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Research Article

Aboveground Forest Carbon Stock in Protected Area: A Case Study of Bukit Tigapuluh National Park, Indonesia

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ABSTRACT
The role of protected areas has been expanded into climate change mitigation, specifically on Reducing Emissions from Deforestation and Forest Degradation (REDD+). A reliable and practical method for measuring, reporting and verifying carbon stock is an essential component for REDD+. This study aims to recognize the characteristic and estimate aboveground forest carbon (AGC) stock in the tropical protected tropical area using a combination of terrestrial forest inventory and spatial data. A 168 cluster plots totaling 33.6 hectares were taken proportionally based on the percentage of forest cover types (dryland primary natural forest/ DPF and dryland secondary natural forest/DSF) using a traditional forest inventory method (more than 5 cm dbh). Results showed that Bukit Tigapuluh National Park secured a significant AGC stock which has been estimated to be 269.2 [247.07; 291.43] tC/ha or 35,823,639 [32,872,312; 38,774,966] tC in total, being stored in approximately 133,051 hectares of the tropical rain forest. This result was higher than other studies in non-protected areas but slightly lower than other studies within protected areas. This finding supported the argument that protected areas possess a higher figure of AGC stock than other forest management units. The high amount of forest carbon biomass in the protected areas shall be very important assets for conducting the role of conservation for REDD+.

INTRODUCTION
The role of protected areas as a valuable tool against the pressures on biodiversity and their related effects on human populations is now well recognized (IUCN 2010). Protected areas vary with respect to governance regimes, and management types, including national parks, nature reserves, wildlife sanctuary, hunting parks and watershed protected forests, among many others (Deguignet et al. 2017; Government of Indonesia 1999). As a world's biodiversity hotspot, Indonesia 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 in

2017, which account for 12% of the overall natural forest in Indonesia (Pusat Data dan Informasi KLHK 2017). However, these parks are at alarming threat of deforestation and degradation, particularly those in Sumatra Island, despite government willingness to protect them (Luskin et al. 2017; Pramudya et al. 2018; Shah & Baylis 2015).

The role of protected areas has been expanded to a climate change mitigation, 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 a 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 the 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 reducing deforestation, reducing 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). Therefore, reliable and practical methods for measuring, reporting and verifying carbon stocks are necessary components of REDD+ (Gardner et al. 2012; Petrokofsky et al. 2012). The IPCC Guideline (IPCC 2006) suggests five carbon pools be included to thoroughly estimate forest carbon stock (i.e. aboveground biomass, belowground biomass, deadwood, litter, and soil carbon). Aboveground biomass (AGB) is the most important carbon pool representing the forest's physical conditions (GOFC-GOLD 2014a; Ministry of Environment and Forestry 2016). Attempts for estimating aboveground tropical forest carbon 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 (Ministry of Environment and Forestry 2016), has established a national forest carbon stock divided into seven regions (Sumatra, 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. However, the figures, particularly those in Sumatra (i.e. 135 [125; 145] tC/ha for dry primary forest/ DPF and 85.6 [80.9; 90.3] tC/ha for dry secondary forest/ DSF) and

