Carbon stock change dynamics of oil palm plantation in Sembilang Dangku Landscape, South Sumatra

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Abstract. One of the land cover type in the Sembilang Dangku Landscape is oil palm plantation, which is developed by changing the type of previous land covers. Land cover change causes changes in carbon stock. If the carbon stock increase in an area, it means the area acts as a carbon sinker, whereas if the carbon stock decrease, inconsequently the area is a carbon emitter. The purpose of this study was to analyze the dynamics of carbon stock changes in 1997-2007 and 2007-2017. The research was carried out on six private oil palm plantations. Carbon stocks were estimated based on the type of land cover interpreted from Landsat 5 imagery with the unsupervised method by using Las Palmas QGIS 2.18.0 Software. Determination of land cover in 1997 was based on the year when oil palm plantation began. Carbon stock of oil palm plantation was estimated based on the Normalized Difference Vegetation Index (NDVI) with the equation: \( Y = 638.13X - 242.65 \) (\( Y \) = carbon stock, \( X \) = NDVI). The value of carbon sequestration or carbon emission were based on carbon stock changes. The types of land cover in 1997 and 2007 were in the form of shrub swamp, oil palm plantation, undisturbed peat swamp forest, disturbed peat swamp forest; while in 2017 land cover was dominated by oil palm plantation. The results showed respectively that carbon stocks in 1997, 2007 and 2017 were 3,333,549.6 tonC, 1,541,825.5 tonC, and 1,626,951.8 tonC. In 1997-2007, carbon stock encountered a decrease, resulting in carbon emission of 18.68 tonCO\(_2\)-eq /ha/year. However, in 2007-2017, carbon stock encountered an increase, leading in carbon sequestration of 0.89 tonCO\(_2\)-eq /ha/year.

1. Introduction
Carbon dioxide (CO\(_2\)) is a greenhouse gas that has the most significant volume, when compared to other greenhouse gases such as CH\(_4\), NOX, CFC [1]. The increase of CO\(_2\) can cause a greenhouse effect which implies global warming, which can cause life disturbance on this earth. In 2016, there was an increase in global CO\(_2\) concentrations of 3.3 ppm, which was due to some tropical countries in 2015/16 encountered El-Nino that triggered land and forest fires [2].
Responding to the above condition, the Government of Indonesia since 2011 had issued a Decree to mitigate greenhouse gases through Presidential Decree Number 61 the year 2011 concerning the National Action Plan for Reducing Greenhouse Gas Emission [3]. The Government of Indonesia has a target of reducing greenhouse gas emission by 26% on its own business and 41% with international assistance in 2020. This Decree is then followed up with Presidential Decree Number 71 the year 2011 concerning the Implementation of Greenhouse Gas Inventories [4].

Monitoring carbon stock change is important to know the role of oil palm plantations as carbon sinker or carbon source [5]. The sink is defined as oil palm plantation as a carbon sequester which is shown by the addition of carbon stock. Conversely, the source is defined as oil palm plantation as a producer of carbon emissions due to a decrease in carbon stocks. Monitoring of carbon stock change is an action of President Decree Number 61 the year 2011 and President Decree Number 71 the year 2011.

By considering the role of oil palm in carbon sequestration and landscape-based management issue, it was necessary to conduct a study of carbon stock in several oil palm plantations in the Sembilang Dangku Landscape. The focus of the research was carbon stock above the soil surface, because this section has large biomass that is 87% [6] and or 81.9-93.4% [7] of total biomass. The purpose of this paper was to analysis carbon stock change dynamics in 1997-2007 and 2007-2017. This paper discussed changes in land cover type and carbon stock, carbon source/carbon sink, and carbon management in oil palm plantation.

2. Materials and methods
2.1. Time and location of research
This research was a follow-up of the research conducted by Rachdian et al. [8] that collected data in January 2018. The study included six private oil palm plantations with an area of 35 211 ha located in Sembilang Dangku Landscape; it consisted of one oil palm plantation in Banyuasin District and five oil palm plantations in Musi Banyuasin District. This area was dominated by peatland with a maturity level of 91% and a hemic maturity level of 9% [9].

