Aboveground forest carbon stock in protected area: A case study of Bukit Tigapuluh National Park, Indonesia

**Arief Darmawan^{*,1}, Zulfira Warta², Elis Molidena², Alexandra Valla², Muhammad Iqbal Firdaus²,
Hisan³, Gunardi Djoko Winarno¹, Bondan Winarno⁴, Teddy Rusolono⁵, Satoshi Tsuyuki⁶**

¹⁾ *Department of Forestry, Lampung University, Jl. Sumantri Brojonegoro No.1, Bandar Lampung, Indonesia*

²⁾ *WWF Indonesia, Graha Simatupang Tower 2, Jakarta Indonesia*

³⁾ *Bukit Tigapuluh National Park, Jl. Raya Rengat No. 70, Pematang Reba - Rengat Indragiri Hulu, Riau
Indonesia*

⁴⁾ *Environment and Forestry Research and Development Institute of Palembang, Jl. Kolonel H. Burlian
Km.6,5 Punti Kayu Palembang*

⁵⁾ *Faculty of Forestry, IPB University, Jl. Raya Dramaga Bogor, West Java, Indonesia*

⁶⁾ *Graduate School of Agriculture and Life Sciences, The University of Tokyo, 1-1-1 Yayoi, Bunkyo-ku,
Tokyo, Japan*

^{*)} *Corresponding Author, email : arief.darmawan@fp.unila.ac.id*

Abstract

Background: In present days, the role of protected areas has been extended to a climate change mitigation action, particularly in Reducing Emissions from Deforestation and Forest Degradation (REDD+). Reliable and practical methods for measuring, reporting and verifying carbon stocks are a necessary component of REDD+. This study aims at recognizing the characteristic and estimating forest carbon stock in a tropical protected area using a combination of terrestrial forest inventory and spatial data.

Results: In the study area of Bukit Tigapuluh National Park in Central Sumatra, 168 cluster plots or 33.6 hectares in total were taken proportionally based on the percentage of forest cover types (dryland primary forest/DPF and dryland secondary forest/DSF) using a traditional forest inventory method (tree up from 5 cm dbh) in combination with the application of information technology. Result revealed that Bukit Tigapuluh National Park secured a significant forest carbon stock which has been estimated to be 269.2 ± 22.2 tC/ha or $35,823,639 \pm 2,951,071$ tC in total, being sequestered in approximately 133,051 hectares of tropical rain forest. This result was higher than other studies located in non-protected areas, but slightly lower than other studies within protected area.

Conclusion: This finding supported the argument that protected areas possess higher figure of carbon stock compared to other forest management units. High amount of forest

carbon biomass in the protected areas shall be very important assets for conducting the role of conservation for REDD+.

Keywords: Forest Carbon Stock, Protected Area, REDD+

1. Introduction

Increasing pressures on natural resources, ecosystems and landscapes have been the consequence of our modern societies' expanding (Deguignet et al., 2017; Michael Lockwood et al., 2006). Environmental degradation, resource scarcity, and a decrease in biodiversity are connected to rapid consumption and unsustainable use of natural resources (Bradshaw et al., 2009; Deguignet et al., 2017; Lazarus et al., 2015). The role of protected areas as a valuable tool against these pressures on biodiversity and their related effects on human populations is now well recognized (IUCN, 2010).

The type of protected area are varies in connection with governance regimes and management styles, including national parks, nature reserves, wildlife sanctuary, hunting parks and watershed protected forests, among many others (Deguignet et al., 2017; Government of Indonesia, 1999). Indonesia, as the world's biodiversity hotspot, has established 53 national parks, either terrestrial or aquatic national parks with a total area of approximately 16 million hectares or about 60% of the total protected areas in Indonesia (Pusat Data dan Informasi KLHK, 2017). Within those areas, nearly 80% were forested which account for 12% of the overall natural forest in Indonesia (Pusat Data dan Informasi KLHK, 2017). These parks are also at alarming threat of deforestation and degradation particularly those in Sumatera Island, in spite of government willingness to protect them (Luskin et al., 2017; Pramudya et al., 2018; Shah and Baylis, 2015).

