

# Biomass potential on several mangrove planting models in Java Island, Indonesia

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**Abstract.** Silvofishery is a technology that refers to the principle of sustainable ecology, because the rehabilitation of the coastal ecosystems does not interfere the ongoing fishery cultivation practices. The aim of this research is to get the total prediction of biomass at Pemalang site, Banten site, and Banyuwangi site on the green belt model and silvofishery model. The method used for vegetation analysis is the method of path and line plot and census method, while the allometric formula was taken from various existing literature. The results showed that the green belt model both natural and plantation has a higher biomass than the silvofishery model. The largest green belt model biomass in the form of natural forest model was recorded in Banten with a total of 182.30 t ha<sup>-1</sup>, followed by forest plantation biomass at Banyuwangi tallying 169.99 t ha<sup>-1</sup>, and forest plantation in Pemalang of 123.90 t ha<sup>-1</sup>. The largest silvofishery model biomass is the Banten site with an amount of 155.03 t ha<sup>-1</sup>, the “komplangan” model (mangrove plants adjacent to ponds) at Banyuwangi recording 121.05 t ha<sup>-1</sup>, the “kao-kao” plantation model (mangrove plants line up in ponds) at Banten 30.00 t ha<sup>-1</sup>, the natural kao-kao at Banten 12.51 t ha<sup>-1</sup>, komplangan at Pemalang 10.73 t ha<sup>-1</sup>, and the lastly the lowest biomass recorded was found in an open ditch model tallying 2.13 t ha<sup>-1</sup> in Pemalang Site. Thus the optimal silvofishey model of ecological and economic aspects is the kao-kao model and the komplangan model.

**Key Words:** planting model, silvofishery, sustainable ecology, rehabilitation, coastal ecosystem.

**Introduction.** The mangrove ecosystem plays a very important role because it is a buffer zone between the terrestrial and marine ecosystems (Hartoko et al 2015). This type of ecosystem has an environmental service which includes physical, biological, and economic services (Setyawan et al 2003; Cohen et al 2013; van Oudenhoven et al 2015), the protection of coastal areas from waves and tsunamis (Kusmana et al 2005), natural recreation, spawning and breeding of fish and other marine animals (Mitra et al 2011; Alongi 2012), carbon sinks and storage, and also provides raw wood materials (Hartoko et al 2015; Wahyudi et al 2014; Van Oudenhoven et al 2015). The quantity of environmental services can be measured by using biodiversity and biomass parameters.

In the context of mangrove, biomass is influenced by the interaction of several factors such as edaphism, climatic factors (tidal), waves, variations in precipitation (Alongi 2012) and topography (Mitra et al 2011). Biomass estimation is the first step to know the carbon content stored in a single tree or the whole forest ecosystem. There are several methods that can be used to estimate the amount of biomass of a stand. The most accurate method is to cut the tree in the stand and measure its dry weight (Jachowski et al 2013). However, this approach is contrary to conservation objectives and endeavors, especially for rare species, in this case one of the most commonly used means is to use allometric stand equations based on dimension parameters such as diameter, wood density (Jachowski et al 2013), tree height, and canopy cover (Soares & Novelli 2005). In addition to its purpose for estimating carbon stocks, biomass can also describe nutrient cycles in an ecosystem (Soares & Novelli 2005).

Degradation of the mangrove ecosystem is estimated to produce up to 0.02-0.12 Pg of carbon per hectare per year or equivalent to 10% of the global deforestation emission (Donato et al 2011) with a decreasing amount of the total area of the global mangrove forest reaching 1-3% per year (Alongi 2012), which is higher compared to tropical forests and coral ecosystems (Duke et al 2007). All of these are happening even

though mangrove forests are only 0.7% of the total area of the tropical forest. The damage and degradation of mangroves occurs due to human economic activities such as the expansion of fishponds, infrastructure development and other agriculture based practices (Setyawan et al 2003; Alongi 2012; Wahyudi et al 2014). Mangrove forest plays an important role in relation to global warming due to their presence as carbon absorption and storage (carbon-sinks) (Setyawan et al 2003; Hartoko et al 2015). Various research data collected by Alongi 2012 shows that mangroves are one of the most carbon-absorbing ecosystems in the tropics which absorbs up to 1,023 tons of carbon per hectare (Donato et al 2011) with one of the largest contributors are mangroves located in the Indo-Pacific (Donato et al 2011). Carbon deposits beneath the surface of mangrove forests ranges from 12-219 tons C ha<sup>-1</sup> which is higher compared to other land covers in Southeast Asia (peat 11-71 tons C ha<sup>-1</sup>, other forest types 11-74 tons C ha<sup>-1</sup>, rubber plantation 5-32 tons C ha<sup>-1</sup>, palm oil 4-22 tons C ha<sup>-1</sup>) (Yeun et al 2013). All the carbon released will be added to the carbon present in the vegetation as an active carbon pool. The absorption and storage of carbon dioxide is closely related to a stand's total biomass. Biomass and carbon sinks in tropical forests are forest services outside of the other biophysical potentials. A major potential of a forest biomass is to absorb and store carbon in order to reduce the content of CO<sub>2</sub> in the air. The immediate benefits of optimal forest management in timber yields are only 4.1%. Meanwhile the optimal function in carbon absorption can reach up to 77.9% (Darusman 2006).