2.2. Research procedure
2.2.1. Land use change analysis
Land cover type was obtained by interpreting Landsat 5 imagery with path/row 124/062 with the acquisition date on May 23, 1997, path/row 125/062 with the acquisition date on May 30, 1997, and path/row 125/061 with the acquisition date on August 18, 1997 and Landsat 5 imagery 124/62 path/row on April 1, 2007 with acquisition date and path/row 125/61 and 125/62 with acquisition date on October 10, 2007. Type of land cover in 2017 refers to the results of [8]. The land cover type classification used the unsupervised method with QGIS Las Palmas Software 2.18.0. Carbon stock change analysis. The unsupervised method was possibly used because this method is grouping pixels with similar spectral characteristics according to specific statistical criteria [10].

Analysis of carbon stock change used the stock-difference method. This method was carried out with a stock-based approach, namely carbon stock change at a certain time interval [11]. Analysis of changes in carbon stock was carried out by comparing carbon stock in 1997, 2007, and 2017. Carbon stock was estimated based on the type of land cover. The 10-year interval was used to estimate the change of land cover area and carbon stock accurately of the beginning, middle, and final condition of oil palm plantations. The value of carbon stock for each land cover type was approached with various existing research results. If there was oil palm, carbon stock was estimated by regression equation Y= 638.13X-242.65 (Y=carbon stock, X=NDVI) [8]. Carbon stock in each type of land cover is presented in table 1.

| Land cover                | Carbon Stock (ton/ha) | Source |
|---------------------------|-----------------------|--------|
| Shrub swamp               | 10.68                 | [5]    |
| Oil palm                  | Data Processing       |        |
| Disturbed swamp forest    | 84.00                 | [12]   |
| Undisturbed swamp forest  | 164.00                | [12]   |

*aUsing the average value of the estimation results from the regression equation of NDVI relationship with carbon stock*
Calculation of the percentage change in carbon stocks was carried out from 1997 to 2007 and 2007-2017 by using this following formula:

$$\Delta C = \frac{C_t - C_i}{C_i} \times 100\%$$  \hspace{1cm} (1)

Description:
$$\Delta C = \text{Carbon stock change (\%)}$$
$$C_t = \text{Carbon stock of t-th year}$$
$$C_i = \text{Carbon stock of i-th year}$$

Then to know the increase or the decrease of carbon stock per ha per year it was used the formula as follows:

$$C = \frac{C_t-C_i}{L/(t-i)}$$  \hspace{1cm} (2)

Description:
$$C = \text{The average of carbon stock increase/decrease per ha per year (ton/ha/year).}$$
$$C_t = \text{Carbon stock of t-th year}$$
$$C_i = \text{Carbon stock of i-th year}$$
$$L = \text{Oil palm plantation area}$$

### 2.2.2. Determination of Carbon Dioxide Equivalent (CO$_2$-eq)

Carbon source occurred when carbon stock if there is a decrease in carbon stock in a certain period. Conversely, carbon sink will occur if there is an increase in carbon stock in a certain period. The amount of carbon lost or added can be converted to equivalent carbon dioxide (CO$_2$-eq) with the equation:

$$\text{CO}_2\text{-eq} = \text{Carbon stock} \times \frac{44}{12}$$  \hspace{1cm} (3)

### 3. Results and discussion

#### 3.1. Land use and carbon stock change

Land use changes occur due to limited land accompanied by an increase in population and its interests. Land changes occur because there are efforts to utilize space appropriately to get optimum benefits for various interests, both agricultural and non-agricultural [13]. Growth and transformation of change in the socio-economic structure of developing communities can lead to land use change, both permanent and temporary [14]. One of the phenomena of land use change is the change of land from natural cover to oil palm; this happened in the Sembilang Dangku Landscape. The land use change began dramatically since 1990, was occurred with a decrease in the area of dryland forests, mangrove forests, swamp forests and swamp areas caused by the conversion of forest to intensive agriculture, one of which was the development of good oil palm plantations by farmers and companies that now number up to 98 oil palm companies [9].

Land use change in Sembilang Dangku Landscape into oil palm plantation has implications for changes in the value of carbon stocks. This is caused by the quantity of carbon stocks in a landscape influenced by (a) vegetation conditions, namely the type, amount and density of trees, and (b) environmental factors, which affect photosynthesis and growth processes, namely sun radiation, water content, temperature and soil fertility [15]. The increase of carbon stocks can occur if the previous area has low carbon stock such as open land and shrubs. Conversely, the decrease of carbon stock can occur if the previous area is in the form of high-density forests. Land changes from shrubs to oil palm can increase carbon stock [16], but on the contrary, the change from forest land to oil palm reduce carbon stocks [17]. Increased carbon stock can occur in areas that are purely oil palm, due to the expansion of plant area and/or the size of the plant.