The role of protected areas has been extended to a climate change mitigation issue, particularly in the tropical countries, which much of the concept embedded in Reducing Emission from Deforestation and Forest Degradation (REDD+) (Harada et al., 2015; Indonesia Forest Climate Alliance (IFCA), 2007). REDD+ is a commitment under UN Framework Convention on Climate Change (UNFCCC) that introduced mechanism for acquiring an international fund- or credit-based mechanism for reducing carbon emissions and protecting forest ecosystems (Brofeldt et al., 2014; Harada et al., 2015). REDD+ has received enormous interest from developing countries as a potential source of international funding for forestry sector. Indonesia has been enthusiastic about the REDD+ initiative following the 13th Conference of Parties (COP13) in Bali, and has actively participated in the international REDD+ negotiations. Protected areas, particularly national parks, became

a target area for REDD+ in Indonesia (Harada et al., 2015; Indonesia Forest Climate Alliance (IFCA), 2007).

Technically, REDD+ is a carbon payment scheme aiming at mitigating climate change through reduced deforestation, reduced forest degradation, conservation of (existing) forest carbon stocks, sustainable management of forests, and enhancement of forest carbon stocks (e.g. through regeneration and planting in previously forest land) (Gardner et al., 2012; Marshall et al., 2012). Reliable and practical methods for measuring, reporting and verifying carbon stocks are therefore a necessary component of REDD+ (Gardner et al., 2012; Petrokofsky et al., 2012). Attempts for estimating tropical forest carbon stocks were mostly related to the type of forest ecosystem (dryland forests, moist forests, peat swamp forests, mangrove forests) and also locations (South East Asia, Africa, South America) (Manuri et al., 2017; Marshall et al., 2012; Yamakura et al., 1986).

Indonesia, through the National Forest Reference Emission Level (FREL) submission to the UNFCCC Secretariat (MoEF, 2016), has established a national forest carbon stock divided into seven regions (Sumatera, Kalimantan, Java, Lesser Sunda and Bali, Sulawesi, Maluku, and Papua). This data was claimed to be derived from analyzing the National Forest Inventory data from 1990 to 2013. The figures, however, particularly those in Sumatera and Kalimantan were very much lower compared to the other figures in similar location (Laumonier et al., 2010; Rutishauser et al., 2013; Yamakura et al., 1986). This disparity shall open a wider window to new forest inventory data, particularly those in a more stable natural forests e.g. in protected areas to support the existing available figures on forest carbon stock. Additionally, estimation of aboveground forest carbon stock in protected areas is very important to invest our knowledge to address the role of conservation activity in REDD+, aside of their high biodiversity circumstance.

The present study aims to help fill our gap in knowledge on: (i) the characteristic of forest stands and carbon stocks in a tropical forest protected area using terrestrial forest inventory; and (ii) to estimate the total carbon stock of natural forest in a tropical forest protected area using combination of spatial data and terrestrial forest inventory. We hypothesized that protected area possessed relatively higher figure of carbon stocks than the forest under different type of tropical forest management, so the role of conservation for carbon stock in protected area as well as the need of significant activities to maintain this high carbon stock will be demonstrated.

2. Methods

2.1. Study area

Figure 1. Study Area

The study area was Bukit Tigapuluh National Park (BTNP), Indonesia. BTNP is a 144,223 hectare of National Park in Eastern Sumatra, consisting primarily of tropical lowland forest (Figure 1). Administratively, BTNP is positioned in two provinces i.e. Riau and Jambi. The National Park was established in 1995, after timber concessions had been issued in this forest block. It is famous as being the last shelter for endangered species such as the Sumatran orangutan, Sumatran tiger, Sumatran elephant, Asian tapir, as well as many endangered bird species. Unfortunately, this important ecosystem is threatened by illegal logging, illegal farming, mining, and poaching (Bukit Tigapuluh Wildlife Protection Unit, 2017). The Park is also inhabited by indigenous peoples of the Orang Rimba (also called Kubu) and Talang Mamak tribes. The Talang Mamak is a sedentary tribe who live only in the surroundings of Bukit Tigapuluh National Park (referred as the Bukit Tigapuluh landscape). The Orang Rimba people are nomadic, because of death, avoiding enemies, and shifting cultivation. The Kubu communities scatter in and around the forest,

in huts with walls made of bark and roofs made of leaves. They live in small groups to facilitate mobility and migrate through natural forests depending on forest products and river for their existence (Sitompul and Pratje, 2009).

