The Estimation of Carbon Reserve Loss in the Batangtoru Ecosystem from 2000 to 2020

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Abstract. The current global issue of climate change and global warming has triggered increased attention from academics worldwide, leading to research efforts aimed at making carbon information easily accessible to people worldwide. The objective of this study is to estimate the potential carbon sequestration lost in the Batangtoru Ecosystem from 2000 to 2020. The total carbon reserve is calculated based on the total land use area with standard carbon reserves for each land use class. The total potential carbon sequestration lost in the Batangtoru ecosystem from 2000 to 2020 is 526,098.9 tons of Carbon.

Keywords: Batangtoru, Carbon, Climate Change, Ecosystem.

1.0 Introduction

1.1 Climate Change

Climate change and global warming, which have become global issues today, have triggered increased attention from academics worldwide to conduct research so that the need for information about carbon can be easily accessed by people around the world. Carbon is a natural cycle where carbon in the atmosphere is absorbed by vegetation and then released back into the atmosphere. Climate change is related to changes in the atmospheric composition, primarily due to an increase in greenhouse gas (GHG) concentrations. The Fourth Assessment Report of the IPCC in 2007 also mentioned a 70% increase in greenhouse gas concentrations from 1974-2005. Approximately 20% of the increase in GHGs is due to the release of CO2 stored for hundreds to thousands of years as biomass above the ground and in peatlands. In addition to industrial advancement, climate change and global warming are also caused by the conversion of forested areas from their primary functions, so that forests are no longer able to store carbon from the air [1].

One of the major sectors contributing to greenhouse gas (GHG) emissions is land-use change (IPCC 2006). In the context of climate change, land-use change can contribute as both carbon sources and sinks depending on its type of use. Factors influencing land-use change include spatial interactions between social, economic, internal, and external activities within a region. Current land-use changes tend to show negative impacts, coinciding with an increase in the population, leading to increased

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GHG emissions. Based on the inventory of GHG emission sources in Indonesia for the period 2000 to 2005, the total GHG emissions, excluding the land-use change and forestry sector, amounted to 556,728.78 Gg CO2-eq. However, with the inclusion of land-use change and forestry, Indonesia's total GHG emissions significantly increased to 1,377,982.95 Gg CO2-eq. The three main categories contributing to GHG emissions in the land-use change and forestry sector are forest and grassland conversion, peatlands, and emissions generated from the soil [2].

1.2 Batangtoru Ecosystem

The total forest area in North Sumatra Province at present is approximately 3,055,795 hectares. This area is divided into various categories, including conservation forests covering approximately 427,008 hectares, protected forests (HL) covering approximately 1,206,881 hectares, limited production forests (HPT) covering approximately 641,769 hectares, permanent production forests (HP) covering approximately 709,452 hectares, and convertible production forests (HPK) covering approximately 75,684 hectares (as per Minister of Forestry Decree No. 579/Menhut-II/2014).

One of the forest blocks in North Sumatra is the Batang Toru Forest Block. According to the Forest Area Stabilization Office (BPKH) of Region I in Medan, the Batang Toru Forest Block covers approximately 151,808 hectares. Within this area, there are natural reserves (KSA) and natural preservation areas (KPA) covering 15,020 hectares, protected forests (HL) covering 17,737 hectares, limited production forests (HPT) covering 1,483 hectares, permanent production forests (HP) covering 57,171 hectares, and other land uses (APL) covering approximately 14,397 hectares [3].

The Batang Toru natural forest area has a high level of uniqueness and biodiversity richness, as well as a diverse ecosystem. Therefore, this forest area is considered a High Conservation Value Forest (HCVF) and can be declared as an important Key Biodiversity Area in North Sumatra Province. The identified biodiversity within the Batang Toru forest area includes 67 mammal species (from 21 families), 287 bird species, 110 herpetofauna species (19 amphibian species from 6 families and 49 reptile species from 12 families). Additionally, the richness of plant diversity is also high, with approximately 688 plant species from 137 families [3].