In 1997 and 2007, land cover in Sembilang Dangku Landscape was shrub swamp, oil palm, disturbed peat swamp forest and undisturbed peat swamp forest. In 2017, land cover consisted of shrub swamp and oil palm. In 1997 land cover was still dominated by undisturbed peat swamp forest covering an area
of 18 366 ha or 52% of the total area, then in 2007 it was dominated by oil palm by 15 885 ha or 45% of the total area, and in 2017 oil palm was still dominated by 30 744 ha or 87% of the total area. Type of land cover in Sembilang Dangku Landscape in 1997, 2007, and 2017 as in figure 1 with details of the area and value of carbon stock for each land cover type in each location as in table 2.

**Table 2.** Land cover and carbon stock change of oil palm plantation in Sembilang Dangku Landscape

| Location | Land cover type          | Year (ha) | Carbon stock (ton) |
|----------|--------------------------|-----------|--------------------|
|          |                          | 1997      | 2007               | 2017                |
|          |                          | 2017      | 1997               | 2007               | 2017               |
| Location 1 | Shrub Swamp                | 692       | 1 571              | 60                  | 7 391              | 16 778             | 641                |
|          | Oil Palm                  | 0         | 112                | 2 000               | 0                  | 2 912              | 58 508             |
|          | Disturbed Peat Swamp Forest | 1 368    | 377                | 0                   | 114 912            | 31 668             | 0                  |
|          | Undisturbed Peat Swamp Forest | 0     | 0                  | 0                   | 0                  | 0                  | 0                  |
|          | **Total**                 | **2 060** | **2 060**          | **2 060**           | **122 303**        | **51 358**         | **59 149**         |
| Location 2 | Shrub Swamp                | 6 148     | 3 351              | 475                 | 65 661             | 35 789             | 5 073              |
|          | Oil Palm                  | 2         | 3 392              | 6 894               | 52                 | 88 192             | 330 912            |
|          | Disturbed Peat Swamp Forest | 1 217   | 626                | 0                   | 102 228            | 52 584             | 0                  |
|          | Undisturbed Peat Swamp Forest | 2     | 0                  | 328                 | 0                  | 0                  | 0                  |
|          | **Total**                 | **7 369** | **7 369**          | **7 369**           | **168 269**        | **176 565**        | **335 985**        |
Table 2 showed the change in land cover types from 1997, 2007 and 2017 in the six oil palm plantation locations. The dynamic of land cover type and area had implications for the magnitude of change in carbon stock. The amount of carbon stock in each type of land cover was determined by the extent and carbon stock per ha. The carbon stock value per ha for undisturbed peat swamp forest, disturbed peat swamp forest, and shrub swamp land cover refers to Table 1. Oil palm carbon stock in 1997 and 2007 was thought to be based on the average carbon stock value of the regression equation, \( Y = 638.13X - 242.65 \) (\( Y = \) carbon reserve, \( X = \) NDVI) with the results of 26.00 tonC/ha. The dynamics of carbon stock changes in each oil palm plantation location as in figure 2.

![Figure 2](image-url)
Figure 2 showed that location which encountered a continuous increase in carbon stock was Location 2 and the location that encountered a decrease continuously in carbon stock was Location 6. The continuous increase in carbon stocks in Location 2 was due to the location being initially in the form of shrub swamp which later turned into a dominated area by oil palm with a plant age of > 10 years [8]. At that age, oil palm can store a large amount of carbon stock.

Location 2 was different in conditions with Location 6. Location 6 was originally dominated by undisturbed peat swamp forest with relatively high carbon stock. Change in the type of land cover become oil palm with implication for reduced carbon stocks. There was an area that had not been planted, so the condition is still in the form of shrub swamp with relatively low carbon stocks.

3.2. The role of oil palm plantation in CO₂ dynamics

In 1997 - 2007 the decline in carbon stocks occurred in almost locations. The highest decrease in carbon stock was in Location 3, which was 77%. The decrease in carbon stocks was due to a decrease in the area of undisturbed peat swamp forest of 99% of the total area in 1997 or decreased by 1 671 ha. Carbon stock increase occurred in Location 2 by 5%; this was due to a decrease in the shrub swamp area of 45% or 2 797 ha and an increase in oil palm plantations that were very large, it was 390 ha from 1997 which was only 2 ha.

