Comparison of several methods of stands inventory prior to logging towards the yield volume of mangrove forest in Bintuni Bay, West Papua Province, Indonesia

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Abstract. *Istomo, Kusmana C, Dwiyanti FG, Malik D. 2020. Comparison of several methods of stands inventory prior to logging towards the yield volume of mangrove forest in Bintuni Bay, West Papua Province, Indonesia. Biodiversitas 21: 1438-1447.* The difference between the estimated volume and the actual harvested volume is the reason that mangrove forest management is unsustainable. To overcome this discrepancy, it is important to do what so called *Inventarisasi Tegakan Sebelum Penebangan (ITSP)* or stands inventory prior to logging for logging concession. However, the study on suitable ITSP methods for mangrove forests has been limited. This study aims to assess three ITSP methods (namely Line Strip Sampling Method, Line Systematic Sampling Method, and CIFOR's Modified Method) using two allometric equations (i.e., equation developed specifically by a logging concession and equation developed that has specific formula for each species), and to select the combination of method and allometric equation that produce the highest accuracy for logging concession in mangrove forest, especially in Bintuni Bay, West Papua. The results showed that CIFOR's Modified Method produces the lowest discrepancy between the estimated volume and the actual harvested volume, followed by Line Strip Sampling Method. In addition, regardless of the ITSP methods employed, the allometric equation by Cole et al. (1999) outperforms the equation developed specifically by a logging concession. While producing the lowest discrepancy with plot size is the smallest than other methods, CIFOR's Modified Method has a disadvantage when applied in the field due to difficulties in making a circular plot. As such, we recommend ITSP method to be used is the Line Strip Sampling method with allometric equation.

Keywords: CIFOR's modified, ITSP, Line Strip Sampling, Line Systematic Sampling, volume

INTRODUCTION

Mangrove forests are tropical and subtropical vegetation communities located in coastal areas. They are dominated by several species of mangrove trees that are able to grow and survive and can develop in tidal areas. Mangrove forest have habitat characteristics including it is generally in intertidal areas where soil types are muddy, argillaceous and/or sandy, the area is periodically flooded with seawater in a daily basis, inundation frequencies determine the composition of mangroves and it can receive sufficient freshwater supply from land and it protects from waves and tidal strong currents (Nontji 2002). The direct benefits of mangroves include fisheries, wood, food, animal feed, medicinal materials and raw materials for industrial use (Van Oudenhoven et al. 2015), raw materials used for wood pellet production (de Ramos et al. 2017) as well as tourism and education (Setyawan and Winarno 2006; Mitra et al. 2011; Alongi 2012).

As of 2011, an estimated area of the world's mangrove forests reached 13 million hectares with 42% of these are located in Asia (Giri et al. 2011). In 2009, the extent of mangrove forests in Indonesia was estimated at 3.2 million ha (Saputro et al. 2009), while another source (Giri et al. 2011) stated Indonesia has 3.1 million ha of mangroves which ranks Indonesia as the country with the largest mangrove area in the world (22.6% of the world's total

mangroves). Yet, this number continues to decrease at a significant rate with estimation of up to 800,000 ha in the last three decades (de Ramos et al. 2017). The decline in area of mangrove forests not only happens in Indonesia but also around the world with estimation of 35% decrease over the last two decades (Valiela et al. 2001) with deforestation rates of up to 1-3% per year (Alongi 2012). Therefore, good management is needed to ensure the sustainability of mangroves' natural resources (Kusmana et al. 2018).

Sustainable management of mangrove forests in Indonesia is a concern for government and private parties to conserve the remaining mangrove ecosystems through various means including reforestation, sustainable harvesting and silvicultural practices, and also attention to the ability of natural regeneration (de Ramos et al. 2017; Istomo et al. 2017). The management of mangrove forests in Java has already been directed to maximize the ecotourism potential of the forest (Van Oudenhoven et al. 2015), while the management of mangrove forests outside the island of Java is still exploiting the potential forest products in the form of wood (de Ramos et al. 2017). This is particularly eminent in a region where mangrove forests still to a large extent, such as in Bintuni Bay, West Papua, Indonesia. Satellite imagery released by Forest Watch Indonesia (FWI) (2001) showed that 11% of Indonesia's mangroves are located in Bintuni Bay and is considered to

be the largest mangrove forest in Southeast Asia. Currently, some part of mangrove forest in this area is managed for logging concession in the form of IUPHHK-HA (*Izin Usaha Pemanfaatan Hasil Hutan Kayu pada Hutan Alam* or Business Permit for the Utilization of Wood Forest-Natural Forest Products).

In general, the permit of IUPHHK-HA is granted in-state forest (*Kawasan Hutan*) allocated for production function (*Hutan Produksi*). The permit allows the managing parties, usually logging concession, to manage the forest in a particular period which can be renewed once the permit expired. The management regime of IUPHHK-HA usually implements selective logging in a natural forest with a particular period of cutting rotation (e.g., 25 years) in which once the forest is logged, it would be left to recover until the next cutting rotation. Often, enrichment planting is required to accelerate the recovery and to increase forest productivity. By regulation, the managing party is required to do stands inventory prior to logging or termed as *Inventarisasi Tegakan Sebelum Penebangan (ITSP)* to assess the potential of harvestable wood.

Stands inventory prior to logging or ITSP is an initial step to find out the potential of wood of a forest (Wanggai 2009) that is conducted two or three years before timber harvesting. In the context of rotational logging, this activity is useful to know the composition of the tree species and the structure of the stand, especially after the timber harvesting in the previous cycle followed by natural regeneration. Pribadi (1998) states that changes in the environment will change in the structure of stands and species composition of forest including mangroves. In addition to changes in the environmental landscape, stand structure and composition may also change due to human activities, ranging from management interventions (such as enrichment planting, climber liberation) to illegal logging activities, and natural disturbances (e.g. fires and winds) (FAO 2001; Mirmanto 2010). The information on the structure and species composition are also useful in predicting the growth rate of a forest stand to establish a sustainable management or forest system (Cole et al. 1999; Gasparini et al. 2017). In principle, ITSP aims to maintain the sustainability of stands by estimating the species, number, and volume of trees to be harvested, as well as identifying the species and composition of trees that will be left in the field to be maintained until the next harvest cycle. Therefore, it is necessary to evaluate the activities carried out before and after forest harvesting.

The ITSP process is an important stage for future decisions of sustainable forest management. The difference between the volume resulted from the ITSP activity and the volume of the actual harvest can cause financial losses or overexploitation on the contrary. Therefore, the ITSP can determine sustainability in term of financial and long-term production of forest management. A proper ITSP method should generate an estimation closest to the actual harvested volume. Based on these problems, this study aims to assess three ITSP methods (namely *Line Strip Sampling Method*, *Line Systematic Sampling Method*, and *CIFOR's Modified Method*) using two allometric equations (i.e. equation developed specifically by a logging concession and equation developed by Cole et al. (1999)), and to select the combination of method and allometric equation that produce the highest accuracy for IUPHHK-HA in mangrove forest, especially in Bintuni Bay, West Papua, Indonesia.