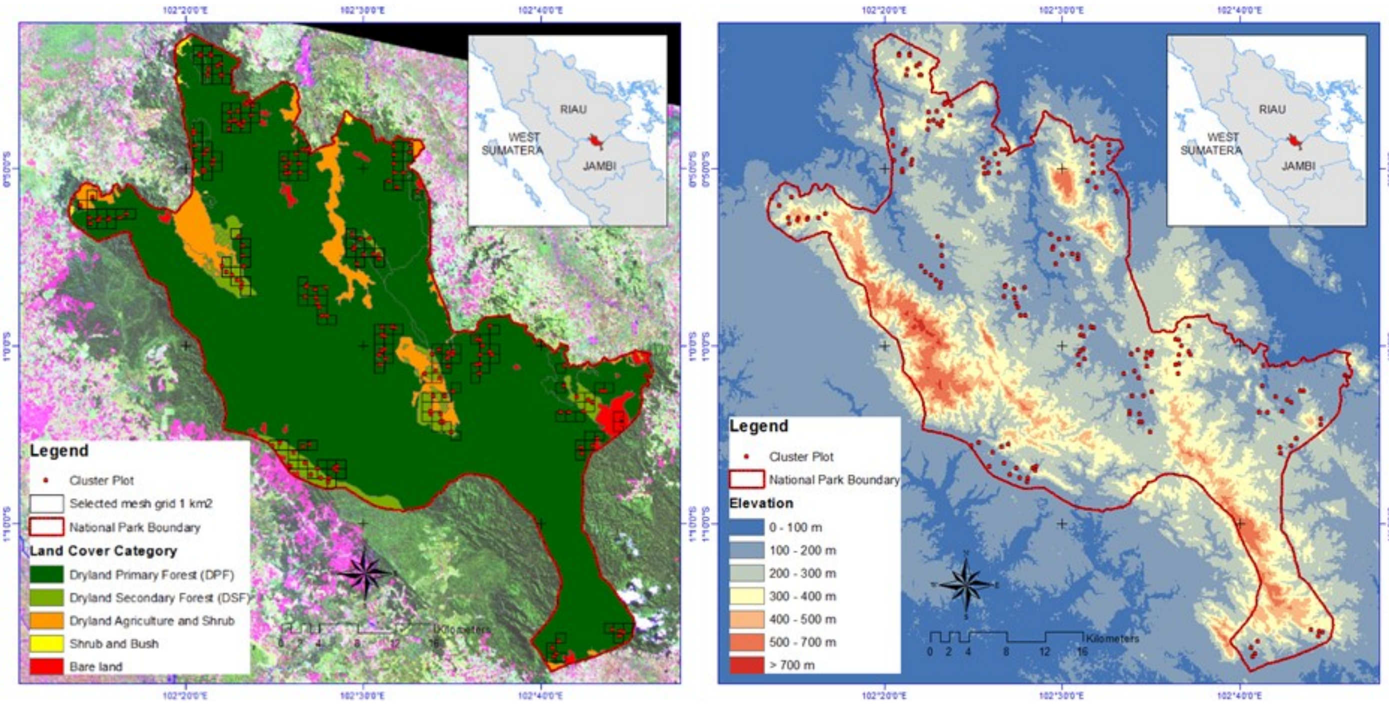
Kalimantan (i.e. 126.6 [121.4; 131.9] tC/ha for DPF and 95.6 [92.3; 98.8] tC/ha for DSF) were much lower than the other figures in a similar location (Laumonier et al. 2010; Rutishauser et al. 2013; Yamakura et al. 1986). This disparity shall open a wider window to new forest inventory data, particularly those in 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 fundamental to invest our knowledge to address the role of conservation activity in REDD+, aside from their high biodiversity circumstance.

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

METHODS

Study Area

The study area is located within Bukit Tigapuluh National Park (BTNP), Indonesia. Geographically located between E102^{0}13’ – E102^{0}46’ and S00^{0}42’ – S01^{0}18’, BTNP is 144,223 hectares of National Park in Eastern Sumatra, consisting of tropical lowland to a hilly undulating forest on mineral soil (Figure 1) at an altitude between 60 to 843 m asl. The climate in Bukit Tigapuluh National Park is a typical of tropical rainforest, i.e. always wet even though it also experiences a dry season with an average rainfall of 2,577 mm per year. The temperature of this area is in the range between 20.8^0 – 33^0 C. The National Park was established in 1995 after timber concessions had been issued in this forest block. This Park is famous as the last shelter for endangered species such as the Sumatran orangutan, Sumatran tiger, Sumatran elephant, Asian tapir, and many endangered bird species. Unfortunately, this vital 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 living only in Bukit Tigapuluh National Park (referred to 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 & Pratje 2009). The surrounding indigenous peoples (especially the Talang Mamak Tribe) believe that the hills and plants in the national park have magi-



(a) (b)

Figure 1. (a) The study area of Bukit Tigapuluh National Park (red line) and the location of the 168 cluster plots, which was selected purposively based on the forest types; (b) and overlaid to the DEM.

cal powers in their lives, so that they indirectly participate actively in maintaining and protecting the hills and plants in the national park.

Data Collection

One hundred sixty-eight cluster plots were taken proportionally based on the area 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 1). One cluster plot was established within one selected mesh grid regarding 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 2. This cluster plot is a modification of the conventional single plot of 400 m² (BSN 2011) or 10,000 m² (FAO 2007). The reason for choosing a cluster plot is that the larger the area of the sample plot, the greater the proportion of total variation that falls within the plot, and as a result the smaller the standard errors (Baraloto et al. 2013; Henttonen & Kangas 2015; Picard et al. 2018). Thus, the cluster plot was designed for compromising the larger sample plot's need and complying with the national standard.