In 2007 - 2017 there was an increase in carbon stock in almost all locations caused by increasing age of oil palm which was able to absorb and to store carbon in more significant quantities. The biggest increase in carbon stock occurred in Location 3 of 222% caused by the aging of oil palm which grew older and the decline only occurred in Location 6 by 49% due to the burning of land into shrub swamp in 2015.

An area can act as a source or CO₂ sink depending on the difference between carbon stock before and after land use change [5]. Source means CO₂ emission occurred due to a decrease in carbon stock in a given period, while sink means CO₂ sequestration occurs due to an increase in carbon stock. Period 1997-2007 five locations act as source CO₂, but from 2007 to 2017 five locations have acted as CO₂ sinks. More fully the percentage changes in carbon stock, the role of oil palm plantation, and CO₂ equivalent values as in Table 3.

### Table 3. Percentage of oil palm carbon stock change in Sembilang Dangku Landscape

| Location | Carbon stock change percentage (%) | Role | CO₂-equivalent (ton/ha/year) |
|----------|-----------------------------------|------|----------------------------|
|          | 1997-2007 | 2007-2017 | 1997-2007 | 2007-2017 | 1997-2007 | 2007-2017 |
| Location 1 | -58       | 15       | Source     | Sink      | 3.44      | 0.38      |
| Location 2 | 5         | 90       | Sink       | Sink      | 0.11      | 2.16      |
| Location 3 | -77       | 222      | Source     | Sink      | 6.09      | 4.11      |
| Location 4 | -67       | 36       | Source     | Sink      | 8.75      | 1.55      |
| Location 5 | -75       | 132      | Source     | Sink      | 8.21      | 3.61      |
| Location 6 | -43       | -49      | Sink       | Source    | 5.79      | 3.71      |
| Location (1-6) | -54.56   | 8.15     | Source     | Sink      | 18.68     | 0.89      |

3.3. Carbon management in an oil palm plantation

As a cultivation area, the primary location is oil palm area. The similar condition of the oil palm planting area with relatively wide spacing will produce lower carbon stock compared to the area in the form of trees with various compositions and vegetation structures that resemble with natural forests. Carbon stock of oil palm plantation in Malaysia is 2 – 60 tonC/ha and tropical forest 4 – 384 tonC/ha [18]. Such condition was certainly difficult for carbon stock to equal or exceed carbon stock before opening the forest land cover. However, it will be different if the initial land cover is in the form of bare land, reeds, and shrubs, the oil palm plantation carbon stock is higher than carbon stock in the condition of the land cover [16].

Referring to the description above, the level of increase in carbon stock in oil palm plantation varies, depending on the condition of the initial land cover. There is a significant decrease in carbon stock when the start of the oil palm plantation development comes from forest land cover. This condition can occur,
the rate of increase in carbon stock can not equal the initial condition. This is different if the type of land cover is in the form of reeds or shrubs. At the beginning of oil palm planting, the carbon stock can equal initial carbon stock is possible. Increasing time and oil palm area and carbon stock is increasing.

Oil palm plantation can increase carbon stock by immediately planting or rehabilitating an area that still has low carbon stocks. Planting area of oil palm after land clearing can immediately be planted. Other areas that are not productive and the HCV (high conservation value) area that is not optimal can also be immediately rehabilitated with various types of fast-growing plants and have a high ability in CO$_2$ sequestration.

4. Conclusion
The dynamic of carbon stock in oil palm plantations has a pattern that varies depending on the initial condition of the type of land cover and the speed of planting or rehabilitation. In general, oil palm plantations in 1997-2007 had a role as a source of CO$_2$ emissions, but in 2007-2017 most of them had acted as CO$_2$ sinkers. From six examples of oil palm plantation in Sembilang Dangku Landscape showed that the amount of CO$_2$-equivalent emission in 1997-2007 amounted to 18.68 tonCO$_2$-eq /ha/year, then in 2007-2017, there was a change in role as sinker with a value of 0.89 tonCO$_2$- eq /ha/ year.

