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

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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 ± 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’ expending (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**

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 km\(^2\) 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 m\(^2\) size (in total 2,000 m\(^2\)) with an arrangement as depicted in Figure 3. This cluster plot is a modification of the conventional single plot of 400 m\(^2\) (BSN, 2011) or 10,000 m\(^2\) (FAO, 2007). Within the 400 m\(^2\) plot, there were 400 m\(^2\), 100 m\(^2\) and 25 m\(^2\) 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 m\(^2\) 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
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/cm\(^3\)), 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).

### Table 1. Statistical analysis

| Forest 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     | $\frac{1}{n} \sum_{i=1}^{n} M_i \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (M_i + M_j)^2}$ | $\frac{SD \times t}{\sqrt{n}}$ | $M_j - CI$ | $M_j + CI$ | $\frac{CI}{M_j} \times 100\%$ |
|                   | 3            | 4.30                    | 5                | 2.78                   |                          |             |             |                   |
|                   | 8            | 2.37                    | 10               | 2.26                   |                          |             |             |                   |
|                   | 50           | 2.01                    | 100              | 1.98                   |                          |             |             |                   |
|                   | $\infty$     | 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   | Auricarpaceae | 1       | 6          | 26  | Icacinaceae   | 1       | 1          | 46  | Rutaceae      | 3       | 17         |
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.
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.

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 (m²/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 (Table 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.

| Forest Cover type | Statistical Analysis |
|-------------------|----------------------|
|                   | Mean (Mj) | Standard Deviation (SD) | Sample Count (n) | t-statistic at 95% (t) | Confidence Interval (CI) | Lower Bound | Upper Bound | Sampling Error (%) |
| **First assumption** |
| Forested area     | 269.25     | 146.69                  | 168              | 1.96                  | 22.18                    | 247.07      | 291.43      | 8.24             |
| **Second assumption** |
| 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 |
| **First assumption**             |           |      |       |       |      |       |       |
| Forested area                    | 133,051   | 269.25 | 247.07 | 291.43 | 35,823,639 | 32,872,312 | 38,774,966 |
| **Second assumption**            |           |      |       |       |      |       |       |
| 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 $269.2 \pm 22.2$ 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).

| 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               | $\leq 152$        | 1 ha        | (Yamakura et al., 1986)        |
| 2.  | Sumatera Landscape (Jambi, Bengkulu, South Sumatra, Lampung) | 31.7 $\pm$ 0.5        | 361 $\pm$ 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 $\pm$ 22 | 135 $\pm$ 10        | NA                | 92 ha       | (MoEF, 2016)                   |
| 5.  | NFI Sumatera (DSF)                              | NA                    | 182.2 $\pm$ 10 | 85.6 $\pm$ 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 $\pm$ 1.4        | 622 $\pm$ 33   | 292.3 $\pm$ 15.5    | $>10$             | 4.8 ha      | (Paoli et al., 2008)           |
| 8.  | Bukit Tigapuluh NP, Riau – Jambi                | 45.93                 | 572.9 $\pm$ 47 | 269.2 $\pm$ 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 ±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.

References

Boissière, M., Herold, M., Atmadja, S., Sheil, D., 2017. The feasibility of local participation in Measuring, Reporting and Verification (PMRV) for REDD+. PLOS ONE 12, e0176897. https://doi.org/10.1371/journal.pone.0176897

Bradshaw, C.J., Sodhi, N.S., Brook, B.W., 2009. Tropical turmoil: a biodiversity tragedy in progress. Frontiers in Ecology and the Environment 7, 79–87. https://doi.org/10.1890/070193

Brofeldt, S., Theilade, I., Burgess, N., Danielsen, F., Poulsen, M., Adrian, T., Bang, T., Budiman, A., Jensen, J., Jensen, A., Kurniawan, Y., Lægaard, S., Mingxu, Z., van Noordwijk, M., Rahayu, S., Rutishauser, E., Schmidt-Vogt, D., Warta, Z., Widayati, A., 2014. Community Monitoring of Carbon Stocks for REDD+: Does Accuracy and Cost Change over Time? Forests 5, 1834–1854. https://doi.org/10.3390/f5081834
BSN, 2011. SNI 7724:2011 Pengukuran dan penghitungan cadangan karbon –Pengukuran lapangan untuk penaksiran cadangan karbon hutan (ground based forest carbon accounting).