We limit our analysis for aboveground biomass and necromass (deadwood) since these carbon pools account for more than 75% of the total forest biomass in mineral soil (GOFC-GOLD 2014b; Manuri et al. 2016; Ministry of Environment and Forestry 2016). In this study, aboveground biomass and deadwood in carbon estimates were combined and called aboveground forest carbon (AGC, in tC/ha). We omit other carbon pools (i.e. be-

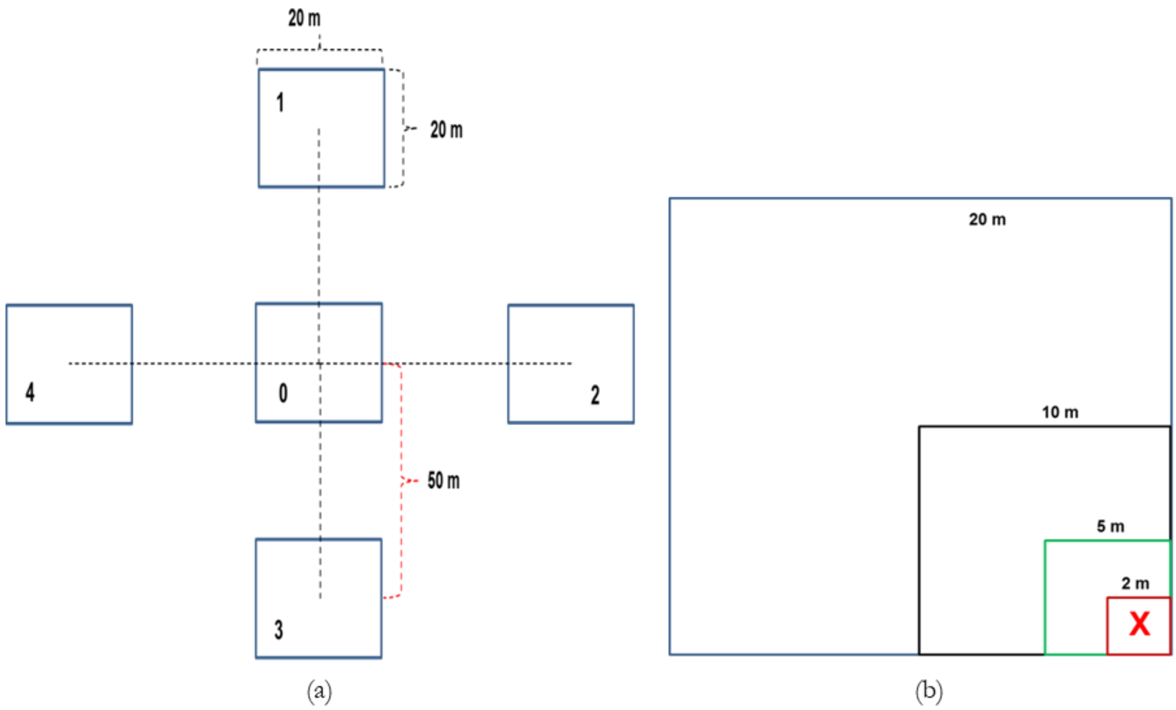


Figure 2. (a) The arrangement of plots in a cluster plot, the distance of center plot and the side plots was 50 m; (b) Each plot was comprised of subplots of 400 m², 100 m² and 25 m².

lowground biomass, litter, and soil carbon) because the study area located on the mineral soil where the fraction of soil carbon is mostly less than 20% and belowground biomass is mostly estimated through a relationship to above-ground biomass as indicated by (GOFC-GOLD 2014b), which does not have critical influence to the variation of data.

The 400 m² sub-plot consists of 400 m², 100 m² and 25 m² of plots to record the diameter at breast height (dbh) of the 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. When the tree was buttressed, the tree diameter was measured approximately 20 cm above the buttress. The dbh of dead-wood was also recorded within 400 m² plot using standing deadwood categories (BSN 2011), i.e. slight (dead tree without leaves, 0.9 carbon offset factor), moderate (dead tree without leaves and twigs, 0.8 carbon offset factor), and intense (dead tree without leaves, twigs and branches, 0.7 carbon offset factor) as depicted in Figure 3. Downed deadwood was planned to be measured, but we did not find it during the field measurement. In total, a 33.6 hectare of plots was measured from November 2016 to July 2017. A supporting smartphone application was used to assist the surveyor in capturing locations' coordinates and taking on-site photos heading north, east, south, west and looking upward for each cluster plot.