Indonesia has the largest area of mangrove, reaching 22.6% of the world's total mangrove area (Giri et al 2011). Areal management is also a major factor of sustainability of the mangrove ecosystem which will affect the mangrove's ability in carrying out its function (van Oudenhoven et al 2015). Various mangrove management schemes have been implemented on the island of Java. The correlation between the mangrove areal management schemes with biomass quantities and potential carbon stocks needs to be identified to provide an overview of how effective a regional management scheme may affect the functioning of the mangrove's environmental services, particularly biomass and carbon potentials. This information can be used to determine the characteristics of forest ecosystems and develop effective conservation and mangrove management strategies both ecologically and economically (Kusmana et al 1992; Morikawa 2002; Chandra et al 2011). Mangrove in Banten, Pemalang, and Banyuwangi were chosen to represent the territory of the island of Java, west and northwest (Banten), south and central (Pemalang), and east and northeast (Banyuwangi).

This study aims to describe the potential of mangroves in the area of Sawah Luhur Village, Serang, Banten; Pesantren Village, Pemalang, Central Java; Wringin Putih Village and Kedungsari Village, Banyuwangi, East Java. These mangrove potential parameters are biodiversity and biomass. This research is expected to provide information about the amount of biomass value in Banten, Pemalang and Banyuwangi sites. Biomass data available in each study site can be used to see the quality and quantity of mangrove vegetation at the three research sites. The biomass data obtained will be the added value of the sustainable mangrove forest management that has been done in the three research sites. The result of this study can also be used to measure the amount of nutrient cycles that occur within the mangrove forest.

## Material and Method

**Study sites.** The research area is located in three locations: (a) The first research location is located in the coastal area of Pesantren Village and Mojo Village in Pemalang Regency, Central Java; (B) The second research location is located in the village of Sawah luhur, Serang Regency, Banten; (C) The third research location is located in Wringin Putih Village and Kedung Asri, Banyuwangi Regency, East Java (Figure 1). Research location coordinates can be seen in Table 1. This study was conducted from October to December 2012.



Figure 1. Research location: (01) Pemalang site, (02) Banten site, (03) Banyuwangi site.

Table 1  
Research location's coordinates

Site	Coordinate	
	Latitude	Longitude
Pemalang	6°47'54.26" S	109°30'46.79" E
Banten	6°01'05"S	106°11'38"E
Banyuwangi	8°28'45.41"S	114°21'24.28"E

**Methods.** Data collected in this research consists of primary and secondary data. The primary data was taken through the collection of the biophysical data at each research location. The main information to consider is the mangrove planting model, plant species, vegetation composition, and its abundance. All individual mangrove plants at each growth rate of each subplot are identified and counted. Growth rates include lower parts of the plants, seedlings, sapling, and trees. The growth rate of the sapling and tree is calculated and the diameter of the tree is also measured. The diameter of the sapling and the tree measured is the diameter of the stem as high as 1.3 m above the surface of the soil or 10 cm above the supporting root (for trees of the Rhizophoraceae family) if the highest supporting root is located at a height of 1.3 m or more.

The mangrove vegetation in the research area was first observed by utilizing a GPS, the data was then inputted in the form of point of plot and transect. The mangrove vegetation that was found was then divided into three categories according to its density, i.e. high, medium, and small densities. Then, a tree treatise was done for each category using the line plot method and the census method according to the planting model found in the field.

Secondary data used in this research are: (A) allometric formulas for estimating total biomass taken from various literature sources; (B) information from residents or farmers in the study sites about the history of Inter Tidal Zone (ITZ) land usage; (C) community activity in the research area; and (D) the literature on mangrove especially about mangrove ecosystem's biomass.

Methods used in this study to obtain data in the field consists of two methods namely the trajectory plot method and the census method. Models of mangrove cultivation such as the open ditch cultivation, komplangan, lane (kao-kao), natural, and plantation forests are assessed by plotting plots. The method used for tree treatment is the trajectory method in combination with line plots (Kusmana 1997). The census method was used for the open ditch and the lane (kao-kao) cultivation model. The size of the measuring plot used is 10 x 30 m. The sampling data area for the trajectory plot method is 0.09 ha/model or may be smaller depending on the actual size found in the field.

The size of regeneration and area of plot used in the analysis of mangrove forest vegetation in this study are as follows: (i) Tree; Individual wood plants with diameters of 10 cm or more, subplot size 10 x 10 m; (ii) Sapling; Less than 10 cm in diameter, forest regeneration with a minimum height of 1.5 m, subplot size 5 x 5 m; (iii) Seedlings;

Forest regeneration ranging from sprouts to saplings with a height less than 1.5 m, subplot size 2 x 2 m; Both methods are used for practical reasons while collecting data in the field. Data collection of mangrove vegetation was done randomly. Illustration of plot used in this research can be seen in Figure 2.

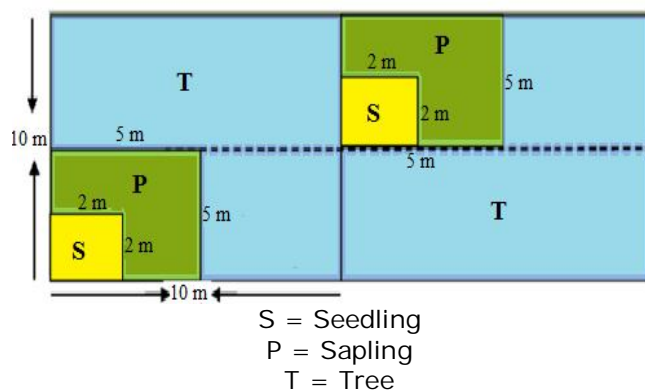


Figure 2. Sketch of the research plot combination method between trajectory and line plots.