MATERIALS AND METHODS

Study period, area and context

This research was conducted from 28 March to 7 April 2016 on an IUPHHK-HA in mangrove forest managed by a logging concession company. The study area is located in the sub-district of Babo, Teluk Bintuni District, West Papua Province (Figure 1). The logging concession has managed the mangrove forests for 27 years that will expire in 2053, and it has a certificate of Sustainable Management of Production Forests (SMPF) or *Pengelolaan Hutan Produksi Lestari* (PHPL) in 2011 (Friess et al. 2016). In the first 25 years of cutting rotation, the logged-over forest following previous cut showed good recovery (Silanpaa et al., 2017). In accordance with the Decree of the Director General of Forestry No: 60/Kpts/DJ/I/1978, the management of mangrove forests in Bintuni Bay implements a silvicultural system of seed trees which is maintained at $\geq$ 40 trees/ha (Ministry of Agriculture 1978). However, the regulation on the density of seed trees has been revised to $\geq$25 trees/ha through the regulation of the Director General of Sustainable Production Forest Management (P.8/PHPL/SET/3/2016) (Ministry of Environment and Forestry 2016).

The total area of the logging concession is 82,120 ha with the utilization of mangrove wood is carried out in about 63.5% of the concession area. Based on the interpretation of satellite Landsat imagery by the Director of Inventory and Monitoring of Forest Resources, the Ministry of Forestry on June 8th, 2009, the land cover in the areas of the logging concession was dominated by primary mangrove forest (51,486 ha). The floristic composition in the area was dominated (60%) by *Rhizophora apiculata* and *R. mucronata* (Wahyudi et al. 2013). The topography is flat with a slope of less than 2%. This condition is advantageous in carrying out wood harvesting activities. Based on the USDA Soil Taxonomy System, soil types in the study areas are Sulfaquent, Tropopsamen, and Tropudult. Soil parent material is a transported sandy clay sediment.

According to Koppen climate classification, the Babo District and its surroundings are classified into Afa category (high-temperature wet tropics), while according to Schmidt-Ferguson it belongs to type A (very wet areas). Annual rainfall based on statistical data from 1993 to 2003 reached 2,000-4, 400 mm. Rainy days in a year can reach 240 days with the highest in December (22 days) and the lowest in February and September (18 days). The temperature in the Babo district has a maximum value of 30.7 degrees Celsius, a minimum of 21.9 degrees Celsius and an average of 26 degrees Celsius. The maximum and minimum absolute temperatures are 35.5 degrees and 22.6 degrees Celsius. The relative humidity is humid with

maximum, minimum, and average values of 90%, 82%, and 85%, respectively. In December to April, the wind blows from the north and northwest while in May to November, the wind blows from the Southeast. Wind speed in the Babo district is moderate with an average of 3.4 m/sec.

Procedures

The working procedure used in this study were divided into two parts, namely data collection and data analysis. The treatments in this study were three ITSP methods used to inventory stands on three logging plots (plot 260, 263, and 266). All three methods were used on the same transect line on each logging plot. The data collected in this study were primary data in the form of vegetational structure of the trees and the regeneration level of the mangrove forest. The definition of tree in this study is an individual woody plant with diameter at breast height of 10 cm or more, while regeneration level is: (i) *sapling*, i.e., plant less than 10 cm in diameter; and (ii) *seedlings*, i.e., plant with a maximum height of 1.5 m. Data taken at the tree level were (i) Diameter Breast High (DBH) at 1.3 m (> 10 cm) which was measured using a diameter tape, and (ii) the species name on the ITSP pathway. Whereas, the data taken at seedlings and saplings were species name and number of individuals. The following are the methods compared in this study.

Line Strip Sampling Method

This method is applied based on the Decree of the Director General of Forestry No: 60/Kpts/DJ/I/1978. The length of the transect line carried out in this study was 250 m and the number of transects was 3 transects per plot (Figure 2). The sample plot size for the tree growth stages was 2.25 ha (250 m x 10 m x 3 plots x 3 replications). The tree DBH was measured at a distance of 5 m on the right and left along the path. Inventory of the number of individuals and species name of sapling stage was carried out in a plot of 5 m x 5 m. Thus the sample plot size for the sapling stage was 0.045 ha (5 m x 5 m x 6 plots x 3 replications). Inventory of the number of individuals and species name of seedlings stage was carried out every 100 m in a plot of 2 m x 2 m. Thus the sample plot size for seedlings stage was 0.0072 ha (2 m x 2 m x 6 plots x 3 replications).
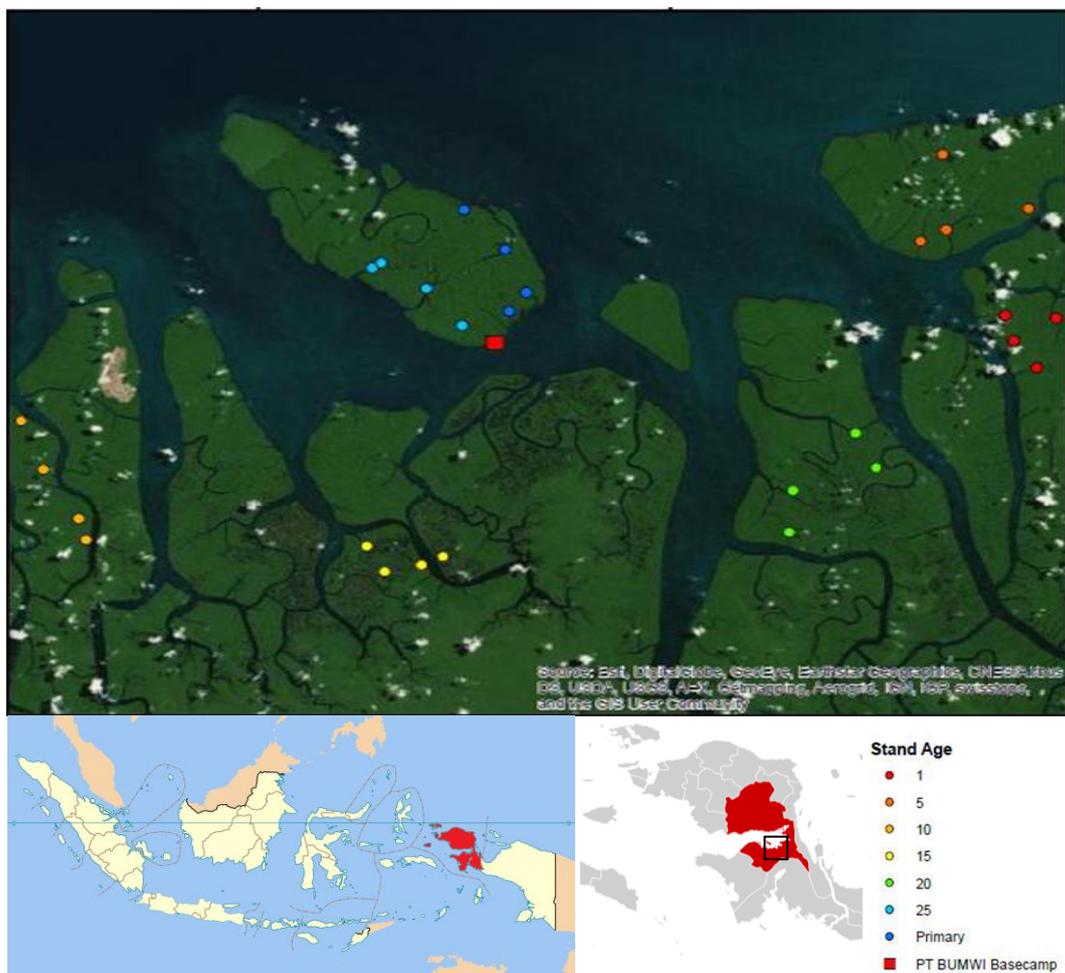
Figure 1. Map of the studied in a forest concession in Babo, Teluk Bintuni District, West Papua Province, Indonesia
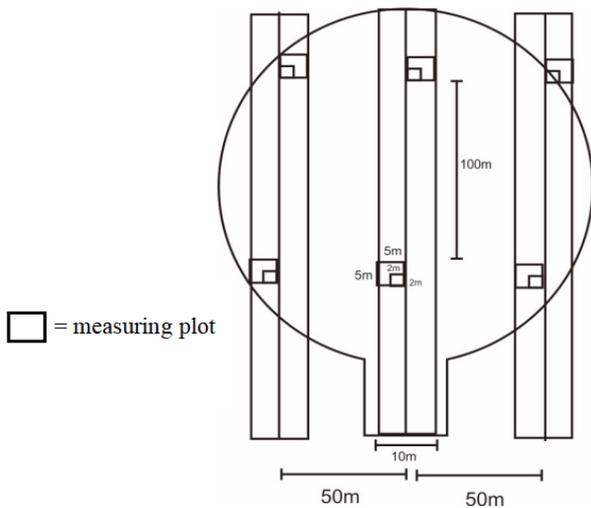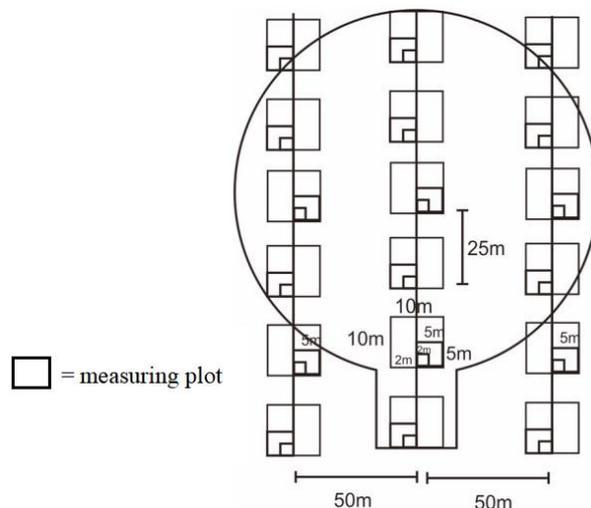
Figure 2. Line Strip Sampling Method Plot