2.2. Data collection

168 cluster plots were taken proportionally based on the percentage of forest cover types (dryland primary forest/DPF and dryland secondary forest/DSF), following a virtual mesh grid of 1 km² established in the study area (Figure 2). A cluster plot was established within one selected mesh grid, with regard to forest cover types and access factors. One cluster plot consists of five plots of 400 m² size (in total 2,000 m²) with an arrangement as depicted in Figure 3. This cluster plot is a modification of the conventional single plot of 400 m² (BSN, 2011) or 10,000 m² (FAO, 2007). Within the 400 m² plot, there were 400 m², 100 m² and 25 m² of plots to record the *diameter at breast height* (dbh) of tree (greater than or equal to 20 cm dbh), pole (greater than or equal to 10 cm dbh and less than 20 cm dbh) and sapling (greater than or equal to 5 cm dbh and less than 10 cm dbh) plant categories, respectively. The dbh of dead wood was also recorded within 400 m² plot using three decay categories (BSN, 2011) i.e. slight (dead tree without leafs, 0.9 carbon offset factor), moderate (dead tree without leafs and twigs, 0.8 carbon offset factor), and intense (dead tree without leafs, twigs and branches, 0.7 carbon offset factor) as depicted in Figure 4. In total, a 33.6 hectare of plots was sampled from November 2016 to July 2017. A supporting smartphone application was used to assist surveyor to capture locations' coordinate as well as taking on-site photos heading to north, east, south, west, and looking upward for each cluster plot. The data was consolidated directly through a web server (<https://forestclimate.wwf.id>).

The 2014's land cover data of BTNP on 1:250,000 scales was collected from the Ministry of Environment and Forestry. This data was modified by refer to the 2016 Landsat 8 Image to get the newest condition of land cover, so that relatively parallel to the time of terrestrial forest inventory was carried out (Figure 2).

Figure 2. Cluster plot locations

Figure 3. (a) The arrangement of plots in a cluster plot; (b) sub plots of 400 m², 100 m² and 25 m² within a plot

Figure 4. (a) Living tree; (b) slight dead wood; (c) moderate dead wood; and (d) intense dead wood (BSN, 2011)

2.3. Data Analysis

Data analysis was carried out in three phases. First, we consolidated forest inventory data into a spreadsheet. We adopted allometric equation from Chave et al., (2005) for moist tropical forest ecosystem to calculate aboveground biomass of each individual tree, since most of the forest stands on mineral soil, as follows:

$$AGB = \exp(-1.499 + 2.148 \ln(D) + 0.207 (\ln(D))^2 - 0.0281(\ln(D))^3) \times WD$$

where AGB, D, and WD are aboveground biomass (in kg), dbh (in cm) and wood density (in g/cm³), respectively. Wood density for each species was derived from International Centre for Research in Agroforestry (ICRAF) wood density database (<http://db.worldagroforestry.org/wd>). When no botanical identification was available, we used 0.66 as a default wood density referred to Biomass Conversion and Expansion Factor (BCEF) for tropical forest (IPCC, 2006). Carbon offset factor (0.9; 0.8 or 0.7) were multiplied to the AGB of a single dead trees (by using similar allometric equation). Aboveground biomass measure were converted into carbon mass (C) by multiplying AGB with 0.47 (IPCC, 2006).

Second, statistical analysis was performed to examine the characteristic of forest stand and forest carbon stock in the study area. This includes mean, standard deviation and sampling error estimates as described in Table 1. The analysis was divided into two assumptions. The first assumption was that forest in the study area is categorized into one

forest category, and the second assumption was that forest in the study area is categorized into dryland primary forest (DPF) and dryland secondary forest (DSF), following the land cover category of Ministry of Environment and Forestry (MoEF).

Tabel 1. Statistical analysis

Forest	Statistical Analysis							
Cover type	Mean (M_j)	Standard deviation (SD)	Sample Count (n)	t -statistic at 95% (t)	Confidence Interval (CI)	Lower Bound	Upper Bound	Sampling Error (%)
Forest type-j	$\frac{1}{n} \sum_{i=1}^n M_i$	$\sqrt{\frac{1}{n-1} \sum_{i=1}^n (M_i - M_j)^2}$	3	4,30	$\frac{SD \times t}{\sqrt{n}}$	$M_j - CI$	$M_j + CI$	$\frac{CI}{M_j} \times 100\%$
			5	2,78				
			8	2,37				
			10	2,26				
			50	2,01				
			100	1,98				
			∞	1,96				
Note: M_i is the amount of carbon stock (in tC/ha) of cluster plot- i in forest type- j , n is the number of plots in forest type- j								

Third, we estimated the total aboveground carbon sequestered in the forest of BTNP by multiplying total forest cover area (in ha) and forest carbon stock (in tC/ha) under the two assumptions earlier.