**Data analysis.** The data of mangrove vegetation obtained were processed by using the formula:

- a. Density (D)  $\text{ind ha}^{-1} = \frac{\text{Total of individuals in a species}}{\text{Area of plot}}$
- b. Relative Density (RD)  $= \frac{\text{Density of a single species}}{\text{Density of total species}} \times 100\%$
- c. Frequency (F)  $= \frac{\text{Total plots of a species}}{\text{Total sum of all plots}}$
- d. Relative Frequency (RF)  $= \frac{\text{Frequency of a single species}}{\text{Frequency of total species}} \times 100\%$
- e. Dominance (D)  $\text{m}^2 \text{ha}^{-1} = \frac{\text{Total basal area of a species}}{\text{Area of plot}}$
- f. Relative Dominance (RD)  $= \frac{\text{Dominance of a single species}}{\text{Dominance of total species}} \times 100\%$
- g. Important Value Index (IVI)  $= \text{RD} + \text{RF} + \text{RD}$
- h.  $BA = \frac{1}{4} \pi (\text{Dbh})^2$
- i.  $V = \text{BA} \cdot \text{Tbc} \cdot f$
- Where, V is volume ( $\text{m}^3$ ), BA is basal Area ( $\text{m}^2$ ), Tbc is branch free height, and F is constant figure form (0.8).
- j.  $H' = -\sum \left[ \left( \frac{n_i}{N} \right) \text{Ln} \left( \frac{n_i}{N} \right) \right]$ .

Where,  $H'$  is Species diversity index (Shannon-Wiener Index of general diversity),  $ni$  is Important Value Index Species  $i$ , and  $N$  is Important Value Index Total.

Measurements of the total biomass storage of the trees are based on the results of vegetation analysis and combined with the existing allometric equations. The total biomass mentioned encompass all above ground biomass. The allometric equations used in this study are as shown in Table 2.

Table 2

Allometric equations used in this study

No.	Species	Allometric equation	Diameter (cm)	Source
1.	<i>Avicennia marina</i>	$Y=0.2905 \text{ DBH}^{2.2598}$	D=6.4-35.2	Dharmawan & Siregar 2008
2.	<i>Rhizophora apiculata</i>	$W_{\text{top}} = 0.235 \text{ DBH}^{2.42}$ $W_r = 0.00698 \text{ DBH}^{2.61}$	Dmax=28	Ong et al (2004)
3.	<i>Rhizophora mucronata</i>	$Y=0.4999022826 \text{ DBH}^{2.3180934}$	D=10-40	Hilmi (2003)
4.	<i>Rhizophora</i> spp.	$B(\text{gram}) = 0.113 \text{ DBH}^{-1.32} H^{2.29}$	D=50-100	Hapsari 2011

Y - the total value of dry biomass per tree (kg); B - the total value of dry biomass per tree; H - tree height. Wtop - above ground biomass (kg); Wr - Subsoil biomass (kg). General equation: Common equation for mangrove species (Komiya et al 2005).

## Results and Discussion

**Mangrove planting models.** According to Surtida (2000) silvofishery is a form of integration between mangrove ecosystems with the input of aquaculture in brackish waters. As described by Ghufraan & Kordi (2012), there are 4 types of silvofishery pond models: (1) Ditch ponds, known as traditional trench ponds, were the first type developed. Mangrove plants are placed in ponds, while the cultivation plots (fish, shrimp, etc.) form a trench surrounding the mangroves. The ditch trench pattern has been reported to provide an increase in pond productivity in areas such as Sinjai, South Sulawesi, Cikong, Cibuaya and Bogor, West Java. (2) *Komplangan* ponds, the mangroves are located adjacent to the fishponds, with a proportion of 60% mangrove and 40% fishponds, or 80% mangrove and 20% fishponds. (3) Kao-kao ponds, the mangroves are planted parallel inside the fishpond, while fish farming plots are located among the mangrove plants. (4) Open ditch fishponds, mangroves are planted on the brink (embankment) surrounding the ponds which are located at the middle of the area. In general, the model of silvofishery ponds located in the four research sites is presented in Figure 3.

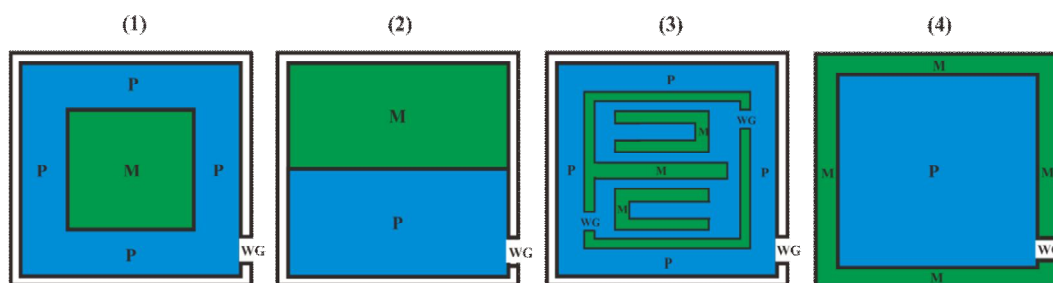


Figure 3. Silvofishery model found in all three research sites (M = mangrove, P = pond water, WG = water gate). (1) Ditch-like Fishponds, (2) komplangan ponds, (3) kao-kao (4) open ditch.