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 referring to the 2016 Landsat 8 Image to get the newest condition of land cover so that it relatively parallel to the time of terrestrial forest inventory was carried out (Figure 1).

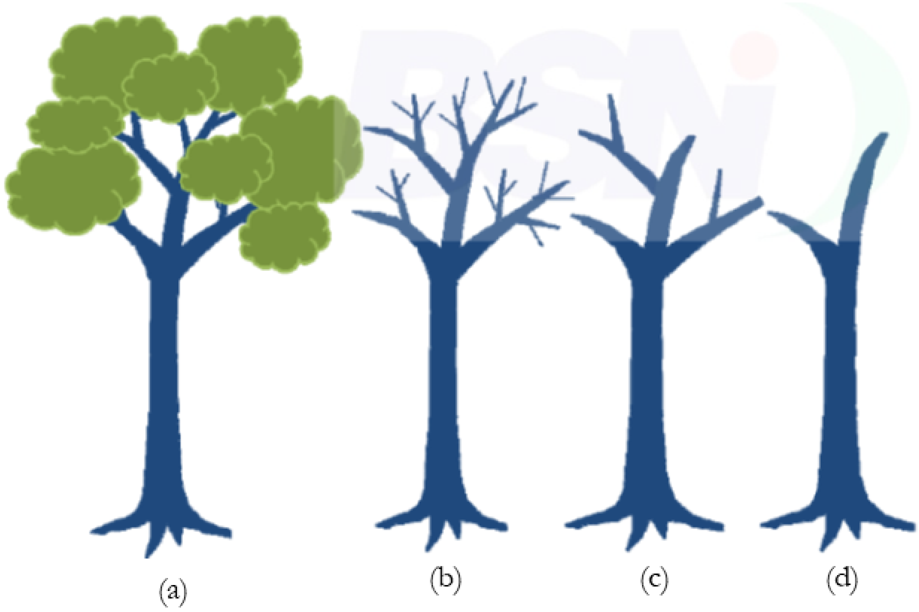


Figure 3. Standing deadwood category of individual tree according to BSN (2011), (a) Living tree; (b) slight deadwood; (c) moderate deadwood; and (d) intense deadwood. This category is used for i.e. the carbon offset factor of individual trees, 1, 0.9, 0.8 and 0.7, respectively.

Data Analysis

Data analysis was carried out in three phases. First, we consolidated the forest inventory data into a spreadsheet. We adopted an allometric equation from Chave et al. (2005) for the moist tropical forest ecosystem to calculate aboveground biomass of each tree since most of the forest stands on mineral soil. This allometric equation was selected to follow similar equation used by the Indonesia's FREL (Ministry of Environment and Forestry 2016) so that a direct comparison between results can be done. The allometric equation is expressed as follows:

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

where AGB is aboveground biomass (in kg), D is dbh (in cm), and WD is wood density (in g/cm^3). 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). The carbon offset factor (0.9; 0.8 or 0.7) was multiplied to the AGB of a single dead tree (using a similar allometric equation). Aboveground biomass estimates were converted into carbon mass (C) by multiplying AGB with 0.47 (IPCC 2006).

Second, statistical analyses were performed to examine forest stand and forest carbon stock characteristics in the study area. This includes mean, standard deviation, and sampling error estimates as described in Table 1. ANOVA was used to see the significant difference between AGC and geo-

Table 1. Statistical analysis of the sample plot data. Uncertainty of estimates is characterized by Sampling Error (SE).

Forest Cover type	Statistical Analysis							
	Mean (Mj)	Standard deviation (SD)	Sample Count (n)	*t-statistic at* 95% (t)	Confidence Interval	Lower Bound	Upper Bound	*Sampling Error* (%)
Forest type-j	$\frac{1}{n}\sum_{i=1}^{n} Mi$	$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(Mi+Mj)^2}$	3	4,30	$\frac{SD \times t}{\sqrt{n}}$	$Mj - CI$	$Mj + CI$	$\frac{CI}{Mj} \times 100\%$
			5	2,78				
			8	2,37				
			10	2,26				
			50	2,01				
			100	1,98				
			∞	1,96				

Mi is the amount of aboveground carbon stock (in tC/ha) of cluster plot-*i* in forest type-*j*, n is the number of plots in forest type-*j*.

graphic variables (i.e. elevation and forest cover types). The analysis was divided into two approaches. The first approach was that the forest in the study area is categorized into one forest category (i.e. natural forest). The second approach was that the forest in the study area is categorized into dryland natural primary forest (DPF) and dryland natural secondary forest (DSF), following the land cover category of the Ministry of Environment and Forestry (MoEF).