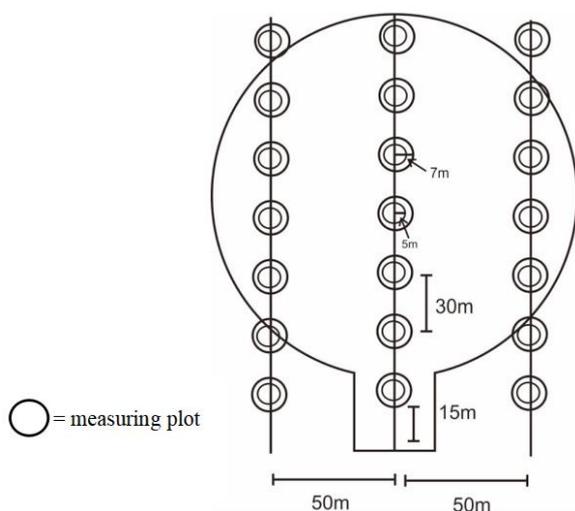**Figure 3.** Line Systematic Sampling Method Plot

Figure 4. CIFOR Modified Method Plot

Line Systematic Sampling Method

This method used a 10 m x 10 m quadrant plot in a transect line that is 25 m apart at the center of the plot (Figure 3). The tree DBH was measured in a plot of 10 m x 10 m, whereas the regenerations were measured in a plot of 5 m x 5 m for saplings and 2 m x 2 m for seedlings. The plot size for tree stage, sapling stage and seedlings stage were 0.54 ha (10 m x 10 m x 18 plots x 3 replications), 0.135 ha (5 m x 5 m x 18 plots x 3 replications), and 0.0216 ha (2 m x 2 m x 18 plot x 3 replications), respectively.

CIFOR's Modified Method

CIFOR's modified method is a modification of the method used in the research conducted by Silanpaa and Vantellingen (2015). This method uses a circular plot with a radius of 7 m to measure the tree DBH. The plot size for tree size was 0.9702 ha (154 m^2 x 21 plots x 3 replications). In terms of saplings and seedlings, the measurement was done by counting the number of individuals in a 5 m circular radius plot. The plot size for saplings and seedlings was 0.49455 ha (78.5 m2 x 21 plots x 3 replications). Figure 4 shows the plot used in the CIFOR modified method.

Data analysis

Species identification was carried out using species identification books and herbarium. Dried herbarium was made in the field for one leaf twig specimen and wet herbarium was made for flower and fruit specimens. Herbarium identification was then carried out at the Herbarium Bogoriense, Indonesian Institute of Sciences (LIPI) at Cibinong, West Java, Indonesia.

Vegetation analysis for the structure and composition of species used in this study is the Important Value Index (IVI). According to Soerianegara and Indrawan (2002), the Important Value Index is used to rank species according to their ecological importance. The IVI value of a tree is the sum of Relative Density (RD), Relative Frequency (FR), and Relative Dominance (RDo) while the IVI value of seedling and sapling is the sum of Relative Density (RD) and Relative Frequency (RF).

$$Density = \frac{Number\ of\ individual\ species\ in\ the\ sampling\ area}{Sample\ Plot\ Area}$$

$$Relative\ Density = \frac{Density\ of\ a\ species}{Desnsity\ of\ all\ species} \times 100\%$$

$$Frequency = \frac{\sum Plots\ inhabit\ by\ species}{Number\ of\ all\ sample\ plots}$$

$$Relative\ Frequency = \frac{Frequency\ of\ a\ species}{Frequency\ of\ all\ Species} \times 100\%$$

$$Dominance = \frac{Basal\ area\ of\ \quad a\ species}{Sample\ plot\ area}$$

$$Relative\ Dominance = \frac{Dominance\ of\ a\ species}{Dominance\ of\ all\ species} \times 100\%$$

Important Value Index (IVI) = Relative Density + Relative Frequency + Relative Dominance

Furthermore, the diameter data that have been obtained were converted into tree volume. The allometric volume equation used to convert the diameter to the tree volume was based on the equation developed for the logging concession (unpublished) and is formulated follows:

$$V = 1.21 \times 10^{-4} \times D^{2.54}$$

Where,
V = Volume (m³)
D = Tree Diameter (m)