Mangrove planting models found in the field is quite diverse. There were 3 models of mangrove planting presented at Pemalang site which consists of forest plantation, open ditch cultivation, and komplangan ponds. Open ditch ponds are the most extensive (areal-wise) planting model. Komplangan model in this area is an experiment applied by the owner as a result of the same model that has been seen presented elsewhere. The species of the mangrove planted is *Rhizophora mucronata*. In Banten there were also 3 models of mangrove planting which is natural forest, artificial komplangan, Natural kao-kao, and kao-kao plantation. The natural forest found at this site consists of mangroves that are located inside Pulau Dua Nature Reserve (CAPD) whose conditions are still well preserved. The natural kao-kao model is a natural succession of mangroves that are converted to fishponds. Generally this type of regeneration is *Avicennia marina*. As for the kao-kao plantation model is a result of a collaboration between the community around the village of Sawah Luhur with Wetlands International Indonesia Program (WI-IP). The mangroves that are planted here are namely *Rhizophora apiculata*, *R. mucronata* and *R. stylosa*. While at the Banyuwangi site only two types of mangrove planting model were found which are the forest plantation model and the komplangan model. The forest plantation model is found almost throughout the length of the Pangpang bay. The species planted there are also quite diverse, among them are *R. mucronata*, *R. apiculata*, *R. stylosa*, *Sonneratia alba*, and *Ceriops tagal*. This forest plantation model is planted by various government agencies, non-governmental organizations, and communities around Pangpang Bay. Meanwhile the komplangan model is located in Perhutani-owned land managed by the community. The species grown here are *R. mucronata*, *R. apiculata*, *R. stylosa*, and *C. tagal*. *R. apiculata* is one of the most widely planted species because it is one of the most important types of mangrove based commercial timber in Asia (Ong et al 2004).

**Extent land use for mangrove planting.** In general, Hapsari (2011) and Sualia (2011) made an illustration regarding the cross-sectional profiles of coastal mangrove vegetation as shown by Figure 4.

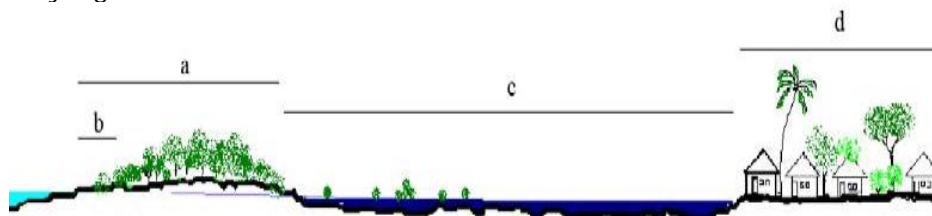


Figure 4. (a) The mangrove formation (green belt), (b) Rehabilitation area, (c) Vegetation around the fishpond (rehabilitation area), and (d) Vegetation around the village.

Based on the map from Project Mangrove Capital 2013, the Pemalang site has the largest area of mangrove with an area of 1,010 ha, followed by the Banyuwangi site with an area of 784 ha, while the site in Banten has the least areal at 603.52 ha even so, this site presented the most mangrove planting model. The area of mangrove planting models on all three sites is presented in Table 3.

According to Table 3, the largest area is sylvofishery ponds for the open ditch models (97.52%) at Pemalang and natural kao-kao sites (87.73%) at Banten site. But on the Banyuwangi site the dominant area is greenbelt or forest plantation (96.43%). Natural kao-kao models on the Banten site are not all overgrown by mangroves; only about 500 meters perpendicular to the greenbelt zone.

The potential of the mangrove ecosystem in Indonesia is that this type of ecosystem holds the highest diversity of species in the world with an area of 22.6% of the total mangrove in Asia (Giri et al 2011). However the quality and quantity of this ecosystem today is threatened due to the deforestation and the increasing activity of converting mangrove forests to other designations.

Table 3

Area of mangrove vegetation at the 3 research sites

<i>Location</i>	<i>Planting model</i>	<i>Area (ha)</i>	<i>Areal percentage (%)</i>
Pemalang	Forest Plantation	23	2.28
	Open ditch	985	97.52
	Komplangan	2	0.20
Banten	Natural Forest	32	9.02
	Artificial Komplangan	2	0.56
	Natural Kao-kao	311.11	87.73
Banyuwangi	Kao-kao Plantation	9.52	2.68
	Forest Plantation	756	96.43
	Komplangan	28	3.57

**Type composition and stand structure.** Most of the remaining mangroves in all of the study locations are spread around the river banks and beaches with various widths. The set of mangroves that once flourished on the coast are currently only visible as a disconnected trajectory due to the expansion of fishponds. The width varies from several tens to one kilometer. The quality and quantity of mangrove vegetation on average has declined in all three research sites. This is due to the shifting of natural mangrove area into fishponds that occurred in 1980s. Van Oudenhoven et al (2015) states that the natural mangrove areas that are converted into ponds has a functioning value as the highest food producer while at the same time eliminates other environmental services of mangroves, while natural mangroves has the highest value for all parameters of environmental services except for producing food.