Bukit Tigapuluh Wildlife Protection Unit, 2017. Quarterly report: January – March 2017.

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B.W., Ogawa, H., Puig, H., Riéra, B., Yamakura, T., 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145, 87–99. https://doi.org/10.1007/s00442-005-0100-x

Collins, M.B., Mitchard, E.T.A., 2017. A small subset of protected areas are a highly significant source of carbon emissions. Scientific Reports 7. https://doi.org/10.1038/srep41902

Deguignet, M., Arnell, A., Juffe-Bignoli, D., Shi, Y., Bingham, H., MacSharry, B., Kingston, N., 2017. Measuring the extent of overlaps in protected area designations. PLOS ONE 12, e0188681. https://doi.org/10.1371/journal.pone.0188681

FAO, 2007. Brief on national forest inventory NFI - Indonesia 14.

Gardner, T.A., Burgess, N.D., Aguilar-Amuchastegui, N., Barlow, J., Berenguer, E., Clements, T., Danielsen, F., Ferreira, J., Foden, W., Kapos, V., Khan, S.M., Lees, A.C., Parry, L., Roman-Cuesta, R.M., Schmitt, C.B., Strange, N., Theilade, I., Vieira, I.C.G., 2012. A framework for integrating biodiversity concerns into national REDD+ programmes. Biological Conservation 154, 61–71. https://doi.org/10.1016/j.biocon.2011.11.018

Government of Indonesia, 2016. First Nationally Determined Contribution Republic of Indonesia.

Government of Indonesia, 1999. Undang-Undang No. 41 Tahun 1999 tentang Kehutanan.

Harada, K., Prabowo, D., Aliadi, A., Ichihara, J., Ma, H.-O., 2015. How Can Social Safeguards of REDD+ Function Effectively Conserve Forests and Improve Local Livelihoods? A Case from Meru Betiri National Park, East Java, Indonesia. Land 4, 119–139. https://doi.org/10.3390/land4010119

Indonesia Forest Climate Alliance (IFCA), 2007. REDDI: REDD Methodology and Strategies: Summary for Policy Makers. The Ministry of Forestry, Jakarta, Indonesia.

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The Institute for Global Environmental Strategies (IGES), Hayama, Japan.

IUCN, 2010. 50 years of working for protected areas. IUCN, Gland, Switzerland. 2010. IUCN, Gland, Switzerland.

Kuswanda, W., Barus, S.P., 2019. Characteristic and Diversity Vegetation of Bukit Tiga Puluh National Park as Dietary Sources for Reintroduced Sumatran Orang Utan (Pongo abelii Lesson). BPN 25, 63. https://doi.org/10.21082/blpn.v25n1.2019.p63-76

Laumonier, Y., Edin, A., Kanninen, M., Munandar, A.W., 2010. Landscape-scale variation in the structure and biomass of the hill dipterocarp forest of Sumatra: Implications for carbon stock assessments. Forest Ecology and Management 259, 505–513. https://doi.org/10.1016/j.foreco.2009.11.007

Lazarus, E., Lin, D., Martindill, J., Hardiman, J., Pitney, L., Galli, A., 2015. Biodiversity Loss and the Ecological Footprint of Trade. Diversity 7, 170–191. https://doi.org/10.3390/d7020170
Luskin, M.S., Albert, W.R., Tobler, M.W., 2017. Sumatran tiger survival threatened by deforestation despite increasing densities in parks. Nature Communications 8. https://doi.org/10.1038/s41467-017-01656-4

Manuri, S., Brack, C., Noor’an, F., Rusolono, T., Angraini, S.M., Dotzauer, H., Kumara, I., 2016. Improved allometric equations for tree aboveground biomass estimation in tropical dipterocarp forests of Kalimantan, Indonesia. Forest Ecosystems 3. https://doi.org/10.1007/s40663-016-0087-2

Manuri, S., Brack, C., Rusolono, T., Noor’an, F., Verchot, L., Maulana, S.I., Adinugroho, W.C., Kurniawan, H., Sukisno, D.W., Kusuma, G.A., Budiman, A., Anggono, R.S., Siregar, C.A., Onrizal, O., Yuniati, D., Soraya, E., 2017. Effect of species grouping and site variables on aboveground biomass models for lowland tropical forests of the Indo-Malay region. Annals of Forest Science 74. https://doi.org/10.1007/s13595-017-0618-1