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

RESULTS AND DISCUSSION

Results

We recorded 14,127 individual trees with dbh (diameter at breast height) ranging from 5 cm to 295 cm. There were 600 individuals classified as unidentified, and other individuals could be identified at least up to the family name. Dipterocarpaceae was the dominant family with 32 total species and 2,572 individuals.

Forest stand characteristic

The distribution of basal area and AGC of sample plots by diameter class is described in Figure 4. The fifth biggest contribution for AGC stock was made by 30 to 70 of diameter classes. These diameter classes accounted for more than 50% of the AGC of the sample plots. Big trees (diameter class more than 150 cm) contributed less than 10% of the overall AGC stock of the sample plots. Overall, the average percentage of AGB and deadwood that constitutes AGC was 96.5% and 3.5%, respectively.

Figure 5 describes the profile of stand basal area against AGC of the sampling plots. The relationship between basal area and AGC stock was relatively linear. Some plots possessed a higher basal area but resulted in low carbon stock because the plots were dominated by low to moderate wood density tree species.

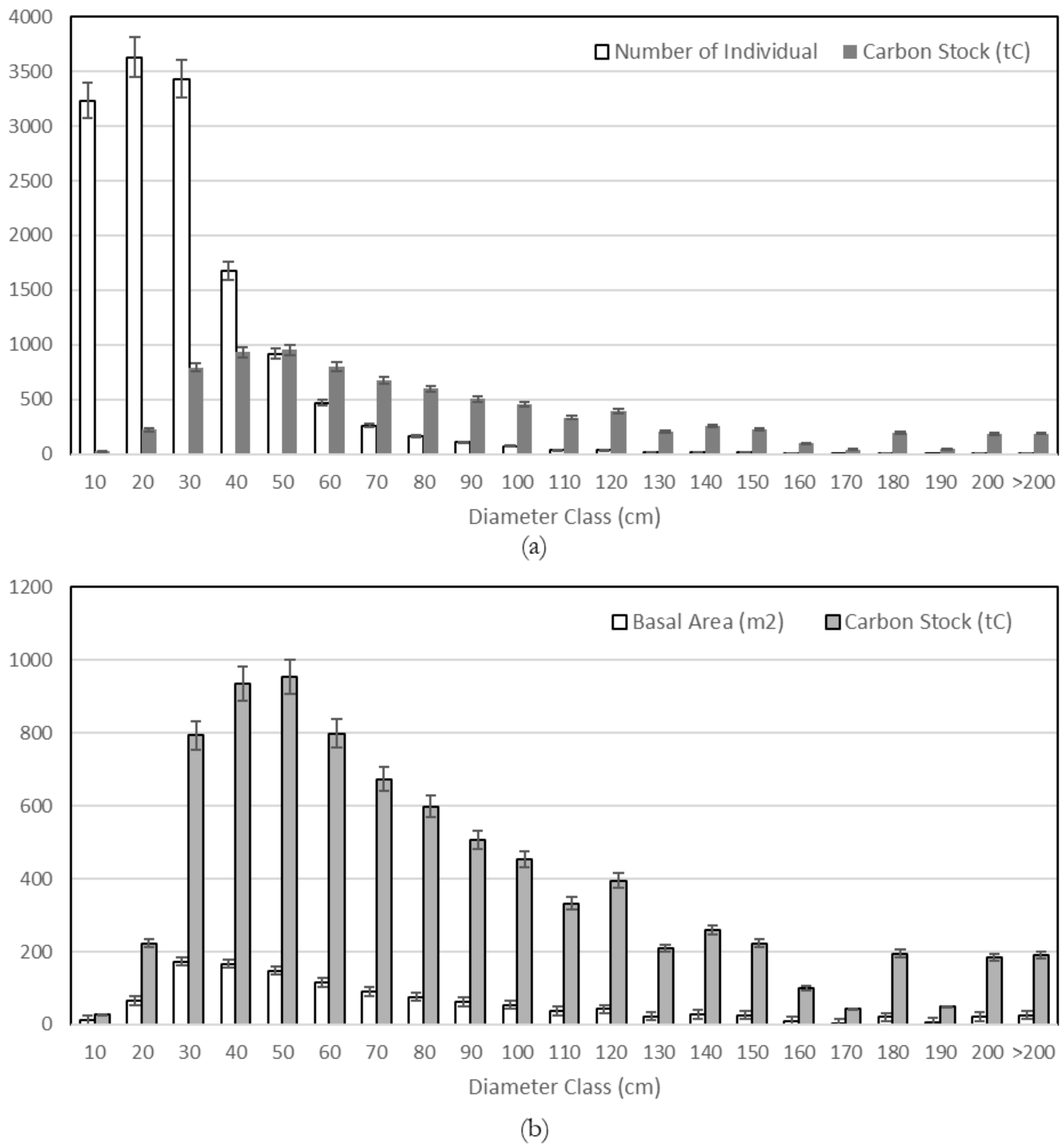


Figure 4. The data distribution of number of individual and AGC (a); and basal area and AGC (b) in the sample plots by diameter class. Each unit of measurements is presented in parentheses.