The result of measurement and calculation of density, basal area, volume, and Shanon-Wiener ( $H'$ ) diversity index at each site and mangrove planting model are presented in Table 4.

As seen in Table 4 there is a large variation between density, BA, IVI and the diversity index of species found in the mangrove planting models at the three study sites. The highest density at the sapling level was found in the komplangan model at Banten with the amount of  $8,160 \text{ ind ha}^{-1}$ , meanwhile the highest value of BA and Volume measured was found in the komplangan model at Banten with the respective values of  $14.24 \text{ m}^2 \text{ ha}^{-1}$  and  $22.25 \text{ m}^3 \text{ ha}^{-1}$ . As for the tree level, the highest density, BA, and volume was found in the natural forest model at Banten for  $609.09 \text{ ind ha}^{-1}$ ,  $21.72 \text{ m}^2 \text{ ha}^{-1}$ , and  $43.40 \text{ m}^3 \text{ ha}^{-1}$  respectively.

Currently the mangrove stands found in the three research sites are the result of reforestation, where the vegetation at the sapling level are predominant. The vegetation found at the Pemalang site consists of 87% sapling and 13% trees, at the Banten site 57% sapling and 43% trees, while at Banyuwangi there are 56% sapling and 44% trees. The existing mangrove vegetation was a result of a reforestation that began in 1995 at Pemalang and Banyuwangi sites, and in the 2000s at Banten.

The age of mangrove stands in the three research sites varied from 2 to 17 years for mangroves that were resulted by reforestation. However, at the Banten site natural mangrove stands that are decades of years old can still be found. Mangrove stands are considered as a slow growing species. A higher growth rate of the tree compared the growth rate of the sapling was only found in one planting model which is found in the natural forest model at Banten site where the growth rate of the tree level is 97.10%. This is influenced by the existence of Pulau Dua Nature Reserve whose mangrove stands are maintained so that its function remains sustainable, which caused it have the highest amount of density, BA and the volume at the tree level. According to a study conducted by Febryano et al (2014) indicates that mangrove managed by local communities in the village of Jaralangan and Kalangan became severely damaged in 2003 due to unsustainable management.

Table 4

Number of Individuals, Density, Basal Area, Volume, IVI, and H' Index in research area

No	Plantation model	Species	n		D (ind/ha)		BA (m2/ha)		V (m3/ha)		IVI (%)		Index H'	
			S	T	S	T	S	T	S	T	S	T	S	T
1	Pemalang													
	a. Forest plantation	<i>Aa</i>	13	2	650.00	25.00	1.82	4.52	0.53	0.19	35.74	109.75	0.31	0.37
		<i>Am</i>	4	3	200.00	37.50	0.88	4.62	0.52	1.12	19.97	144.01	0.23	0.35
		<i>Rm</i>	104	1	5200.00	12.50	10.33	1.35	7.53	0.31	144.28	46.24	0.24	0.29
	Sub-total a		121	6	6050.00	75.00	13.03	10.50	8.57	1.62	200.00	300.00	0.77	1.01
	b. Open Empang parit	<i>Rm</i>	203	51	44.51	11.18	0.04	0.12	0.05	0.37	200.00	300.00	0.00	0.00
	c. Komplangan	<i>Rm</i>	58	0	3866.67	0.00	1.61	0.00	0.64	0.00	200.00	0.00	0.00	0.00
2	Banten													
	a. Natural forest	<i>Am</i>	2	67	72.73	609.09	0.54	21.72	1.09	43.40	200.00	300.00	0.00	0.00
	b. Komplangan	<i>Am</i>	5	21	400.00	420.00	5.39	7.31	10.67	14.01	63.39	300.00	0.36	0.00
		<i>Rm</i>	97	0	7760.00	0.00	8.84	0.00	11.58	0.00	136.61	0.00	0.26	0.00
	Sub-total b		102	21	8160.00	420.00	14.24	7.31	22.25	14.01	200.00	300.00	0.62	0.00
	c. Natural Kao-kao	<i>Am</i>	1	85	0.40	34.27	0.00	1.44	0.00	2.63	66.67	272.17	0.37	0.09
		<i>Ra</i>	5	2	2.02	0.81	0.01	0.01	0.02	0.13	133.33	27.83	0.27	0.22
	Sub-total c		6	87	2.42	35.08	0.01	1.44	0.02	2.75	200.00	300.00	0.64	0.31
	c. Kao-kao plantation	<i>R spp.</i>	109	0	4844.44	0.00	1.48	0.00	0.15	0.00	200.00	0.00	0.00	0.00
3	Banyuwangi													
	a. Forest plantation	<i>Ct</i>	1	0	14.81	0.00	0.03	0.00	0.01	0.00	3.94	0.00	0.08	0.00
		<i>Ra</i>	47	62	696.30	229.63	3.12	2.87	10.72	11.09	58.66	105.63	0.36	0.37
		<i>Rm</i>	101	20	1496.30	74.07	4.51	1.12	7.80	2.52	111.59	45.55	0.33	0.29
		<i>Sa</i>	15	74	222.22	274.07	0.90	4.83	1.60	6.80	25.81	148.82	0.26	0.35
	Sub-total a		164	156	2429.63	577.78	8.56	8.82	20.14	20.41	200.00	300.00	1.03	1.00
	b. Komplangan	<i>Ct</i>	26	0	1155.56	0.00	0.69	0.00	0.28	0.00	46.55	0.00	0.34	0.00
		<i>Ra</i>	39	3	1733.33	33.33	3.27	0.31	3.50	0.57	86.49	38.94	0.36	0.27
		<i>Rm</i>	22	37	977.78	411.11	2.92	4.46	5.01	9.56	66.95	261.06	0.37	0.12

n - number of individuals (individuals); D - Density (ind ha<sup>-1</sup>); S - Sapling; T - Tree; BA - Basal area; IVI - Important value index; H' - Shannon-Wiener index; *Aa* - *Avicennia alba*; *Am* - *Avicennia marina*; *Ct* - *Ceriops tagal*; *Ra* - *Rhizophora apiculata*; *Rm* - *Rhizophora mucronata*; *R spp.* - *Rhizophora spp.*, *Sa* - *Sonneratia alba*.