Calculating emissions in the forestry sector (land-based sector) requires information on activity data and emission factors. Emission factors are determined by the carbon reserves in various land cover types. Therefore, information on carbon reserves in different types of forests is crucial for calculating the reference emission levels. Forest carbon reserves vary and are influenced by various factors, including forest type, vegetation type, soil type, climate type and rainfall, topography, elevation, and other biophysical conditions, including silviculture techniques and forest management practices applied [4].

2.0 Literature Review

The research on carbon reserve estimation using remote sensing has also been conducted by Sitanggang et al. [5] in the Dolok Sanggul District. The results of this research showed that the Dolok Sanggul District, which has forest land cover, has a carbon sequestration potential of 47.73 tons of carbon, while for rice field land cover, it is 24.06 tons of carbon, and for shrubland land cover, it is 16.99 tons. The total carbon stock in the Dolok Sanggul District is 88.79 tons. Meanwhile, the total carbon content in the peatland area of Humbang Hasundutan Regency is 170.46 tons, with a peatland area of 6,289.08 ha.

Djaingsastro et al. [6] titled 'Potential Carbon Stored Above Ground in Community Rubber Plantations and PTP. Nusantara III Based on Biomass by Age Class in Asahan Regency,' conducted research using a non-destructive method with allometric equations. The highest stored carbon was found in the S. Silau PTPN III estate, which is 11.51 tons of C/ha at 6 years old and 42.98 tons of C/ha at 21 years old. In contrast, in community plantations, it was 12.36 tons of C/ha at 9 years old and 36.35 tons of C/ha at 22 years old. The highest carbon dioxide absorption in the S. Silau PTPN III estate was 42.23 tons/ha at 6 years old and 157.73 tons/ha at 21 years old, compared to community plantations which absorbed 45.36 tons/ha at 9 years old – 133.42 tons/ha at 22 years old.

Calculation models for carbon reserves using different methods have also been conducted by Banurea et al. [7]. The research titled 'Carbon Reserve Estimation in *Tectona grandis, Gmelina arborea*, and *Alstonia scholaris* Stands in the Universitas Sumatra Utara Arboretum' used an allometric method with research locations in the Plantation Forest Area of the Universitas Sumatra Utara Arboretum, with each stand covering an area of 1 ha. The results are as follows: carbon reserves in *Tectona grandis* stands were 37.6 tons/ha, in Gmelina arborea stands were 70.6 tons/ha, and in Alstonia scholaris stands were 109.5 tons/ha. The amount of carbon dioxide absorbed by *Tectona grandis* stands was 138.1 tons/ha, by *Gmelina arborea* stands was 259.29 tons/ha, and by *Alstonia scholaris* stands was 401.8 tons/ha.

3.0 Methodology

3.1 Time and Location

This research was conducted in the Batang Toru Ecosystem, spanning 24 districts across three regencies in North Sumatra Province. The research was carried out from January 2023 to April 2023.

3.2 Tools and Materials

The tools used in this research included an Asus laptop, ArcGIS 10.8 software, and land cover data from the Ministry of Environment and Forestry year 2000, 2006, 2011, 2015 and 2020.

3.3 Estimation of Carbon Reserves

The calculation of carbon stock was performed using the following formula: Carbon Stock (tons) = Land Cover Area (ha) x Emission Factor (t/ha) The land cover area was obtained through the classification of land cover data, while the emission factor was derived from the Intergovernmental Panel on Climate Change (IPCC) data. The emission factor values were assigned based on various land cover classes established by the IPCC (Table 1).

Table 1. Carbon reserves for various land uses [8].