Another allometric equation used to compare the research result is the allometric equation used specifically for each species according to Cole et al. (1999). Each species has the following allometric volume equation:

Sonneratia alba; $\quad V = 1.97 \times 10^{-4} \times D^{2.221}$
Rhizophora mucronata ; $\quad V = 1.34 \times 10^{-4} \times D^{2.249}$
Rhizophora apiculata; $\quad V = 4.83 \times 10^{-4} \times D^{2.542}$
Bruguiera gymnorrhiza; $\quad V = 4.83 \times 10^{-4} \times D^{2.542}$
Xylocarpus granatum; $\quad V = 1.43 \times 10^{-4} \times D^{2/359}$
Ceriops tagal ; $\quad V = 1.21 \times 10^{-4} \times D^{2.54}$

Where,
V = Volume (m³)
D = Tree Diameter (m)

Once converted to tree volume, it will be used to estimate the potential tree volume per hectare. The equation for estimating the volume of trees per hectare is as follows (Ministry of Environment and Forestry, 2016):

$$Volume\ per\ hectare = \frac{\sum Tree\ Volume}{ITSP\ Area} \times 1\ ha$$

The experimental design used in this study was a completely randomized design consisting of three ITSP treatment methods (line strip sampling, line systematic sampling, CIFOR's modified method) and 3 sample plot replications. The tree volume per hectare of each method will be compared with the actual harvested volume. Tree volume data from the calculation will then be analyzed its variance using analysis of variance (ANOVA) to see the significant differences between the three ITSP methods used. This analysis is performed using the SPSS version 23 software (IBM Corp 2015). The variance analysis model used in this study is as follows (Mattjik and Sumertajaya 2006):

$$Y_{ij} = \mu + \tau_i + \epsilon_{ij}$$

Where,
i : 1, 2, 3, 4
j : 1,2,3

Y : Observation value (tree volume from i-th treatments and j-th replication)
μ : General average
τ_I : The effect of i-th treatment
ϵ_{ij} : The effect of experimental error from i-th treatment and j-th replication

Variance testing with the F test was carried out to determine the effect of this treatment if (i) p-value > α (0.05), then the treatment did not have a significant effect on the observed parameters; (ii) p-value < α (0.05), then the treatment has a significant effect on the observed parameters, thus the test is continued with Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Species composition

The number of mangrove species found in the study site varied. The results of vegetation analysis at the seedling, saplings and trees stages can be seen in Tables 1, 2, and 3, respectively. At the seedling stage, 5 species (*R. apiculata, B. gymnorrhiza, R. mucronata, B. parviflora*, and *C. tagal*) were found in the Line Strip Sampling Method, 6 species (*R. apiculata, B. gymnorrhiza, B. parviflora, R. mucronata, C. tagal,* and *S. alba*) were found in the Line Systematic Sampling Method and 5 species (*R. apiculata, B. parviflora, B. gymnorrhiza, C. tagal,* and *R. mucronata*) were found in the CIFOR's Modified Method (Table 1). The number of species found in the Line Strip Sampling Method, the Line Systematic Sampling Method and the CIFOR's Modified Method at the sapling stage were 5 species (*R. apiculata, B. gymnorrhiza, C. tagal, R. mucronata*, and *B. parviflora*), 7 species (*R. apiculata, C. tagal, B. gymnorrhiza, B. parviflora, R. mucronata, X. granatum,* and *S. alba*) and 6 species (*R. apiculata, B. parviflora, B. gymnorrhiza, R. mucronata, C. tagal,* and *X. granatum*), respectively (Table 2). While, at tree stage, 6 species (*R. apiculata, B. parviflora, B. gymnorrhiza, C. tagal, R. mucronata,* and *S. alba*) were found in the Line Strip Sampling Method, 6 species (*R. apiculata, B. gymnorrhiza, B. parviflora, R. mucronata, S. alba*, and *C. tagal*) were found in the Line Systematic Sampling Method and 7 species (*R. apiculata, B. parviflora, B. gymnorrhiza, R. mucronata, C. tagal, S. alba,* and *X. granatum*) were found in the CIFOR's Modified Method (Table 3). The measurement results for the number of species indicate the balance between the number of seedling, saplings, and trees which range between 5 and 7 species from seedling to the tree stage. The results of the present study are in accordance with Silanpaa et al. (2017), who reported that mangrove stands in Bintuni Bay were composed of seven trees species, namely *R. apiculata, C. tagal, B. gymnorrhiza, B. parviflora, R. mucronata, X. granatum*, and *S. alba*.

Table 1. Important Value Index (IVI) of seedlings

Species	D (ind/ha)	RD (%)	RF (%)	IVI (%)
Line Strip Sampling Method				
R. apiculata	8055.56	51.79	35.71	87.50
B. gymnorrhiza	2638.89	16.96	17.86	34.82
R. mucronata	2083.33	13.39	17.86	31.25
B. parviflora	1805.56	11.61	17.86	29.46
C. tagal	972.22	6.25	10.71	16.96
Total	15555.56	100.00	100.00	200.00
Line Systematic Sampling Method				
R. apiculata	6620.37	52.96	46.57	99.54
B. gymnorrhiza	2129.63	17.04	8.22	25.26
B. parviflora	1759.26	14.07	17.81	31.88
R. mucronata	879.63	7.04	15.07	22.10
C. tagal	555.56	4.44	9.59	14.03
S. alba	555.56	4.44	2.74	7.18
Total	12500.00	100.00	100.00	200.00
CIFOR Modified Method				
R. apiculata	313.42	44.54	48.31	92.85
B. parviflora	145.59	20.69	5.62	26.31
B. gymnorrhiza	141.54	20.11	16.85	36.97
C. tagal	58.64	8.33	22.47	30.81
R. mucronata	44.48	6.32	6.74	13.06
Total	703.67	100.00	100.00	200.00

Note: D: Density, RD: Relative Density, RF: Relative Frequency, and IVI: Important Value Index

Table 2. Important Value Index of saplings

Species	D (ind/ha)	RD (%)	RF (%)	IVI (%)
Line Strip Sampling Method				
R. apiculata	555.56	28.09	33.33	61.42
B. gymnorrhiza	688.89	34.83	22.22	57.05
C. tagal	355.56	17.98	18.52	36.50
R. mucronata	200.00	10.11	14.81	24.93
B. parviflora	177.78	8.99	11.11	20.10
Total	1977.78	100.00	100.00	200.00
Line Systematic Sampling Method				
R. apiculata	911.11	47.86	35.37	83.23
C. tagal	288.89	15.18	4.88	20.05
B. gymnorrhiza	333.33	17.51	20.73	38.24
B. parviflora	266.67	14.01	13.41	27.42
R. mucronata	59.26	3.11	23.17	26.28
X. granatum	22.22	1.17	1.22	2.39
S. alba	22.22	1.17	1.22	2.39
Total	1903.70	100.00	100.00	200.00
CIFOR Modified Method				
R. apiculata	270.95	36.31	27.13	63.45
B. parviflora	192.09	25.75	27.13	52.88
B. gymnorrhiza	188.05	25.20	16.28	41.48
R. mucronata	32.35	4.34	19.38	23.72
C. tagal	60.66	8.13	8.53	16.66
X. granatum	2.02	0.27	1.55	1.82
Total	746.13	100.00	100.00	200.00