3. Results and discussion

3. 1. Results

We recorded 14,229 individuals vegetation consisting of 14,200 individuals with dbh ranging from 5 cm to 150 cm and 29 individuals with dbh ranging from 155 cm to 295 cm. Dipterocarpaceae was the dominant family with 32 total species and 2,572 individuals. The floristic information of this data is described in Table 2.

Table 2. Floristic information of forest inventory plot

No. Family	Species	Individual	No. Family	Species	Individual	No. Family	Species	Individual
1. Alangiaceae	1	31	21. Elaeocarpaceae	1	11	41. Papilionaceae	1	27
2. Ampelidaceae	1	1	22. Euphorbiaceae	31	1330	42. Pinaceae	1	29
3. Anacardiaceae	18	957	23. Fagaceae	9	230	43. Pittosporaceae	1	6
4. Annonaceae	7	228	24. Flacourtiaceae	3	66	44. Rosaceae	2	4
5. Apocynaceae	6	90	25. Guttiferae	14	216	45. Rubiaceae	8	136
6. Auricariaceae	1	6	26. Icacinaceae	1	1	46. Rutaceae	3	17

7. Barringtoniaceae	1	83	27. Lauraceae	15	1356	47. Salicaceae	1	3
8. Bignoniaceae	2	3	28. Leguminosae	23	783	48. Sapindaceae	9	312
9. Bombacaceae	5	55	29. Linaceae	1	68	49. Sapotaceae	15	521
10. Boraginaceae	2	6	30. Loganiaceae	1	12	50. Simaroubaceae	2	41
11. Burseraceae	10	285	31. Magnoliaceae	2	4	51. Sterculiaceae	5	230
12. Celastraceae	3	289	32. Melastomataceae	4	53	52. Styracaceae	1	10
13. Chrysobalanaceae	1	23	33. Meliaceae	18	135	53. Symplocaceae	1	14
14. Combretaceae	1	11	34. Moraceae	12	864	54. Theaceae	2	76
15. Compositae	1	8	35. Myristicaceae	8	259	55. Thymelaceae	4	15
16. Cupressaceae	1	2	36. Myrtaceae	11	970	56. Tiliaceae	2	9
17. Datisceae	1	4	37. Olacaceae	4	429	57. Torricelliaceae	1	59
18. Dilleniaceae	4	138	38. Oleaceae	3	21	58. Ulmaceae	2	298
19. Dipterocarpaceae	32	2572	39. Oxalidaceae	1	28	59. Unidentified	1	600
20. Ebenaceae	4	104	40. Palmae	3	17	60. Verbenaceae	3	72

Forest stand characteristic

The distribution of basal area and carbon stock of sample plots is described in Figure 5. A Gaussian distribution curves were showed by both parameters. The minimum and maximum basal area were 12.67 m²/ha and 123.71 m²/ha, respectively. Whereas, the minimum and maximum carbon stock were 61.62 tC/ha and 864.16 tC/ha, respectively.

(a)

(b)

Figure 5. The distribution of (a) basal area and (b) forest carbon stock in the sample plots

Figure 6 stands a profile of basal area against carbon stock profile of the sample plots. The relationship between basal area and carbon stock was relatively linear. Some plots possessed higher basal area but resulted with low carbon stock, because the plots were dominated by low to moderate wood density tree species.

Figure 6. Profile of basal area against carbon stock profile of the sample plots

The characteristic of sample plots with regard to elevation was described in Table 3. Most of the plots were established at 100 – 200 m asl elevation, while the least plots were

set up at below 100 m asl elevation (Figure 7). Both basal area and carbon stock had a relatively similar increasing trend until 200 – 300 m asl, but then decreasing pattern until the highest elevation (above 400 m asl).