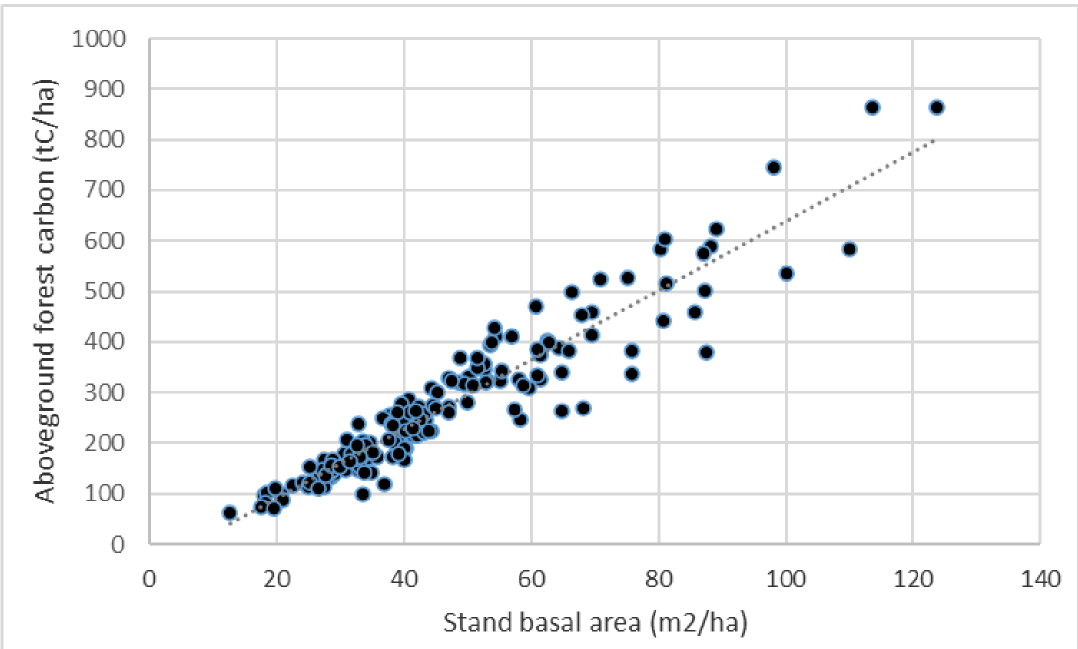


Figure 5. The profile of stand basal area against aboveground carbon stock of the sampling plots. The line represents a linear regression ($R^2 = 0.8919$, $F1,166 = 1370$, $P < 0.0001$).

The characteristic of sample plots with regard to elevation was described in Table 2. Most of the plots were established at 100 – 200 m asl elevation, while only one plot was set up below 100 m asl elevation (Table 3). 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). However, ANOVA did not show a significant relation among elevation and aboveground forest carbon, where Pr(>F) was 0.1825, and the F value was 1.5783.

Aboveground carbon stock

The First approach of AGC estimates resulted in 269.25 [247.07; 291.43] tC/ha with 8.24 % of sampling error (SE) (Table 3). By the Second approach, AGC estimates in DPF resulted 287.03 [258.80; 315.26] tC/ha, while DSF resulted 230.67 [197.82; 263.52] tC/ha. ANOVA showed significant relation among forest types (DPF and DSF) and aboveground forest carbon, where Pr(>F) was 0.0202, and the F value was 5.4987. However, SE estimates were rising into 9.84% and 14.24% of DPF and DSF, respectively.

Total AGC in the study area using the first and second approaches are presented in Table 4. The 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 approach, the estimate of total AGC was lower than the second approach, i.e. 35,823,639 tC and 37,847,600 tC for first and second approaches.