Note: D: Density, RD: Relative Density, RF: Relative Frequency, and IVI: Important Value Index

Table 3. Important Value Index of trees

Species	D (ind/ha)	RD (%)	RF (%)	RDo (%)	IVI (%)
Line Strip Sampling Method					
R. apiculata	308.89	57.82	20.93	55.74	134.49
B. parviflora	104.44	19.55	11.63	13.20	44.38
B. gymnorrhiza	64.44	12.06	20.93	16.80	49.79
C. tagal	30.22	5.66	20.93	2.99	29.58
R. mucronata	24.00	4.49	20.93	4.62	30.04
S. alba	2.22	0.42	4.65	6.64	11.70
Total	534.22	100.00	100.00	100.00	300.00
Line Systematic Sampling Method					
R. apiculata	427.78	54.61	33.33	46.04	133.99
B. gymnorrhiza	120.37	15.37	25.19	19.34	59.89
B. parviflora	151.85	19.39	21.48	10.45	51.31
R. mucronata	46.30	5.91	8.89	5.64	20.44
S. alba	3.70	0.47	1.48	16.56	18.52
C. tagal	33.33	4.26	9.63	1.97	15.85
Total	783.33	100.00	100.00	100.00	300.00
CIFOR Modified Method					
R. apiculata	258.71	56.03	38.00	58.55	152.58
B. parviflora	83.49	18.08	9.33	14.32	41.73
B. gymnorrhiza	71.12	15.40	19.33	19.92	54.66
R. mucronata	25.77	5.58	22.67	6.97	35.22
C. tagal	19.58	4.24	8.67	0.14	13.04
S. alba	2.06	0.45	1.33	0.10	1.88
X. granatum	1.03	0.22	0.67	0.00	0.89
Total	461.76	100.00	100.00	100.00	300.00

Note: D: Density, RD: Relative Density, RF: Relative Frequency, RDo: Relative Dominance, and IVI: Important Value Index

Dominant species at seedling stage

The IVI value of seedlings using three different ITSP methods is presented in Table 1. Based on the three ITSP methods used in this study, there is one mangrove species that has the highest IVI across all methods namely *R. apiculata* (IVI = 87.50% in Line Strip Sampling, IVI = 99.54% in Line Systematic Sampling, and IVI = 92.85% in CIFOR Modified), indicating that *R. apiculata* is the dominant species and has an important role in the observed stand. The high IVI of *R. apiculata* seedlings creates a high probability that this species will also dominate the forest in the next rotation. Vegetation which has the smallest IVI (7.18%) is *S. alba*, which was only found in the observed stand using the ITSP method of Line Systematic Sampling.

Dominant species at sapling stage

The IVI of saplings using three different ITSP methods is presented in Table 2. Based on this table, *R. apiculata* has the highest IVI value across the three ITSP methods (IVI = 61.42% in Line Strip Sampling, IVI = 83.23% in Line Systematic Sampling, and IVI = 63.45% in CIFOR Modified). This result is in accordance with the research reported by Silanpaa et al. (2017). The species of *S. alba* was only found using the Line Strip Sampling method with an IVI value of 2.39%. Saplings of *X. granatum* were found on the Line Systematic Sampling and CIFOR's modified method plots with IVI values of 2.39% and 1.82% respectively. The species of *X. granatum* are indeed the rarest species observed and is only found in secondary

stands of 20-25 years old and pristine forests (Silanpaa et al. 2017).

Dominant species at tree stage

Tree vegetation that has the highest IVI value across all three methods is *R. apiculata* (IVI = 134.49% in Line Strip Sampling, IVI = 133.99% in Line Systematic Sampling, and IVI = 152.58% in CIFOR Modified). This species has the highest IVI value at each growth stage which indicates that this species has an important role in the Bintuni Bay mangrove ecosystem. This condition is consistent with the results of a survey conducted by Silanpaa and Vantellingen (2015) and Silanpaa et al. (2017). Wahyudi et al. (2013) also found that the species of *R. apiculata* and *R. mucronata* were the most common species found in the mangroves of Bintuni Bay with a density of 69% of the entire population followed by *B.* spp. 20% and *C. tagal* 10%. In line with these results, Onrizal and Mansor (2016) also stated that in 2005 (a year after the Aceh tsunami) *R. mucronata* and *R. apiculata* dominated mangrove ecosystems on the north coast of Sumatra. *S.* spp. was only found in plots using the Line Systematic Sampling method even though the density and IVI were low. This shows that different inventory methods affect the number of distribution of species found.

Rhizophora apiculata (Kusmana and Watanabe 1991) and *R. mucronata* (Nybacken 1992) are shade-intolerant species, thus allowing this species to grow dominantly on harvested sites. In addition, the ability of fast root growth makes it easier for the species of *Rhizophora* to grow and dominate the mangrove ecosystem in Bintuni Bay compared to species with low root growth ability such as *C. tagal* (De Ryck et al. 2012). The research results of Rahmat et al. (2015) shows that the transition from the dry season to the rainy season is one indication of the root's adjustment in the balance system for adaptation. It is known that *R. apiculata* is a family of Rhizophoraceae which has many roots and extends towards the soil surface. This is a way to adapt in cases of low oxygen levels. Apart from ecological aspects, *R. apiculata* also has good potential to be used as wood chips. Mangrove wood itself can be used for carpentry, boat building, chips, charcoal construction, and fuel (Da Silva et al. 1993; Duke et al. 2002). Moreover, the bark of trees is rich in tannin, which is used in some industrial processes (Da Silva et al. 1993; Duke et al. 2002).

Stand structure

The structure of the stand can be viewed horizontally and vertically. Horizontal stand structure can be seen based on the relationship of individual density/ha with the growth rate or class diameter of the tree so that it will describe the condition of a forest stand. The structure of the stands at the study site based on growth rates (seedlings, saplings, and trees) and based on diameter classes can be seen in Figure 5 and Figure 6, respectively.

Figure 5 shows that the number of individuals per hectare decreases as the growth stage moves toward maturity. Most individuals found were at the seedling stage, while the least was found at the growth stage of the

tree. This graph forms an inverse J curve showing that the growth of natural forest stands in that location are not the same age, in this case, tree stands and their regeneration are in normal conditions (Meyer and Stevensonand 1961; Sorianegara and Indrawan 2002).

Figure 6 shows that the number of individuals decreases as the diameter class increases, forming an inverse J curve. This condition is normal due to the regeneration of a stand. Reduction in the number of individuals occurs due to competition and death, while the seedlings and saplings continue to grow into larger individuals. Regeneration of mangrove stands itself is influenced by various factors, both from external factors (environment) and internal factors (genetic factors). According to Cunha et al. (2006), leaf shedding of mangrove trees will affect the sustainability of the regeneration process.