Table 3. The characteristic of sample plots with regard to elevation

Height (m asl)	Number of Plot	Mean Basal Area (m ² /ha)	Mean Carbon Stock (tC/ha)
below 100	2	51.33	234.49
100 – 200	83	45.90	263.13
200 – 300	58	49.18	300.88
300 – 400	21	38.81	226.31
above 400	4	33.90	180.18
Total	168	45.93	269.25

Figure 6. Sample plots elevation

Aboveground carbon stock

The first assumption of carbon stock estimates resulted 269.25 (± 22.18) tC/ha with 8.24 % of SE (Tabel 4). By the second assumption, SE of estimates were rising into 9.84% and 14.24% of DPF and DSF, respectively. Carbon stock estimates in DPF resulted 287.03 (± 28.23) tC/ha, while DSF resulted 230.67 (± 32.85) tC/ha. This result revealed that detailing forest cover into more specific forest classes in the study area was not improving uncertainty of estimates.

Table 4. Statistical Analysis of aboveground forest carbon stock

Forest Cover type	Statistical Analysis							
	Mean (<i>Mj</i>)	Standard Deviation (SD)	Sample Count (n)	<i>t</i> -statistic at 95% (t)	Confidence Interval (CI)	Lower Bound	Upper Bound	Sampling Error (%)
<i>First assumption</i>								
Forested area	269.25	146.69	168	1.96	22.18	247.07	291.43	8.24
<i>Second assumption</i>								
DPF	287.03	154.46	115	1.96	28.23	258.80	315.26	9.84
DSF	230.67	120.77	53	1.98	32.85	197.82	263.52	14.24

Total aboveground forest carbon sequestered in the study area by using the first and second assumptions are explained in Table 5. Total forested area in BTNP based on the land cover map of 2016 was 133,051 ha which includes 126,992 ha of DPF and 6,059 ha of DSF. Using the first assumption, the estimates of total aboveground carbon sequestered was more conservative than using the second assumption i.e. 35,823,639 tC and 37,847,600 tC for first and second assumptions, respectively.

Table 5. Aboveground forest carbon sequestered in Bukit Tigapuluh National Park

Land cover category	Area (ha)	Carbon density/stock (tC/ha)			Total carbon sequestered (tC)		
		Mean	Lower	Upper	Mean	Lower	Upper
<i>First assumption</i>							
Forested area	133,051	269.25	247.07	291.43	35,823,639	32,872,312	38,774,966
<i>Second assumption</i>							
DPF	126,992	287.03	258.80	315.26	36,449,909	32,864,849	40,034,969
DSF	6,059	230.67	197.82	263.52	1,397,691	1,198,664	1,596,717
Total	133,051				37,847,600	34,063,514	41,631,686

3. 2. Discussion

Forest stand and carbon stock characteristics

We evidenced a high diversity of vegetation by 59 families of trees covering at least 331 species. In addition, the forest ecosystem in BTNP was dominated by dipterocarp family as the flagship of a tropical lowland rainforest in South East Asia (e.g. Kuswanda and Barus, 2019; Laumonier et al., 2010; Manuri et al., 2016; Yamakura et al., 1986). The existence of some fruit trees families (e.g. Myrtaceae, Sapindace, Anacardiaceae, Leguminosae, Euphorbiaceae and Moraceae) also proved that this forest block is very important for wildlife food as well as their habitat. Kuswanda and Barus (2019) recommended that the vegetation composition in Bukit Tigapuluh National Park was more than enough to support the lives of orangutan. The vegetation composition showed the same value even higher compared to the orangutans natural habitat in the Batang Toru Forest and Gunung Leuser National Park (Kuswanda and Barus, 2019). Sitompul and Pratje (2009) also pointed out that at least 660 species of useful plants found in BTNP and its surrounding area, 20% were obtained from primary forests, 11% from degraded areas, 29% from secondary forests, 15% from community rubber plantations, 5% from unirrigated agricultural fields and 19% from yards.

Our analysis of carbon stock estimation showed that the first assumption marked better uncertainty (lower SE) than the second assumption, although in the second assumption the mean value of carbon stock of DPF and DSF resulted as expected. There are two reasons for this. First reason is the number of plot was decreasing in the DPF and DSF resulting in an increase of data disparity as indicated by the increase of SE. The second reason is the differentiation between DSF and DPF that was only based on visual characteristic of remote sensing data, so it was not really related to the type of carbon stock in each forest class.