Land Cover	Carbon (C ton/ha)	Source
Primary Forest	132.99	NFI 1996-2013, 2014
Secondry Forest	98.84	NFI 1996-2013, 2014
Shrubs	30	Juknis PED RAD GRK, 2013
Settlement	4	Juknis PED RAD GRK, 2013
Rice Field	2	Juknis PED RAD GRK, 2013
Swamp	0	Juknis PED RAD GRK, 2013
Open Land	2.5	Juknis PED RAD GRK, 2013
Water	0	Juknis PED RAD GRK, 2013
Mixed Plantation	30	Juknis PED RAD GRK, 2014

When using the Stock Difference Method for a specific land use category, it is essential to ensure that the land area within the category at times t1 and t2 remains the same to avoid confusion in estimating changes in reserves due to changes in area [8].

$\Delta C = (Ct2 - Ct1) / (t2 - t1)$
Where:
ΔC = Annual change in carbon reserves in the carbon pool, tons of C/year
Ct2 = Carbon reserve at time t2, tons of C
Ct1 = Carbon reserve at time t1, tons of C

4.0 Findings

4.1 The total carbon sequestration potential and the lost carbon sequestration.

Table 2. The total carbon sequestration potential and the lost carbon sequestration.

No	Land Cover	Area		Carbon ton/ha	C t1	Ct2	Ct2-Ct1/t2-t1
		t1 (2000)	t2 (2020)				
1	Primary Forest	56.769,53	54.869,0	132,99	7.549.779,8	7.297.021,8	-12.637,9
2	Secondry Forest	66.556,15	74.017,7	98,84	6.578.410,0	7.315.909,4	36.875,0
3	Shrubs	12.395,62	3.334,0	30	371.868,7	100.021,3	-13.592,4
4	Settlement	28,24	68,9	4	113,0	275,7	8,1
5	Rice Field	949,43	202,7	2	1.898,9	405,4	-74,7
6	Swamp	5,98	0	0	0.0	0,0	0,0
7	Open Land	0	411,8	2,5	0.0	1.029,4	51,5
8	Water	0	17,058987	0	0.0	0,0	0,0
9	Mixed Plantation	10.044,38	13.828,18	30	301.331,3	414.845,5	5.675,7
	Total	146.749,33	146.749,3		14.803.401,5	15.129.508,5	16.305,3

5.0 Discussion

The total carbon reserve in the Batangtoru Ecosystem in 2020 was 15,129,508.5 tons of C. Secondary Forest land cover contributed the highest amount of carbon in 2020, with a total of 7,315,909.4 tons of C. Conversely, the land cover category with the smallest carbon contribution was settlement land cover, totaling 275.7 tons of C. In contrast, for the year 2000, the total carbon reserve in the Batangtoru Ecosystem was 14,803,401.5 tons of C. To analyze the change in carbon reserves in the Batangtoru Ecosystem from the year 2000 to 2020, can be calculated the difference in carbon reserves between the two years and then determine the percentage change.

Calculate the difference in carbon reserves:
Carbon reserves in 2020 - Carbon reserves in 2000

= 15,129,508.5 tons of C - 14,803,401.5 tons of C
= 326,107 tons of C

Calculate the percentage change:
(Difference / Carbon reserves in 2000) * 100
= (326,107 tons of C / 14,803,401.5 tons of C) * 100
≈ 2.20%

So, between the years 2000 and 2020, the carbon reserves in the Batangtoru Ecosystem increased by approximately 2.20%. This indicates a positive trend in carbon storage in the ecosystem during that time period. Despite the observed increase in carbon sequestration potential in the Batangtoru ecosystem from 2000 to 2020, the change in primary forest cover of 1,900 hectares indicates that human activities converting forested areas remain significantly high within the Batangtoru ecosystem region.

To calculate the contribution of each land cover type to carbon sequestration potential using the following equation: Carbon Sequestration Potential (CSP) = Total Area of Land Cover Type (A) × Carbon Stock (CS) where:

- Carbon Sequestration Potential (CSP) is the potential amount of carbon sequestered by a specific land cover type.
- Total Area of Land Cover Type (A) is the total area covered by that specific land cover type.
- Carbon Stock (CS) is the carbon content per unit area for that land cover type.