Table 2. The characteristic of sample plots about elevation. Lower and upper are the 95% confidence interval (CI).

Height (m asl)	Number of Plot	Basal Area (m^2/ha)			Carbon Stock (tC/ha)		
		Mean	Lower	Upper	Mean	Lower	Upper
below 100	1	68.1	NA	NA	268.8	NA	NA
100 – 200	77	45.5	43.4	47.6	259.5	230.0	289.1
200 – 300	61	49.3	44.5	54.1	299.9	256.8	343.0
300 – 400	24	40.4	30.9	49.8	240.5	184.9	296.1
400 – 500	5	33.6	13.5	53.8	183.1	111.2	255.0

Table 3. Statistical analysis of aboveground forest carbon (AGC) stock.

Forest Cover type	Statistical Analysis							
	Mean (M_j)	Standard Deviation (SD)	Sample Count (n)	*t-statistic at* 95% (t)	Confidence Interval (CI)	Lower Bound	Upper Bound	*Sampling Error* (%)
First approach								
Forested area	269.25	146.69	168	*1.96*	22.18	247.07	291.43	*8.24*
Second approach								
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*

Table 4. Aboveground forest carbon (AGC) stored in Bukit Tigapuluh National Park

Land cover category	Area (ha)	Carbon density/stock (tC/ha)			Total carbon stock (tC)		
		Mean	Lower	Upper	Mean	Lower	Upper
First approach							
Forested area	133,051	269.25	247.07	291.43	35,823,639	32,872,312	38,774,966
Second approach							
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

Discussion

Forest stand and carbon stock characteristics

We evidenced a high diversity of vegetation in the study area by 59 families of trees (5 cm up, i.e. including saplings and poles) covering at least 331 species. The forest ecosystem in BTNP was dominated by the dipterocarp family as the flagship of tropical lowland rainforest in South East Asia (Kuswanda & Barus 2019; Laumonier et al. 2010; Manuri et al. 2016; Yamakura et al. 1986). This forest showed a decent condition of vegetation structure which is characterized by an inverted J graph (negative exponential) of the distribution of the number of individuals by diameter class. This structure is the characteristic of a stable natural forest, where small trees that make up the ecosystem tend to be more dense than large trees (Gunawan et al. 2011). This trend is unlike the distribution of basal area and AGC, where the tendency is more like a normal curve (inverted bell) with the highest value in the diameter class 30 – 70 cm. Stand characteristics like this indicate a natural regeneration process that runs properly where the number of saplings and poles are abundant, and the highest productivity is in the middle classes of diameter which then decreases in the larger diameter classes.

Our analysis of carbon stock estimation showed that using a single class of forest (i.e. natural forest) is more consistent, as demonstrated by low sample error compare to that separating the natural forest class into DPF and DSF (higher SE). This result revealed that detailing forest cover into more specific forest classes in the study area did not improve estimates' uncertainty. There are two reasons for this. The first reason is that the decreasing number of plots in DPF and DSF, increases the data disparity as indicated by the increase of SE. The second reason is the differentiation between DSF and DPF are based only on the visual characteristic of remote sensing data, so it was not related to the type of carbon stock in each forest class.

Ministry of Environment and Forestry (2016) stated that the difference between DPF and DSF is merely related to an exhibit sign 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 & Barus 2019). So, it is possible that DPF and DSF does not necessarily relate to the actual amount of carbon stocks. On the other hand, 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. 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, attention on how carbon stock has been included into consideration needs to be addressed.

We selected the first approach based on the above considerations. Using this selection, we estimated AGC stock in BTNP is 269.2 ± 22.2 tC/ha. In total, forested area in BTNP stored 35,823,639 ± 2,951,071 tC of AGC. This result was higher than other studies conducted in non-protected area (e.g. Laumonier et al. 2010; Ministry of Environment and Forestry 2016; Rutishauser et al. 2013; Slik et al. 2010; Yamakura et al. 1986), but lower estimates than other studies located in the protected area, i.e. Gunung Palung National Park, West Kalimantan (Paoli et al. 2008) (Table 5). Our results were higher than Avitabile et al. (2016), which produced a pan-tropical biomass map covering Bukit Tigapuluh National Park.

Table 5. Forest stand and carbon stock characteristics in various tropical lowland evergreen forests. Each unit of measurements is presented in parentheses.