MoEF (2016) stated that the difference between DPF and DSF is merely related to an exhibit signs of logging activities indicated by patterns and spotting of logging (appearance of roads and logged-over patches), hence difficult to distinguish through Landsat 8 image although some areas of BTNP were a logging concession in the past (Kuswanda and Barus, 2019). So, it is possible that DPF and DSF does not necessarily relate to the real amount of carbon stocks. Romijn et al. (2013) pointed out that countries shall select the major GHG emissions from land use changes (e.g. forest cover change) through robust methodology and definitions used. This allows them to make a land cover classification that differentiates between different forest types and other important land

cover classes. Therefore, to decide forest or land cover classification, an attention on how carbon stock has been included into consideration needs to be addressed.

We selected the first assumption based on the above considerations. By using this selection, we estimated aboveground forest carbon stock in BTNP is 269.2 ± 22.2 tC/ha. In total, forested area in BTNP sequestered $35,823,639 \pm 2,951,071$ tC. This result was higher than others studies conducted in non-protected area (e.g. Laumonier et al., 2010; MoEF, 2016; Rutishauser et al., 2013; Slik et al., 2010; Yamakura et al., 1986), but lower estimates than others studies located in protected area i.e. Gunung Palung National Park, West Kalimantan (Paoli et al., 2008) (Table 6).

Tabel 6. Forest stand and carbon stock characteristics in various tropical lowland evergreen forests

No.	Locality	Basal area (m ² /ha)	Biomass (t/ha)	Carbon stock (tC/ha)	Range of dbh (cm)	Sample area	Authors
1.	Borneo (Sebulu, East Kalimantan)	36.8	509	239.23	≤152	1 ha	(Yamakura et al., 1986)
2.	Sumatera Landscape (Jambi, Bengkulu, South Sumatra, Lampung)	31.7 ± 0.5	361 ± 7	180	10 – 210	70.2 ha	(Laumonier et al., 2010)
3.	East Kalimantan, Pasir Mayang Sumatra	32.98	316 – 378	149 – 178	10 – 140	12 ha	(Rutishauser et al., 2013)
4.	NFI Sumatra (DPF)	NA	268.6 ± 22	135 ± 10	NA	92 ha	(MoEF, 2016)
5.	NFI Sumatra (DSF)	NA	182.2 ± 10	85.6 ± 4.7	NA	265 ha	(MoEF, 2016)
6.	Borneo	25 – 48	457.1	214.8	NA	83 plot	(Slik et al., 2010)
7.	Gunung Palung NP, West Kalimantan	39.6 ± 1.4	622 ± 33	292.3 ± 15.5	>10	4.8 ha	(Paoli et al., 2008)
8.	Bukit Tigapuluh NP, Riau – Jambi	45.93	572.9 ± 47	269.2 ± 22.2	5 – 295	33.6 ha	This study

The three highest estimates on forest carbon stock were Paoli et al. (2008), this study, and Yamakura et al. (1986), while the lowest estimates was from the MoEF (2016). A conservative estimate from MoEF (2016) probably occurred because of their data selection mechanism. MoEF (2016) stated that the data validation included, among others, checking measurement data through abnormality filtering of DBH and species name of individual trees in the plots. This filtering mechanism can reduce data variation thus reducing the number of oversized trees. As estimates from MoEF (2016) was the lowest (both DPF and DSF), a re-enumeration of this national carbon stock with newly available data is

advisable, among others, with the inclusion of public participation such as university, research center and other non-state actors (e.g. Boissière et al., 2017).

Implication to the management of protected area

This study and Paoli et al. (2008) supported the argument that protected areas possess higher figure of carbon stock compare to other forest management unit. The national government administers national parks in Indonesia strictly prohibits access of people to the parks to ensure the integrity of forest ecosystems (Harada et al., 2015), so a purely intact forest or an old secondary forest are typically found. Collins and Mitchard (2017) have estimated carbon emissions in large forest protected areas in tropical countries (N=2018) and found that 36 ± 16 Pg C is stored in protected area's trees, representing 14.5% of all tropical forest biomass carbon. These results suggest that protected areas have been a successful instrument of protecting carbon biomass, thus a subset causing a disproportionately high share of emissions should be an urgent priority for management interventions.