Type composition is a variable to know the ongoing succession process done to a mangrove community in an area, so it can be known whether a community and the ecosystem are disrupted or not. The growth rate of seedlings cannot be defined in the research plots because saplings of the dominant mangrove trees such as *R. mucronata* were intolerant to shade (Nybakken 1993).

To see the dominance of a typical species, an important value index (IVI) is used. The dominance of a species towards other species are determined by IVI, volume, biomass, canopy closure percentage, basal area, and the number of individuals or its abundance. One of the indicators for predicting species diversity is by using the index of diversity or often called the Shannon-Wiener Index ( $H'$ ) (Shannon-Wiener 1949 in Ludwig & Reynolds 1988). Based Table 3 the highest IVI is recorded 300% for tree level and 200% for sapling level. The Shannon-Wiener ( $H'$ ) Index value seen in Table 3 has an average below one. The  $H'$  that has a value above one are found in the plantation model at the Pemalang site (1.01) and at the Banyuwangi site also in the plantation model. In the plantation model at Pemalang site, three mangroves were found, *A. alba*, *A. marina* and *R. mucronata*, while the plantation model at the Banyuwangi site four species was found, namely *Ceripos tagal*, *R. apiculata*, *R. mucronata* and *S. alba*.

**Biomass.** The results of biomass calculations based on diameter measurement results and by using allometric equations (Table 1) can be seen in Table 5 and Figure 5.

Table 5  
Results of tree-level biomass level and total biomass calculations at three research sites

No	Plantation model	Area (ha)	Species	BS ( $t\ ha^{-1}$ )	BT ( $t\ ha^{-1}$ )	TB ( $t\ ha^{-1}$ )
1			Pemalang			
	a. Plantation Forest	23	<i>Aa</i>	14.44	3.90	18.34
			<i>Am</i>	5.75	2.39	8.13
			<i>Rm</i>	95.97	1.46	97.43
	Sub-total a			116.16	7.74	123.90
	b Open Empang Parit (Ditch model)	985	<i>Rm</i>	0.47	1.65	2.13
	c. Komplangan	2	<i>Rm</i>	10.73	0.00	10.73
2			Banten			
	a. Natural Forest	32	<i>Am</i>	3.58	178.71	182.30
	b. <i>Komplangan</i>	2	<i>Am</i>	35.33	46.70	82.03
			<i>Rm</i>	73.00	0.00	73.00
	Sub-total b			108.33	46.70	155.03
	c. Natural <i>Kao-kao</i>	560	<i>Am</i>	0.02	12.30	12.32
			<i>Ra</i>	0.11	0.09	0.19
	Sub-total c			0.12	12.39	12.51
	d. Plantation <i>Kao-kao</i>	9.52	<i>R spp.</i>	30.00	0.00	30.00
3			Banyuwangi			
	a. Plantation Forest	756	<i>Ct</i>	0.32	0.00	0.32
			<i>Ra</i>	23.62	26.40	50.02
			<i>Rm</i>	44.77	15.62	60.39
			<i>Sa</i>	7.20	52.06	59.25
	Sub-total a			75.91	94.08	169.99
	b <i>Komplangan</i>	28	<i>Ct</i>	5.46	0.00	5.46
			<i>Ra</i>	20.89	2.59	23.47
			<i>Rm</i>	29.62	62.50	92.12
	Sub-total b			55.96	65.09	121.05

*Aa* - *Avicennia alba*; *Am* - *Avicennia marina*; *Rm* - *Rhizophora mucronata*; *Ra* - *Rhizophora apiculata*; *Ct* - *Ceripos tagal*; *Sa* - *Sonneratia alba*. BS - Biomass of sapling. BT - Biomass of tree, TB - Total biomass.