No.	Locality	Methodology	Stand Basal Area (m2/ha)	Forest Carbon (tC/ha)	Range of dbh (cm)	Sample area	Authors
1.	Borneo (Sebulu, East Kalimantan)	Terrestrial sampling for AGB, allometric equation (Ogawa & Kira 1977)	36.8	239.23	≤152	1 ha	Yamakura et al. (1986)
2.	Sumatera Landscape (Jambi, Bengkulu, South Sumatra, Lampung)	Terrestrial sampling for AGB, allometric equation (Brown 1997; Yamakura et al. 1986)	31.7 [31.2; 32.2]	180 [135; 240)	10 – 210	70.2 ha	Laumonier et al. (2010)
3.	East Kalimantan, Pasir Mayang Sumatra	Terrestrial sampling for AGB, allometric equation (Chave et al. 2005)	30.1	160 148; 164)	10 – 140	12 ha	Rutishauser et al. (2013)
4.	NFI Sumatra (DPF)	Terrestrial sampling for AGB, allometric equation (Chave et al. 2005)	NA	135 [125; 145]	NA	92 ha	Ministry of Environment and Forestry (2016)
5.	NFI Sumatera (DSF)	Terrestrial sampling for AGB, allometric equation (Chave et al. 2005)	NA	85.6 [80.9; 90.3]	NA	265 ha	Ministry of Environment and Forestry (2016)
6.	Borneo	Terrestrial sampling for AGB, allometric equation (Chave et al. 2005)	26 – 49	214.8	≥10	83 plot	Slik et al. (2010)
7.	Gunung Palung NP, West Kalimantan	Terrestrial sampling for AGB, allometric equation (Brown 1997; Chave et al. 2005)	39.6 ± 1.4	292.3 [276.8; 307.8]	≥10	4.8 ha	Paoli et al. (2008)
8.	Bukit Tigapuluh NP	Data fusion approach of two pantropical biomass maps	NA	160 [114; 206]	NA	NA	Avitabile et al. (2016)
9.	Bukit Tigapuluh NP, Riau – Jambi	Terestrial sampling plot and spatial data	45.93	269.2 [247.1; 291.4]	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 were from the (Ministry of Environment and Forestry 2016). A conservative estimate from (Ministry of Environment and Forestry 2016) probably occurred because of their data selection mechanism. (Ministry of Environment and Forestry 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. However, as estimates from (Ministry of Environment and Forestry 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 a higher figure of carbon stock compared to other forest management unit. The national government administers national parks in Indonesia strictly prohibits the 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 the 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 in 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 & Mitchard 2017). Apart from its role in biodiversity conservation, the benefits they deliver to society include 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 AGC, which is very important to be conserved in the perspective of climate change mitigation. The high amount of AGC stock 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 needs to be completed as soon as possible since REDD+ has been a commitment of Indonesia's Government for conducting Nationally Determined Contribution (Republic of Indonesia 2016).

Many national parks in Indonesia have frequently been suffering from conflicts between government and local people (Harada et al. 2015).

REDD+ initiatives may become a way 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 national regulations in Indonesia had strictly prohibited. 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 project outputs can become a model for collaborative forest management with multiple stakeholders in different national parks, such as Bukit Tigapuluh National Park.

CONCLUSION

Stand characteristics in Bukit Tigapuluh National Park indicate that the natural regeneration process is going well. The highest AGC was found in the middle diameter class which then decreases in the larger diameter classes. This stable forest ecosystem secured a significant forest carbon stock estimated as 269.25 [247.07; 291.43] tC/ha or in total 35,823,639 [32,872,312, 38,774,966] tC being stored in approximately 133,051 hectares of the tropical rain forest. This result was higher than other studies in non-protected areas, but was lower than other studies in protected areas, such as Gunung Palung National Park, West Kalimantan. This study and Paoli et al. (2008) supported the argument that protected areas possess higher carbon stock figures compared to other non-protected forest management units. The 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 aside from merely biodiversity conservation and life-support system.

AUTHORS CONTRIBUTION

A.D. is lead researcher, conducting overall strategy to conduct this research from planning, data collection, analysis and writing report and paper. Z.W. is giving general suggestion and managing the field data collection. E.M. is analyzing spatial data. A.V. is giving suggestion and English proofread. M.I.F. is giving suggestion on database and data analysis. G.D.W. is giving suggestion on data analysis and discussion. B.W. is giving suggestion the data analysis and discussion especially on National Park Management. T.R. is giving suggestion on the data analysis and discussion on carbon inventory. S.T. is giving suggestion on the general part of the manuscript and English proofread.

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CONFLICT OF INTEREST

No competing interest among author and co-authors.

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