Marshall, A.R., Willcock, S., Platts, P.J., Lovett, J.C., Balmford, A., Burgess, N.D., Latham, J.E., Munishi, P.K.T., Salter, R., Shirima, D.D., Lewis, S.L., 2012. Measuring and modelling above-ground carbon and tree allometry along a tropical elevation gradient. Biological Conservation 154, 20–33. https://doi.org/10.1016/j.biocon.2012.03.017

Michael Lockwood, Graeme L. Worboys, Ashish Kothari (Eds.), 2006. Managing Protected Areas: A Global Guide. Earthscan, London ; Sterling, VA.

MoEF, 2016. National Forest Reference Emission Level for Deforestation and Forest Degradation: In the Context of Decision 1/CP.16 para 70 UNFCCC (Encourages developing country Parties to contribute to mitigation actions in the forest sector). Directorate General of Climate Change (DG-PPI), The Ministry of Environment and Forestry, Jakarta, Indonesia.

Paoli, G.D., Curran, L.M., Slik, J.W.F., 2008. Soil nutrients affect spatial patterns of aboveground biomass and emergent tree density in southwestern Borneo. Oecologia 155, 287–299. https://doi.org/10.1007/s00442-007-0906-9

Petrokofsky, G., Kanamaru, H., Achard, F., Goetz, S.J., Joosten, H., Holmgren, P., Lehtonen, A., Menton, M.C., Pullin, A.S., Wattenbach, M., 2012. Comparison of methods for measuring and assessing carbon stocks and carbon stock changes in terrestrial carbon pools. How do the accuracy and precision of current methods compare? A systematic review protocol. Environmental Evidence 1, 6. https://doi.org/10.1186/2047-2382-1-6

Pramudya, E.P., Hospes, O., Termeer, C.J.A.M., 2018. The disciplining of illegal palm oil plantations in Sumatra. Third World Quarterly 39, 920–940. https://doi.org/10.1080/01436597.2017.1401462

Pusat Data dan Informasi KLHK, 2017. Statistik Kementerian Lingkungan Hidup dan Kehutanan Tahun 2016. Kementerian Lingkungan Hidup dan Kehutanan, Jakarta, Indonesia.

Romijn, E., Ainembabazi, J.H., Wijaya, A., Herold, M., Angelsen, A., Verchot, L., Murdiyarso, D., 2013. Exploring different forest definitions and their impact on developing REDD+ reference emission levels: A case study for Indonesia. Environmental Science & Policy 33, 246–259. https://doi.org/10.1016/j.envsci.2013.06.002

Rutishauser, E., Noor’an, F., Launonier, Y., Halperin, J., Rufi’ie, Hergoualc’h, K., Verchot, L., 2013. Generic allometric models including height best estimate forest biomass and carbon stocks in Indonesia. Forest Ecology and Management 307, 219–225. https://doi.org/10.1016/j.foreco.2013.07.013
Shah, P., Baylis, K., 2015. Evaluating Heterogeneous Conservation Effects of Forest Protection in Indonesia. PLOS ONE 10, e0124872. https://doi.org/10.1371/journal.pone.0124872
Sitompul, A., Pratje, P. (Eds.), 2009. The Bukit Tigapuluh Ecosystem Conservation Implementation Plan. Bukit Tigapuluh National Park, Directorate General Forest Protection and Nature Conservation.
Slik, J.W.F., Aiba, S.-I., Brearley, F.Q., Cannon, C.H., Forshed, O., Kitayama, K., Nagamasu, H., Nilus, R., Payne, J., Paoli, G., Poulsen, A.D., Raes, N., Sheil, D., Sidiyasa, K., Suzuki, E., van Valkenburg, J.L.C.H., 2010. Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo’s tropical forests: Forest carbon and structure gradients. Global Ecology and Biogeography 19, 50–60. https://doi.org/10.1111/j.1466-8238.2009.00489.x
Yamakura, T., Hagihara, A., Sukardjo, S., Ogawa, H., 1986. Aboveground Biomass of Tropical Rain Forest Stands in Indonesian Borneo. Vegetatio 68, 71–82.

Declarations

List of abbreviations

| Abbreviation | Description |
|--------------|-------------|
| 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 |

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

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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
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