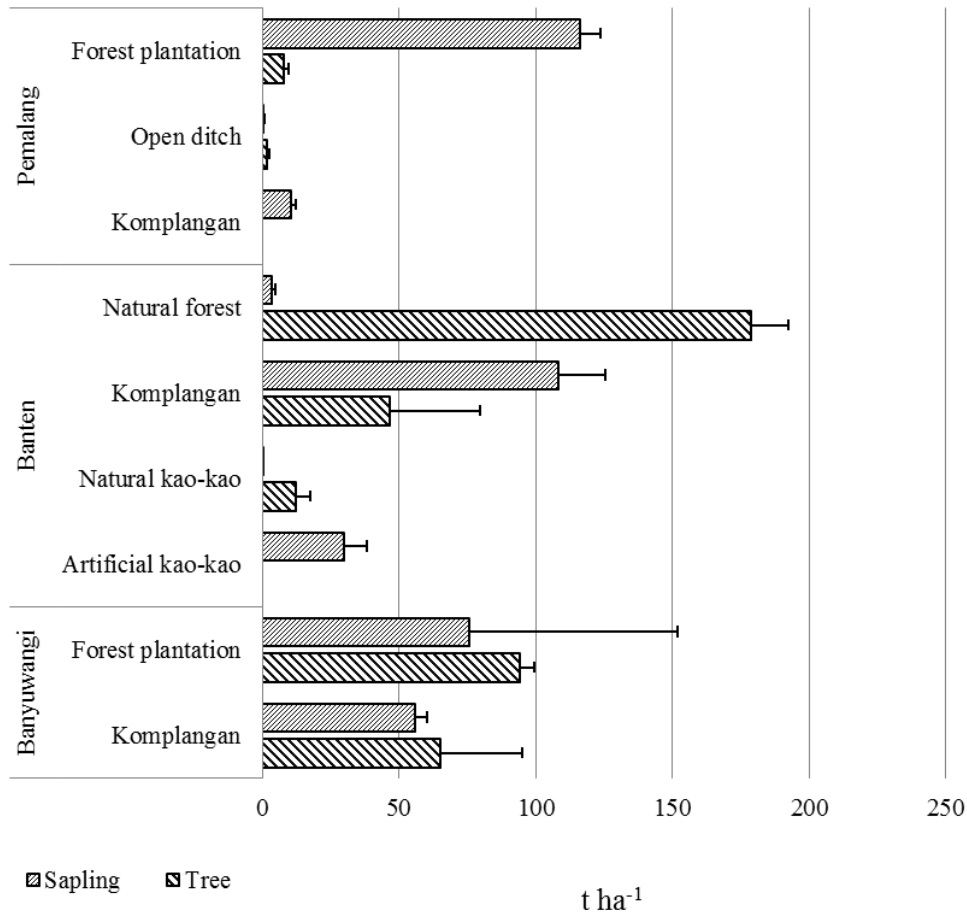


Figure 5. Calculations of above ground biomass at three research sites.

As seen in Table 5 the largest total biomass is found in the natural forest at Banten site at 182.30 t ha<sup>-1</sup>, followed by the forest plantation biomass at Banyuwangi site with the amount of 169.99 t ha<sup>-1</sup>, then the forest plantation at Pemalang plantation of 123.90 t ha<sup>-1</sup>, komplangan at Banten site 155.03 t ha<sup>-1</sup>, komplangan at Banyuwangi of 121.05 t ha<sup>-1</sup>, kao-kao plantation at Banten site 30.00 t ha<sup>-1</sup>, kao-kao plantation at Banten site 12.51 t ha<sup>-1</sup>, Pemalang 10.73 t ha<sup>-1</sup>, and lowest total biomass was found on open ditch model of 2.13 t ha<sup>-1</sup> at the Pemalang Site. This result is understandable considering that the mangroves in the open ditch model is only found on the embankment of the fishpond resulted on the lowest density and BA of mangroves (Table 3). The natural forest model at Site Banten is dominated by large trees resulting in high density and BA (Table 3).

Figure 5 shows that the largest amount of biomass either sapling as well as tree-level was found in the model of natural forest, followed by the forest plantation model, then in the komplangan model, next is the kao-kao model and lastly the lowest amount of biomass produced was found in the open ditch model. Natural and plantation forest models grew closely together throughout the surveyed areas, while mangroves found in the komplangan model grew 60% to 89% adjacent to the fishpond, in the kao-kao model mangroves are seen to be lined up in the center of the pond while mangroves in the open ditch model grew only on the edge or the embankment of the pond (Figure 3).

The results of biomass measurement presented in Table 4 and Figure 5 in natural and plantation forests are similar to that of mangrove biomass measurement conducted to *R. mucronata* species in Parang island which is also managed based on conservation with an amount of 116.22 t ha<sup>-1</sup> - 147.44 t ha<sup>-1</sup> of biomass (Hartoko et al 2015). Several research results on above ground biomass in mangroves and basal areas in several parts of Indonesia are presented in Table 6. Based on the data presented in Table 5 and Table

6 a biomass comparison can be conducted between these research areas with areas in various locations in Indonesia. The total biomass value resulted in this study ranges from 2.13 to 182.30 t ha<sup>-1</sup>, while studies done in other locations in Indonesia resulted in total biomass of 40.7-256.8 t ha<sup>-1</sup> (Table 6). While the total amount of basal area of the sapling and tree found in these research sites are 0.15 m<sup>2</sup> ha<sup>-1</sup> (open ditch), 23.52 m<sup>2</sup> ha<sup>-1</sup> (forest plantation), while in other parts of Indonesia 2.5-25.1 m<sup>2</sup> ha<sup>-1</sup> (Table 6).