The stand structure and composition of species need to be maintained to prevent changes in the ecosystem which can have negative impacts such as the loss of a particular plant species. The dominance of one plant species should also be considered because of its ability to suppress the growth rate of other species, and can even cause a stand to become monoculture. This is certainly not ideal for the ecosystem due to the fact that the higher the uniformity, the higher the chances of vulnerability to damage (Bosire et al. 2006).
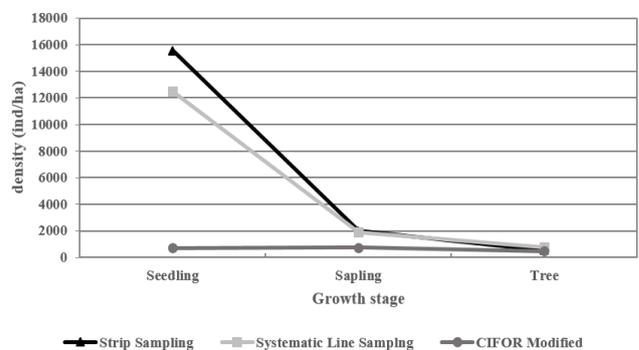
Figure 5. Number of individuals at each growth stage based on each ITSP method
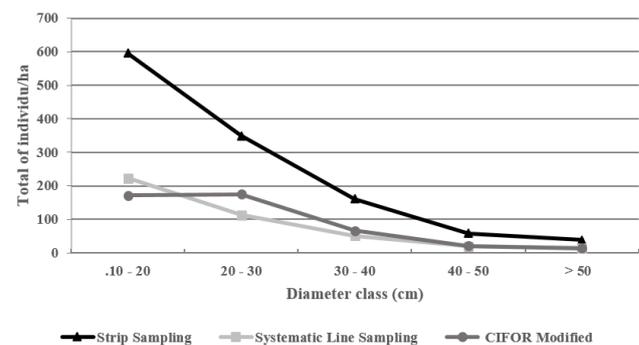
Figure 6. Number of individual according to diameter distribution based on each ITSP method

The patterns in Figures 5 and 6 are in line with the general shape of the diameter class distribution (the inverse exponential J shape), which indicates that the larger the diameter class, the smaller the density. The number of trees decreases along with the increase in size so that only a few trees with large diameter are left (Hilwan 2012; Oladoye et al. 2014). Natural forest stands have dynamic growth because this growth is not only caused by the increase in the dimensions of the tree that creates the stand but also due to the emergence of new individuals so that there is a change in the trees that create the stands over time (Suhendang et. al. 1995; Prasetyo 2006; Hilwan 2012).

Comparison of ITSP methods in term of estimated volume and actual harvested volume

The comparison between the actual harvested volume and the volume estimated from the three ITSP methods can be seen in Table 4. The estimated volume was calculated using a specific allometric volume equation developed for the logging concession in the studied area (see Methods).
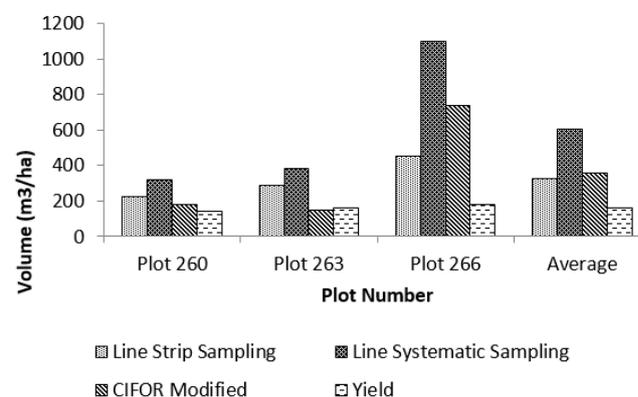
Based on Table 4 it can be seen that the average volume of tree with diameter $\geq$ 10 cm estimated using the three ITSP methods with allometric equations specifically developed for the logging concession produces values that are much higher than the actual harvested volume. The difference between the average volume of the Line Strip Sampling method with the average volume of the actual harvested is 162.83 m³/ha. This difference is the smallest among the other methods used, although it is still considered as a large overestimate. However, analysis of variance to statistical test difference among volume estimated using the three ITSP methods and actual harvested shows that the *p*-value is 0.3446, indicating that four methods are not significantly different at the 95% confidence level (Table 5). Thus the three ITSP methods are incompatible when employing the allometric equation specifically developed for the logging concession due to the lack of accuracy in estimating the harvested volume, as seen it is almost double the actual harvested volume (Figure 7).

The allometric equation uses tree diameter to estimate the harvested volume and has been used to estimate the volume of all species of mangrove trees in the logging concession area. Allometric equations created by the logging concession (unpublished) have a tendency that these equations are formulated using a large number of tree samples and a large diameter range, this will increase the difference in value when repeated measurements are done due to dynamic tree growth. On the other hand, each allometric equation is developed based on stand conditions and certain species variations that differ from one another (Sutaryo 2009). Thus the use of an equation developed in a particular location is not necessarily suitable when applied to other areas.

The allometric equation specifically developed for the logging concession is applied to all species of trees inventoried. However, if there are differences in increment levels among species, their growth will be considered the same. This is likely the cause of the gap between the actual harvested yield and the estimated stand volume (i.e.,

overestimation) which has been often complained by the management. In addition to the allometric equation used by the logging concession, we then used several allometric equations from Cole et al. (1999) to estimate the ITSP volumes. The average value of estimated stand volume using allometric equations from Cole et al. (1999) in this study is presented in Table 6.

Based on Table 6, the average tree volume estimated using the three ITSP methods ranges from 153.99 to 250.00 m³/ha. These results are similar to the study of Kairo et al. (2002) in Lamu, Kenya, which reported the standing volume range between 6.85 to 710.0 m³/ha for stem with a diameter above 5.0 cm and the average volume of the entire study area was 145.88 m³/ha. The study of Phan et al. (2019) reported tree volume for *R. apiculata* plantations in Vietnam with a range of ages from 14 to 24 years having tree volumes of 142.1 ± 38.5 m³/ha to 175.8 ± 55.7 m³/ha. The results of Heriyanto and Subiandono (2012) research in Alas Purwo National Park, East Java, Indonesia reported that the volume of the *R. mucronata* tree has a volume of 236.11 m³/ha (number of trees = 1033 individuals/ha), *B. cylindrica* has a volume of 127.1 m³/ha (number of trees 1377/ha) and *X. moluccensis* 9.35 m³/ha (number of trees 167 individuals/ha)

Figure 7. The comparison of tree volume per hectare estimated using the three ITSP methods (with allometric equation specifically developed for the logging concession) and actual harvested

Table 4. The estimated volume of trees (diameter $\geq$ 10 cm) based on the allometric volume equation.