In the year 2000, the land cover with the highest contribution to carbon sequestration potential in the Batangtoru ecosystem was primary forest cover, with an area of 56,769.53 hectares, and the calculated total carbon sequestration potential was 7,549,779.8 tons of carbon.

When calculated using the formula provided earlier, the contribution of primary forest cover to the total carbon sequestration potential in the Batangtoru ecosystem is as follows:

CSP = Total Area Primary Forest (2000)*Carbon Stock (2000)
= 56,769.53 ha*132.99 ton C/ha
= 7,549,779.8 ton C

The contribution of primary forest in percentage terms to the total carbon sequestration potential in the year 2000 in the Batangtoru ecosystem can be calculated using the following equation:

Contributution of Primary Forest = Carbon potential of Primary Forest/Total carbon per year 2000*100%
CPF = 7,549,779.8 / 14,803,401.5*100
= 51%

From the results above, it can be seen that in the year 2000, primary forest land cover was the highest contributor to the total carbon sequestration potential in the Batangtoru ecosystem, accounting for a percentage of 51%.

Meanwhile, for the land cover with the smallest contribution to the total carbon sequestration potential in the Batangtoru ecosystem in the year 2000, based on the carbon sequestration potential table above, you can observe the calculations below:

Contribution of Settlement = Carbon Potential of Settlement/Total carbon per year 2000*100%
CS = 113/14,803,401.5*100
= 0.0007 %

The highest contribution in percentage terms to the total carbon sequestration potential in the year 2020 in the Batangtoru ecosystem base on table 2 can be calculated using the following equation:

Contributution of Secondry Forest = Carbon potential of Secondry forest/Total carbon per year 2020*100%
CSF = 7.315.909,4/ 15.129.508,5*100
= 48.3%

From the results above, it can be seen that in the year 2020, Secondry land cover was the highest contributor to the total carbon sequestration potential in the Batangtoru ecosystem, accounting for a percentage of 48.3%.

Meanwhile, for the land cover with the smallest contribution to the total carbon sequestration potential in the Batangtoru ecosystem in the year 2020, based on the carbon sequestration potential table above, you can observe the calculations below:

Contribution of Settlement = Carbon Potential of Settlement/Total carbon per year 2000*100%
CS = 275,7/15.129.508,5*100
= 0.0018 %

The highest carbon potential in the Batangtoru Ecosystem in 2020 was 7,315,909.4 tons of C. When compared to the research on carbon reserve estimation conducted by Djaingsastro et al. [6], where the highest stored carbon was found in S. Silau PTPN III estate at 11.51 tons of C/ha at 6 years old and 42.98 tons of C/ha at 21 years old, the carbon reserve potential in the Batangtoru Ecosystem is significantly higher. The difference in methods used is indicated as a significant factor, as Djaingsatro et al. [6] employed an allometric method, while this research used remote sensing by multiplying land cover emission factors by the area of each land cover class.

Additionally, differences in the research intervention areas and land cover also contribute to the significant differences in carbon potential values between the respective intervened areas. High carbon sequestration levels typically occur in areas with high fertility, sufficient rainfall, fast-growing vegetation, and dense forest cover, even though decomposition rates may also be relatively high in such locations. Effective forest cover management also affects carbon sequestration rates. Conversely, low carbon sequestration levels usually occur in areas with low rainfall, poor soil fertility, and sparse forest cover.