Table 6

Above Ground Biomass and Basal Areas of mangrove forest in several locations in Indonesia

Location	Forest condition	Species	AGB (t ha <sup>-1</sup> )	BA (m <sup>2</sup> ha <sup>-1</sup> )	Reference
Halmahera	Primary Forest	<i>R. apiculata</i> forest	356.8	25.1	Komiyama et al (1988)
East Sumatera	Concession area	<i>B. sexangula</i> stand	279.0	22.1	Kusmana et al (1992)
Halmahera	Primary Forest	<i>R. stylosa</i> forest	178.2	14.0	Komiyama et al (1988)
Halmahera	Primary Forest	<i>Sonneratia</i> forest	169.1	21.2	Komiyama et al (1988)
East Sumatera	Concession area	<i>B. parvifolia</i> stand	89.7	9.2	Kusmana et al (1992)
East Sumatera	Concession area	<i>R. apiculata</i> stand	40.7	2.5	Kusmana et al (1992)

Overall, the highest total biomass of all planting locations and models are found in the natural forest model at Banten site in the form of green belt with the total amount of 182.30 t ha<sup>-1</sup>. The green belt zone found in all locations has a larger biomass contribution compared to the silvofishery zones. The green belt zone at Pemalang contributes to the amount of biomass as much as 123.9 t ha<sup>-1</sup> while silvofishery zones only contribute 12.85 t ha<sup>-1</sup> of the total biomass. In the Banten site the green belt zone in the form of natural forest stores biomass up to 182.30 t ha<sup>-1</sup> close to that of the biomass in the silvofishery zone (natural kao-kao and kao-kao plantation) which is 197.54 t ha<sup>-1</sup>. Similarly, the Banyuwangi site has a higher biomass in the green belt zone of 169.99 t ha<sup>-1</sup> compared to the silvofishery zone of 121.05 t ha<sup>-1</sup>. This result is because the green belt zone is a forest that is intended to maintain the function of the mangrove environment resulting in its preserved existence.

The amount of mangrove biomass in these three areas are still lower than that of biomass produced by mangrove forests on the coast of Talidandang Besar Riau as reported by Kusmana et al (1992) which ranges around 42.94 t ha<sup>-1</sup> to 279.0 t ha<sup>-1</sup> and also lower than that of above ground biomass in the south west coast of Thailand dominated by *R. mucronata* and *R. apiculata* 226.24 t ha<sup>-1</sup> (Jachowski et al 2013). Fromard et al (1998) also estimates the above ground biomass content in French Guiana for *Avicennia* and *Rhizophora* which has a range from 180 t ha<sup>-1</sup> to 315.5 t ha<sup>-1</sup>, that also larger than the amount of biomass found in the three study sites. However, biomass measured in the three study sites are still higher when compared to mangrove biomass found in Sundarbands India dominated by *S. apetala*, *A. alba* and *Excoecaria agallocha* of 9.82-84.79 t ha<sup>-1</sup> (Mitra et al 2011) and mangrove forest biomass found in Sarawak which is dominated by *R. mucronata* with a total biomass of 116.79 t ha<sup>-1</sup> (Chandra et al 2011). Mangrove forest biomass is relatively smaller in stands located closer to the sea and then that located towards inland (Komiyama et al 2008).

Individual density, base area, and volume are directly proportional to biomass. This means that the greater the value of individual density, the area of the base, and the volume of mangrove stands, the greater the biomass value. Fromard et al (1998) in his research and observation of various biomass data concluded that the characteristic of stand structure especially basal area has a direct correlation and is one of the more

important parameter to total biomass of a stand compared to important value index which is not directly correlated to the biomass value of a stand. This is supported by Kusmana et al (1992) which states that the increase in biomass is directly proportional to the increase of basal area but not significantly affected by the stands density. Differences of biomass content in the three research sites, in addition to being influenced by its management model, is also influenced by climatic factors such as temperature, solar radiation intensity and precipitation level of the location (Kusmana et al 1992; Komiyama et al 2008). Conversion of mangrove forests into fishponds has a very big impact on biomass.

**Conclusions.** The study concludes that the green belt models both natural and plantation has a higher amount of total biomass than the sylvofishery model. The highest amount of total biomass was found in the green belt model in the form of natural forest model at Banten with the amount of 182.30 t ha<sup>-1</sup>, followed by the forest plantation biomass at the Banyuwangi sites of 169.99 t ha<sup>-1</sup>, and forest plantation in Pemalang has an amount of 123.90 t ha<sup>-1</sup>. The highest biomass found in a sylvofishery model is the found in Banten with the amount of 155.03 t ha<sup>-1</sup>, the komplangan model at Banyuwangi is up to 121.05 t ha<sup>-1</sup>, the kao-kao plantation at Banten 30.00 t ha<sup>-1</sup>, the kao-kao plantation at Banten 12.51 t ha<sup>-1</sup>, Pemalang 10.73 t ha<sup>-1</sup>, and lastly the lowest biomass recorded during this research was found on open ditch model at Pemalang with a total biomass of 2.13 t ha<sup>-1</sup>. The results of this study indicate that the highest value of ecological function with the parameters of individual density and biomass was found in green belt zones in the form of natural and plantation forest. Because of the potential of mangrove biomass in natural and plantation forest areas indicates the need for green belt zones in every coastal region.

**Acknowledgements.** The authors would like to thank the Mangrove Capital project funded by Wetlands International and also supported financially by the Foundation for Sustainable Development, The Waterloo Foundation (Project Number 1277), Otter Foundation (Project Number 1277), The Dutch government (Project No. 1232) and other private donors that have involved Berto Dionsius Naibaho.

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Received: 31 May 2017. Accepted: 17 July 2017. Published online: 24 July 2017.

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How to cite this article:

Istomo, Kusmana C., Naibaho B. D., 2017 Biomass potential on several mangrove planting models in Java Island, Indonesia. *AAFL Bioflux* 10(4): 754-767.