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References
[1] IPCC. 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K. (eds). Published: IGES, Japan
[2] Olivier JGJ, Schure, KM, Peters JAHW. 2017. Trends in Global CO$_2$ and Total Greenhouse Gas Emissions: 2017 Report. PBL Netherlands Environmental Assessment Agency, the Hague
[3] Pemerintah Republik Indonesia. 2011. Peraturan Presiden No. 61 tahun 2011 tentang Rencana Aksi Nasional Penurunan Gas Rumah Kaca. Jakarta (ID): Sekretariat Negara RI
[4] Pemerintah Republik Indonesia. 2011. Peraturan Presiden No. 71 tahun 2011 tentang Rencana Aksi Nasional Penurunan Gas Rumah Kaca. Jakarta (ID): Sekretariat Negara RI
[5] Agus F, Gunarso P, Sahardjo BH, Harris N, Van Noordwijk M, Killen T J. 2013.Historical CO$_2$ Emissions from Land Use and Land Use Change from the Oil Palm industry in Indonesia, Malaysia and Papua New Guinea [Internet]. [Downloaded on 2018 Sep 17]. Available on: http://www.tropenbos.org/resources/publications/historical+co2+emissions+from+land+use+and+land+use+change+from+the+oil+palm+industry+in+indonesia,+malaysia+and+papua+new+guinea
[6] Zhang H, Wang K, Xu X, Song T, Xu Y, Zeng F. 2015. Biogeographical patterns of biomass allocation in leaves, stems and roots in China’s forests. Scientific Report. 5(15997): 1-12
[7] Syahrinudin. 2005. The potential of oil palm and forest plantations for carbon sequestration on degraded land in Indonesia. Ecology and Development Series. (28): 1-112
[8] Rachdian A, Hariyadi, Setiawan Y. 2018. Estimasi cadangan karbon kelapa sawit di Lanskap Sembilang Dangku, Sumatera Selatan. Media Konservasi. 23 (3). Inpress
[9] [KELOLA Sendang] Kemirnaan Pengelolaan Lanskap Sembilang Dangku. 2017. Bogor (ID): Zoological Society of London
[10] Al-Doski J, Mansor SB, Shafri HZM. 2013. Image classification in remote sensing. Journal of Environment and Earth Science. 3(10): 141-147
[11] Direktorat Inventarisasi dan Pemantauan Sumberdaya Hutan, Direktorat Jenderal Planologi Kehutanan dan Tata Lingkungan, Kementerian Lingkungan Hidup dan Kehutanan. 2015. *Buku Kegiatan Serapan dan Emisi Karbon*. Jakarta (ID): Direktorat Inventarisasi dan Pemantauan Sumberdaya Hutan

[12] Syamani, Agustina A, Susilawati, Nugroho Y. 2012. Cadangan karbon di atas permukaan tanah pada berbagai sistem penutupan lahan. *Jurnal Hutan Tropis* 13(2): 148-158

[13] Junaedi A. 2008. Konsistensi dan inkonsistensi pemanfaatan ruang dan implikasinya terhadap pelaksanaan rencana tata ruang wilayah Kabupaten Sumedang [tesis]. Bogor (ID): Institut Pertanian Bogor

[14] Nasoetion LI, Winoto J. 1996. Masalah Alih Fungsi Lahan Pertanian dan Dampaknya terhadap Keberlangsungan Swasembada Pangan. Prosiding Lokakarya: Persaingan Dalam Pemanfaatan Sumberdaya Lahan dan Air; Bogor, Indonesia [Waktu tidak diketahui]. Yogyakarta (ID): Hlm 113-120

[15] Sugirahayu L, Rusdiana O. 2011. Perbandingan simpanan karbon pada beberapa penutupan lahan di Kabupaten Paser Kalimantan Timur berdasarkan sifat fisik dan sifat kimia tanahnya. *Jurnal Silvikultur Tropika*. 2(3): 149 – 155

[16] Asmani N. 2014. *Kelapa Sawit Komoditas Unggulan Sumatera Selatan yang Ramah Lingkungan*. Makalah pada Seminar Pelantikan Pengurus Gabungan Pengusaha Kelapa Sawit Indonesia (GAPKI) Sumatera Selatan, Palembang 16 Januari 2014

[17] Ramdani F, Hino M. 2013. Land use changes and GHG emissions from tropical forest conversion by oil palm plantations in Riau Province, Indonesia. *PLOS ONE*. 8(7): e70323. https://doi.org/10.1371/journal.pone.0070323

[18] Kho LP. 2015. Carbon stock of oil palm plantations and tropical forests in Malaysia: A review. *Singapore journal of tropical geography*. https://doi.org/10.1111/sjtg.12100