Method	Volume of tree (diameter $\geq$ 10 cm) of each logging plots (m³/ha)			Average (m³/ha)
	Plot 260	Plot 263	Plot 266	
Line Strip Sampling	226.65	285.71	455.61	322.66
Line Systematic Sampling	322.56	383.91	1098.98	601.82
CIFOR modified	179.45	149.18	740.47	356.46
Actual Harvested	140.35	159.74	179.40	159.83

Note: p-value 0.6, not significantly different in the estimation of tree volume

Table 5. Analysis of variance to test statistical difference among volume estimated using the tree ITSP methods (with allometric equation specifically developed for the logging concession) and actual harvested

Source	DF	Sum of square	Mean square	F value	Pr>F
Model	3	299852.8278	99950.9426	1.28	0.3446
Error	8	623421.5622	77927.6953		
Corrected total	11	923274.3900			

Note: p-value > α (0.05), then the treatment did not have a significant effect on the observed parameters

Table 6. The estimated volume of trees (diameter ≥ 10 cm) based on the allometric volume equation of Cole et al. (1999)

Method	Volume of tree (diameter ≥ 10 cm) of each logging plots (m³/ha)			Average (m³/ha)
	Plot 260	Plot 263	Plot 266	
Line Strip Sampling	107.27	147.76	197.91	150.98
Line Systematic Sampling	148.51	192.55	408.92	250.00
CIFOR modified	85.97	77.53	298.47	153.99
Actual Harvested	140.35	159.74	179.40	159.83

Note: p-value 0.6, not significantly different at the 95% confidence level in the estimation of tree volume

Table 7. Analysis of variance of tree volume based on tree volume allometric of Cole et al (1999)

Source	DF	Sum of square	Mean square	F value	Pr>F
Model	3	20453.39630	6817.79877	0.73	0.5643
Error	8	75089.43207	9386.17901		
Corrected total	11	95542.82837			

Note: p-value > α (0.05), not significantly different at the 95% confidence level in the estimation of tree volume
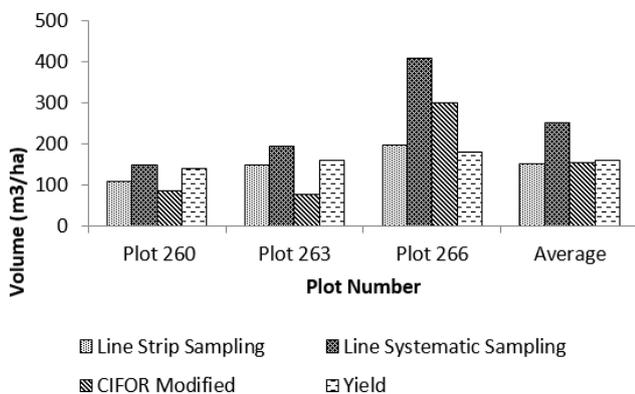
Figure 8. The comparison of tree volume per hectare estimated using the three ITSP methods with allometric equation using Cole et al. (1999) and actual harvested

The advantage of the equation developed by Cole et al. (1999) is that it is specific to each species which will increase the accuracy of the estimated data, resulting in a lower difference of measurement between the three ITSP methods compared to the harvested results. CIFOR modified ITSP method has the smallest difference with 5.82 m³/ha, followed by the Line Strip Sampling method with a difference of 8.86 m³/ha, while the Line Systematic Sampling has the largest difference.

The analysis of variance to test statistical difference among volume estimated using the three ITSP methods with allometric equations of Cole et al. (1999) and actual harvested showed is presented in Table 7. The analysis of variance shows that the *p*-value is 0.5643, indicating that four methods are not significantly different at the 95% confidence level (Table 7). This indicates that the three ITSP methods combined with the Cole et al. (1999) allometric equation can be used to estimate the harvested volume of trees (diameter ≥ 10 cm) more accurately.

When using the allometric equation of Cole et al. (1999) to estimate volume of trees (diameter ≥ 10 cm), the Line Strip Sampling method and the CIFOR modified method have an average tree volume per hectare closer to the actual harvested (Figure 8). Thus, in general, the allometric equation developed by Cole et al. (1999) is more suitable when combined either with the CIFOR modified method or the Line Strip Sampling method to estimate volume of trees (diameter ≥ 10 cm) in units of area as these methods have the closest value to the actual harvested volume.

In conclusion, the three ITSP methods used in this study have their own advantages and disadvantages. The plot size in CIFOR's Modified Method is smaller than other methods. This will certainly simplify and shorten the time for data collection. As stated by Siahaan et al. (2012) that square sample plots are more time-consuming. This is due to the addition of time for creating the boundaries in the sample unit and the use of a compass to reduce the perpendicular angle bias which is quite difficult. However, CIFOR's Modified Method also has disadvantage when applied in the field due to difficulties in making a circular plot, which causes unclear plot boundaries. The Line Strip Sampling ITSP method is more applicable to be used than other methods because it is easy to create a straight line in the field. However, the Line Strip Sampling method also has disadvantage, which is the lack of representation of seedlings and saplings. Therefore, additional plots for seedlings and saplings data collection are needed, not only for every 100 m.

REFERENCES

Alongi DM. 2012. Carbon sequestration in mangrove forest. Carbon Manag 3 (3): 313-322.

Bosire JO, Dahdouh-Guebass F, Kairo JG, Wartel S, Kazungu J, Koedam N. 2006. Success rates of recruited tree species and their contribution to the structural development of reforested mangrove stands. Mar Ecol Prog Ser 325: 85-91.

Cole TG, Ewel KC, Devoe NN. 1999. Structure of mangrove trees and forestry in Micronesia. Forest Ecol Manag 117: 95-109.

Cunha SR, Togenella-de-Rosa MMP, Costa CSB. 2006. Structure and litter production of mangrove forests under different tidal influences in Babitonga Bay, Santa Catarina, Southern Brazil. J Coast Res SI II (39): 1169-1174.

Da Silva JAA, De Melo MRCS, Borders BE. 1993. A volume equation for mangrove trees in northeast Brazil. For Ecol Manag 58: 129-136.

de Ramos RMQ, Abundo MLS, Taboada EB. 2017. Life cycle assessment of secondary mangrove forest in Bintuni Bay, West Papua, Indonesia. Curr World Environ 12 (3): 616-627.

De Ryck DJR, Robert EMR, Schmitz N, der Stcoken TV, Nitto DD, Dahdouh-Guebas F, Koedam N. 2012. Size does matter, but not only size: Two alternative dispersal strategies for viviparous mangrove propagules. Aquat Bot 103: 66-73.

Duke NC, Lo E, Sun M. 2002. Global distribution and genetic discontinuities of mangroves-emerging patterns in the evolution of *Rhizophora*. Trees 16: 65-79.

FAO. 2001. Global Forest Resource Assessment 2000. FAO, Rome.

Forest Watch Indonesia (FWI/GFW). 2001. Keadaaan Hutan Indonesia. Forest Watch Indonesia dan Washington DC: Global Forest Watch, Bogor, Indonesia. [Indonesian]

Friess DA, Thompson BS, Brown B, Aldier Amir A, Cameron C, Koldewey HJ, Sasmito SD, Sidik F. 2016. Policy challenges and approaches for the conservation mangrove forest in Southeast Asia. Conserv Biol 30 (5): 933-949.

Gasparini P, Cosmo LD, Rizzo M, Giuliani D. 2017. A stand-level model derived from national forest inventory data to predict periodic annual volume increment of forest in Italy. J For Res 22 (4): 209-217.

Giri C, Ochieng E, Tieszen LL, Zhu Z, Singh A, Loveland T, Masek J, Duke N. 2011. Status and distribution of mangrove forest of the world using earth observation satellite data. Glob Ecol Biogeogr 20 (1): 154-159.