A different method for calculating carbon reserves was also conducted by Banurea et al. [7]. The research was titled "Carbon Reserve Estimation in *Tectona grandis, Gmelina arborea*, and *Alstonia scholaris* Stands in the Universitas Sumatra Utara Arboretum." This study used an allometric method with research locations in the Plantation Forest Area in the Universitas Sumatra Utara Arboretum, with each stand covering an area of 1 ha. The results presented in this study are as follows: carbon reserves in *Tectona grandis* stands were 37.6 tons/ha, in *Gmelina arborea* stands were 70.6 tons/ha, and in *Alstonia scholaris* stands were 109.5 tons/ha. The amount of carbon dioxide absorbed by *Tectona grandis* stands was 138.1 tons/ha, by *Gmelina arborea* stands was 259.29 tons/ha, and by *Alstonia scholaris* stands was 401.8 tons/ha. However, when compared to carbon sequestration in this research, the carbon sequestration in the Universitas Sumatra Utara Arboretum is relatively low. The small intervention area of only 3 ha in the research by Banurea et al., [7] is a contributing factor to the limited carbon sequestration in the Universitas Sumatra Utara Arboretum.

6.0 Conclusion and Recommendation

The total carbon reserve in the Batangtoru Ecosystem in 2020 was 15,129,508.5 tons of C. In contrast, for the year 2000, the total carbon reserve in the Batangtoru Ecosystem was 14,803,401.5 tons of C. The highest loss in carbon sequestration potential is in shrubland land cover, with a total of 13,592.4 tons of C per year. The total change in carbon sequestration potential in the Batangtoru ecosystem due to land cover changes over a 20 -year period is 326,107 tons of carbon, representing a 2.20% increase in carbon sequestration potential. Primary Forest land cover was the highest contributor to the total carbon sequestration potential in the Batangtoru ecosystem in 2000 with 7,549,779.8-ton C, accounting for a percentage of 51%. and Settlement was the lowest contributor to the total carbon potential in the Batangtoru Ecosystem in 2000 with 113-ton C, accounting for a percentage of 0.0007 %. Secondary Forest land cover was the highest contributor to the total carbon sequestration potential in the Batangtoru ecosystem in 2020 with 7.315.909,4-ton C, accounting for a percentage of 48 %. and Settlement was the lowest contributor to the total carbon potential in the Batangtoru Ecosystem in 2000 with 275,7-ton C, accounting for a percentage of 0.0018 %.

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References

1. Ginting, T. T., & Prayogo, C.: Estimation of carbon stock of teak forest (*Tectona Grandis Linn.* F) using various allometric equations on various age classes of teak. Jurnal Tanah Dan Sumberdaya Lahan **5**, (2018)
2. Kencono, A. W.: Data Inventory Emisi Grk Sektor Energi. (2015)
3. Kuswanda, W.: Orangutan Batang Toru : Kritis Diambang Punah. (2014)
4. Rochmayanto, Y., Wibowo, A., Lugina, M., Butarbutar, T., & Mulyadin, R. M.: Cadangan karbon pada berbagai tipe hutan dan jenis tanaman di Indonesia. 2nd edn. Penerbit Pt Kanisius (2014)
5. Sitanggang, G., Rahmawaty, & Rauf, A.: Pemetaan potensi karbon di Lahangambut Topogen pada berbagai kecamatan di Kabupaten Humbang Hasundutan, Provinsi Sumatera Utara. Peronema Forestry Science Journal **2**(2), 93-98 (2013)
6. Djaingsastro, A., Aththorick, A., & Nursahara, P. (2018). Potensi karbon tersimpan di permukaan (above ground biomass) perkebunan karet rakyat dan PTP. Nusantara III pada beberapa kelas umur tanam di kabupaten asahan. Universitas Sumatera Utara (2018)
7. Banurea, D., Hartini, K., & Delvian.: Estimation of carbon stock in Gmelina arborea stands, Tectona grandis stands and Alstonia scholaris stands at Arboretum of Universitas Sumatera Utara. Universitas Sumatera Utara, The University Institutional Repository (2019)
8. Kementerian Lingkungan Hidup dan Kehutanan. EFDB Indonesia, (2017)