Protected areas aim at protecting multiple ecosystem services (Collins and Mitchard, 2017). Apart from its role for biodiversity conservation, the benefits they deliver to society include provision of water, food and medicine, and they also provide important recreational, educational, spiritual and cultural places (Deguignet et al., 2017). We have demonstrated that protected areas in the tropics secure exceptionally high amount of carbon biomass, which is very important to be conserved in the perspective of climate change mitigation issue. High amount of forest carbon biomass in the protected areas shall be very important assets for conducting the role of conservation for REDD+. Therefore, the management of BTNP shall enlarge their perspectives on climate change mitigation action apart from merely biodiversity conservation and life-support system. REDD+ readiness for protected areas need to be completed as soon as possible, since REDD+ has been a commitment of Indonesia's Government for conducting Nationally Determined Contribution (Government of Indonesia, 2016).

Many national parks in Indonesia have been frequently suffering from conflicts between government and local people (Harada et al., 2015). REDD+ initiatives may become a way out to tackle social and political problems and guarantee people's right to use and manage forests. REDD+ initiatives are expected to resolve such forest tenure issues, which may become a key precondition to implementing REDD+ projects effectively. Harada et al. (2015) confirmed that the REDD+ demonstration activities (DA)

project in Meru Betiri NP could secure land use inside the national park and the participation of local people in the REDD+ DA project in the park, which had been strictly prohibited by national regulations in Indonesia. Consequently, the project in the national park could successfully introduce alternative livelihoods to improve income, particularly for economically disadvantaged people, by implementing a rehabilitation program with agroforestry while conserving forests. Harada et al. (2015) also demonstrated the necessity of further discussion of effective benefit-sharing of REDD+ incentive while realizing local participation in REDD+ projects and improving local livelihoods. These outputs of the project can become a model for collaborative forest management with multiple stakeholders in different national parks such as Bukit Tigapuluh National Park.

4. Conclusion

Bukit Tigapuluh National Park secured a significant forest carbon stock which has been estimated as 269.2 ± 22.2 tC/ha or in total $35,823,639 \pm 2,951,071$ tC, being sequestered in approximately 133,051 hectares of tropical rain forest. This result was higher than other study located in non-protected area, but was lower estimates than other study located in protected area i.e. Gunung Palung National Park, West Kalimantan. This study and Paoli et al. (2008) supported an argument that protected areas possess higher figure of carbon stock compare to other forest management unit. High amount of forest carbon biomass in the protected areas shall be very important assets for conducting the role of conservation for REDD+. Therefore, the management of BTNP shall enlarge their perspectives on climate change mitigation action aside for merely biodiversity conservation and life-support system.

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Declarations

List of abbreviations

WWF	: World Wildlife for Nature
REDD+	: Reducing Emissions from Deforestation and Forest Degradation Plus
DPF	: Dry Primary Forest
DSF	: Dry Secondary Forest
tC	: tonnes carbon
KLHK	: Kementerian Lingkungan Hidup dan Kehutanan (Ministry Environment and Forestry/MoEF)
IFCA	: Indonesia Forest Climate Alliance
UNFCCC	: UN Framework Convention on Climate Change
COP	: Conference of Parties
BTNP	: Bukit Tigapuluh National Park
BSN	: Badan Standar Nasional (National Standard Agency)
FAO	: Food and Agriculture Organization of the United Nations
Dbh	: diameter at breast height
AGB	: Aboveground Biomass
WD	: Wood Density
ICRAF	: International Centre for Research in Agroforestry
IPCC	: Intergovernmental Panel on Climate Change
Asl	: Above Sea Level
SE	: Sampling error

Ethics approval and consent to participate

Not Applicable

Consent for publication

Not Applicable

Availability of data and material

The data for this analysis was reposed at <http://repository.lppm.unila.ac.id/17972/>

Competing interests

No competing interest among author and co-authors

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Authors' contributions

- Arief Darmawan : lead researcher, conducting overall strategy to conduct this research from planning, data collection, analysis and writing report and paper.
- Zulfira Warta : giving general suggestion and managing the field data collection.
- Elis Molidena : analyzing spatial data.
- Alexandra Valla : giving suggestion and english prove read
- Muhammad Iqbal Firdaus : giving suggestion on database and data analysis
- Hisan : giving suggestion on field data collection, recording and analysis
- Gunardi Djoko Winarno : giving suggestion on data analysis and discussion
- Bondan Winarno : giving suggestion the data analysis and discussion especially National Park Management
- Teddy Rusolono : giving suggestion on the data analysis and discussion on carbon inventory
- Satoshi Tsuyuki : giving suggestion on the general part of the manuscript and english prove read

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