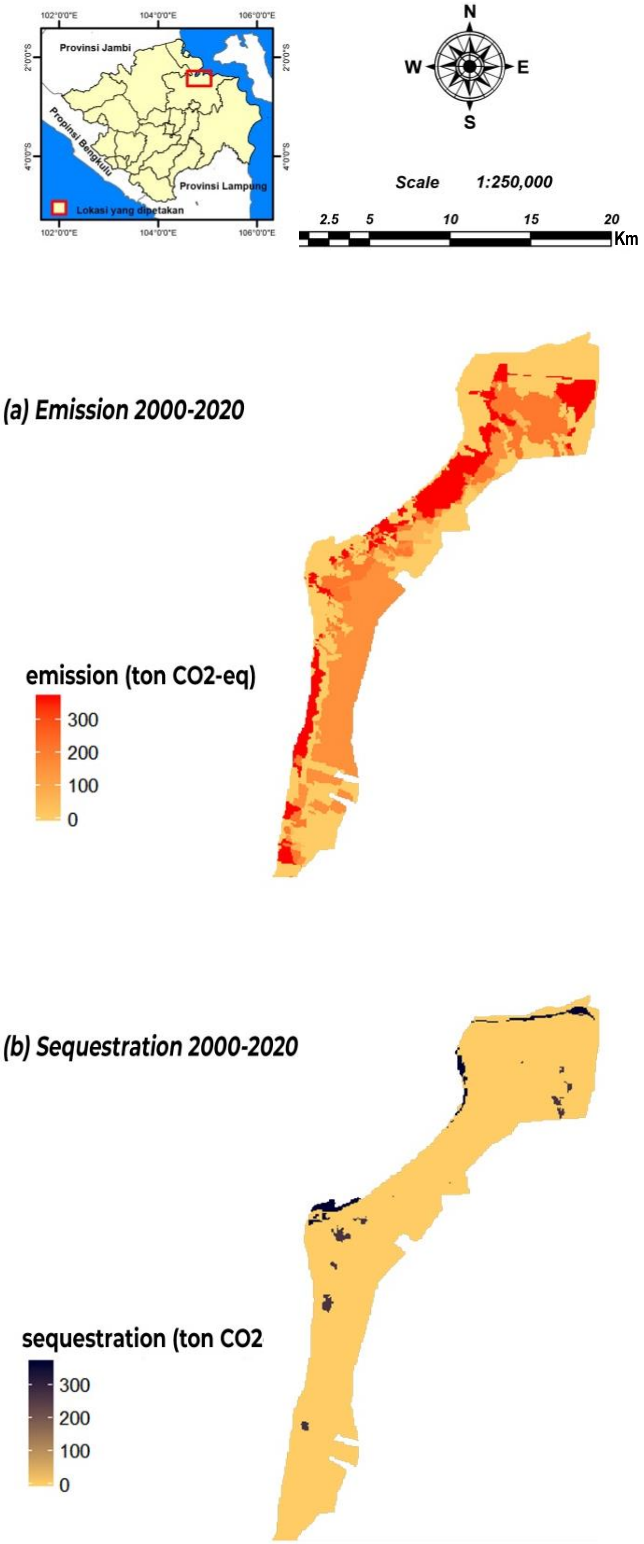

Figure 4. Emissions and sequestration generated during the 2000-2020 period

Table 4. Amount of emissions (tons CO_2-eq) resulting from each change in land cover during the 2000-2020 period

Land cover changes	Emission (ton CO_2-eq)	%
Primary forest to open area	873,853.31	44.10
Coconut plantation open area	503,865.75	25.43
Secondary forest to open area	372,037.08	18.78
Primary forest to coconut plantation	77,895.42	3.93
Primary forest to secondary forest	57,807.12	2.92
Primary forest to fishond	53,501.22	2.70
Secondary forest to coconut plantation	28,858.09	1.46
Secondary forest to fishpond	10,340.23	0.52
Coconut plantation to fishpond	3,233.86	0.16
Total	1,981,392.08	100.00

Table 5. Quantity of sequestration (tonnes CO_2-eq) resulting from each change in land cover during the 2000-2020 period

Land cover changes	Sequestration (ton CO_2-eq)	%
Secondary forest to primary forest	29,362.35	55.07
Waterbody to secondary forest	13,294.58	24.94
Open area to secondary forest	6,752.80	12.67
Open area to coconut plantation	3,541.84	6.64
Open area to primary forest	363.95	0.68
Total	53,315.52	100.00

Table 6. Statistical data on CO_2 emissions and sequestration during the 2000-2020 period