Heriyanto NM, Subiandono E. 2012. Composition and structure, biomass, and potential of carbon content in mangrove forest at National Park Alas Purwo. Jurnal Penelitian hutan dan Konservasi Alam 9 (1): 23-32. [Indonesian]

Hilwan I. 2012. Species composition and stand structure in logged over area in forest concession of PT Salaki Summa Sejahtera, Province of West Sumatra. Jurnal Silvikultur Tropika 3 (3): 155-16. [Indonesian]

IBM Corp. 2015. IBM SPSS Statistics for Windows, Version 23.0. IBM Corp, Armonk, NY.

Istomo, Kusmana C, Naibaho BD. 2017. Biomass potential on several mangrove planting models in Java Island, Indonesia. AACL Boflux 10 (4): 754-967.

Kairo JG, B Kivyatu, N. Koedam. 2002. Application of remote sensing and GIS in the management of Mangrove forest within and adjacent to Kiunga Marine Protected Area, Lamu, Kenya. Environ Dev Sustain 4: 153-166.

Kusmana C, Hidayat T, Istomo, Rusdiana O. 2018. Growth performance of *B. gymnorrhiza* derived from cut-propagule seedling. Biodiversitas 19 (1): 208-214.

Kusmana C, Watanabe H. 1991. Production structure of main commercial tree species in a mangrove forest in East Sumatera, Indonesia. Biotropia 5: 1-9.

Mattjik AA, Sumertajaya IM. 2006. Perancangan Percobaan dengan Aplikasi SAS dan Minitab. IPB Press, Bogor. [Indonesian]

Meyer HA, Recknagel AB, Stevenson DD, Bartoo RA. 1961. Forest Management 2nd ed. The Ronald Press Company, New York.

Ministry of Agriculture. 1978. Regulations of The Director General of Forestry No. 60/Kpts/DJ/I/1978 Concerning Guidelines for Silviculture Systems in Mangrove Forests. Director General of Forestry, Directorate General of Forestry, Indonesia.

Ministry of Environment and Forestry. 2016. Regulations of The Director General of Sustainable Production Forest Management No.P.8/PHPL/SET/3/2016 Concerning Guidelines for Silviculture Systems in Mangrove Forests. Director General of Sustainable Production Forest Management, Directorate General of Sustainable Production Forest Management, Indonesia.

Mirmanto E. 2010. Vegetation analyses of Sebangau peat swamp forest, Central Kalimantan. Biodiversitas 11 (2): 82-88.

Mitra A, Sengupta K, Banerjee K. 2011. Standing biomass and carbon storage of above-ground structures in dominant mangrove trees in the Sundarbans. For Ecol Manag 261 (7): 1325-1335.

Nontji A. 2002. Laut Nusantara. Jakarta (ID), Djambatan

Oladoye AO, Aduradola AM, Adedire MO, Agboola DA. 2014. Composition and stand structure of regenerating tropical rainforest ecosystem in South-western Nigeria. Intl J Biodivers Conserv. 6 (11): 765-776

Onrizal, Mansor M. 2016. Status of coastal forest of the Northern Sumatra in 2005 (after 2004's tsunami catastrophe). Biodiversitas 17 (1): 44-54.

Phan SM, HTT Nguyen, TK Nguyen, C Lovelock. 2019. Modelling above ground biomass accumulation of mangrove plantations in Vietnam. For Ecol Manag 432: 376-386.

Prasetyo D. 2006. Kajian Komposisi dan Struktur Tegakan serta Pertumbuhan Jenis-jenis Komersial, Khususnya Jenis Ramin (*Gonystylus bancanus* (Miq.) Kurz.) di Hutan Rawa Gambut IUPHHK PT. Diamond Raya Timber, Propinsi Riau. [Hon. Thesis]. Fakultas Kehutanan, Institut Pertanian Bogor, Bogor. [Indonesian]

Pribadi R.1998. The ecology of mangrove vegetation in Bintuni Bay, Irian Jaya, Indonesia. [Dissertation]. Universitas Stirling, Skotlandia

Rahmat D, Fauziyah, Sarno. 2015. Seedling growth of *R. apiculata* at mangrove restoration area Sembilang National Park South Sumatera. Jurnal Maspari 7 (2): 11-18. [Indonesian]

Saputro GB, Hartini S, Sukardjo S, Sutanto A, Kertopermono AP. 2009. Peta Mangroves Indonesia. Bakosurtanal, Bogor, Indonesia.

Setyawan AD, Winarno K. 2006. The direct exploitation in the mangrove ecosystem in Central Java and the land use in its surroundings; degradation and its restoration effort. Biodiversitas 7 (3): 282-291. [Indonesian]

Siahaan OP, Latifah S, Afifuddin Y. 2012. The comparison of circular plots and tree sampling on potential guessed stands at pine public plant forest, case study of Pondok Buluh Village, Subdistrict of Dolok Panribuan, Simalungun Regency. Peronema Forestry Science Journal 1 (1): 1-6. [Indonesian]

Silanpaa M, Vantellingen J, Friess D. 2017. Vegetation regeneration in a sustainably harvested mangrove forest in West Papua, Indonesia. For Ecol Manag 390: 137-146.

Silanpaa M, Vantellingen J. 2015. Forest Survey Report: Assessing Secondary Mangrove Forest Regeneration in PT BUMWI concessions, Bintuni Bay, West Papua. Green Forest Product & Tech. Pte. Ltd., Research Department, Indonesia

Soerianegara I, Indrawan A. 2002. Ekologi Hutan Indonesia. Laboratorium Ekologi Hutan, Fakultas Kehutanan IPB, Bogor. [Indonesian]

Suhendang E, SooerianegaraI, Rusolono T, Prihanto B, Purnomo H, dan Muhdin. 1995. Petunjuk Operasional Metode Pengaturan Hasil Berdasarkan Jumlah Pohon pada Hutan Alam Campuran Tidak Seumur. Fakultas Kehutanan, Institut Pertanian Bogor, Bogor. [Indonesian]

Sutaryo D. 2009. Perhitungan Biomassa: Sebuah Pengantar untuk Studi Karbon dan Perdagangan Karbon. Wetlands International Indonesia Programme, Bogor, Indonesia. [Indonesian]

Valiela I, Bowen JL, York JK. 2001. Mangrove forest: one of the world's threatened major tropical environments. Bioscience 51 (10): 807-815.

Van Oudenhoven APE, Siahainenia AJ, Sualia I, Tonneijk FH, van der Ploeg S, de Groot RS, Alkemade R, Leemans R. 2015. Effects on different management regimes on mangrove ecosystem services in Java, Indonesia. Ocean Coast Manage116: 353-367.

Wahyudi, Machmud, Sudjarmaji. 2013. Seed trees method system of silviculture for harvesting and managing mangrove forest in Indonesia: study case learned from Bintuni Bay, West Papua after being in practices from 24 years. J Sustain 100: 1-7.

Wanggai F. 2009. Manajemen Hutan. Grasindo, Jakarta, Indonesia. [Indonesian]