Category	Summary
Total area	12,660.87
Total emission (ton CO_2-eq)	1,981,392.08
Total sequestration (ton CO_2-eq)	53,315.52
Net emission (ton CO_2-eq)	1,928,076.56
Emission rate (ton CO_2-eq/year)	96,403.83
Emission rate per-unit area (ton CO_2-eq/ha.year)	7.61

Discussion

Conversions carried out by the community that occurred in the mangrove forest in ATPF were in the form of changing the mangrove forest to a coconut plantation, fishpond, settlement and agriculture. Anthropogenic activities in the form of land clearing for plantations and agriculture as well as the development of coconut plantation are the dominant activities in this region. This can be seen from the increase in the number of open areas and coconut plantations in 2020, where each area is 6,334.23 ha and 1,834.56 ha. The open area reaches half of the ATPF area, while the coconut plantation area reaches almost 15% of the total ATPF area. The large increase in open area and coconut plantation has the consequence of decreasing the area of primary forest and secondary forest. The remaining primary and secondary forests in 2020 are only around 23.19% and 8.87% of the total area of ATPF. Anthropogenic disturbances that occur in this area are very massive, so that this area is degraded due to conversion, while reclamation activities have not been maximally carried out. Reclamation was carried out in 2011 by the government and the community, but it only covers a small area so that it is unable to keep up with the speed of degradation due to anthropogenic activities. Various anthropogenic activities in mangrove forests are the main cause of degradation in various regions of the world (Thu and Populus 2007; Donders et al. 2008; Giri et al. 2008, 2014; Ilman et al. 2011; Bryan et al. 2013; Li et al. 2013; Nfotabong-Atheull et al. 2013; Satyanarayana et al. 2013; Jones et al. 2014; Komiyama 2014; Laulikitnont 2014; Sannigrahi et al. 2020).

Emissions that occur in the ATPF region are much greater than sequestration where the magnitude of the emissions is more than 37 times compared to sequestration. The highest emission resulted from the conversion of primary forest to open areas with an emission level of 873,853.31 ton CO_2-eq, while the highest sequestration resulted from the conversion of secondary forest to primary forest, which was only 29,362.35 ton CO_2-eq. This indicates that there has been massive degradation in this area due to anthropogenic activities and has not been matched by restoration efforts. To restore the natural function of ATPF as a protected forest, restoration efforts are needed both by the government and the community. However, it is not easy to restore ATPF to its original condition as a protected forest because degraded mangrove forests are not easy to restore in a short time. Development activities in various countries that cause mangrove forest degradation are the main causes of damage and require a restoration time of more than 20 years (Mukherjee et al. 2014). In addition, government support and community participation are needed in an effort to accelerate the success of restoration. The restoration process will be disrupted if there is dysfunction of government institutions and a lack of community participation (Mangora 2011).

The strength of this research is that it can obtain an overall picture of land cover types in ATPF and at the same time can determine the amount of CO_2 emission and sequestration and determine the main factors that can increase CO_2 emissions. This is very important in an effort to assist the government in regional planning. In addition, it is also useful in planning the mitigation of CO_2 emissions in anticipation of global warming. The present work was supported by previous reports how difficult it is to accurately measure the various carbon components even in clearly defined mangrove areas (Serrano et al. 2019; Ouyang and Lee 2020).

In conclusion, emissions resulting from land conversion in ATPF during the 2000-2020 period amounted to 1,981,392.08 tons of CO_2-eq (96,403.83 ton CO_2-eq/year). While, sequestration was far below the total emissions, which was only 53,315.52 tons CO_2-eq (2.7% of total emissions). The largest source of emissions comes from the conversion of primary forest, coconut plantation and secondary forest to open areas; while the largest source of sequestration is the return of this area to primary and secondary forest. The emission results in ATPF is much greater than the emission produced in one of the mangrove forests of North Sumatra, which is only 3,804.70 ton CO_2-eq/year, where the biggest emission source has resulted from the conversion of secondary mangrove forest to aquaculture and oil palm plantation (Basyuni et al. 2015).

The main source of degradation in ATPF is new land clearing, some of which come from primary and secondary forests, wherein 2020 the open area will reach half of the ATPF area. The result of this situation is massive primary and secondary forest loss. For that, it is necessary to immediately restore and conserve this area in an effort to restore the function of ATPF as a coastal protection forest.

ACKNOWLEDGEMENTS

Our deepest gratitude goes to Directorate of Research and Community Service, Ministry of Research and Technology and National Research and Innovation Agency, Republic of Indonesia (No. 11/AMD/E1/KP.PTNB/2020), through the Post-Doctoral Research Scheme 2021.

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