Carbon stock potency of mangrove ecosystem at Tapak Sub-village, Semarang, Indonesia

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Abstract. The mangrove ecosystem is very important in reducing carbon emissions because of its ability to absorb carbon. Nevertheless, contribution of carbon emissions of mangrove forests is also quite large due to the destruction of their ecosystems. Tapak Sub-village of Semarang City has typical variation of coastal ecosystems, consisting of pond ecosystem (artificial), river ecosystem (natural) and coastal ecosystem (natural). Each of these ecosystems has different structure in terms of types of plants and mangrove density. This study aims to assess the amount of biomass and carbon stocks in each type of mangrove ecosystem in coastal area of Tapak Sub-village, Semarang. Biomass measurement was conducted by allometric equations. Estimations of carbon stock was based on biomass calculation with carbon fraction as coversion factor. The results obtained showed the six research locations contributed 1507.91 ton ha^{-1} in mangrove biomass content, 708.20 ton C ha^{-1} carbon stock, and 2598.65 ton ha^{-1} CO_2 absorption capability. The highest biomass value in each plot is from *Avicennia marina* contributing 913.94 ton ha^{-1} biomass content and 429.55 ton C ha^{-1} carbon content.
Key Words: biomass content, carbon stock, mangrove, Tapak Sub-village, carbon emission, coastal ecosystem.

Introduction. Global warming becomes one of the major environmental issues in the world recently. It begins with the emission of greenhouse gases that form a layer in the atmosphere. As a result, the sun heat that enters the earth can not return to the atmosphere because its energy is not able to pass through the layer (Andrew 2011).

Antropogenic activities is the biggest contributor of green house gases. Intergovernmental Panel on Climate Change (IPCC) Report in 2014 recorded that agriculture sector, forestry and land use contributed 24% emission, while transportation and industrial sectors contibuted 14% and 21%, respectively, of global emissions. The biggest contribution to the escalation of green house gases from anthropogenic activity, was from land use sector, particularly, deforestation and land use change, contributing 8-20% (van der Werf et al 2009). Various strategies for reducing emissions were conducted in order to reduce the global warming rate. One of the strategy is the REDD Policy (Reducing Emissions from Deforestation and Forest Degradation), which offers incentives for developing countries to control carbon emissions from forest land.

The REDD Policy was proposed by United Nations Environment Programme (UNEP), World Bank, Global Environment Facility (GEF) and Environmental NGO as a strategy of climate change mitigation which integrates forest management into the scheme of carbon absorption (Beymer-Farris & Bassett 2012). According to Munawar et al (2015), the incentive suggested the amount of carbon which could be used for sustainable livelihood of the community around the forest. However, the lack of data on the amount of forest area and carbon stocks contained limited implementation of the REDD Policy (Alongi 2011).

Land mitigation efforts have been well implemented in terrestrial forest area; while coastal degradation is yet to be given a major priority. However, coastal area with mangrove forest vegetation are known to have high potentials as carbon absorber compared to other types of tropical forest (Donato et al 2011). Pendleton et al (2012) also recommended that coastal ecosystem management policy be given significant attention in reducing carbon emissions though it is currently given less attention.

The mangrove ecosystem is very important in reducing carbon emissions because of its ability to absorb carbon. Eong (1993) estimated that mangrove vegetation could absorb carbon from the atmosphere between 75-150 Tg C ha^{-1} y^{-1}. Nevertheless, contribution of carbon emissions of mangrove forests is also quite large due to the destruction of their ecosystems. Some research results indicate that mangrove forest area is a region with quick rate of land use change and deforestation due to aquaculture activities and development center (Primavera 1997; Donato et al 2011; Bournazel et al 2015). Generally, mangrove waters release more than 2.5 times the amount of CO_2 into the atmosphere (-42.8 Tg C y^{-1}) which emitted from another entire subtropical and tropical coastal water area (Alongi & Mukhopadhyay 2015).

Tapak Sub-village of Semarang City has typical variation of coastal ecosystems, consisting of pond ecosystem (artificial), river ecosystem (natural) and coastal ecosystem (natural). Each of these ecosystems has different structures: types of plants and mangrove density which could influence the amount of carbon content in each type of ecosystem. This is strengthened by evidence obtained in China that mangrove density could affect carbon content of mangrove forest (Liu et al 2013).

Based on desk study, until 2015, there was no record of carbon stock database (carbon squestration) of mangrove ecosystem at coastal area of Semarang. This study aims to assess the amount of biomass and carbon stocks in each type of mangrove ecosystem in coastal area of Tapak Sub-village, Semarang. It is important because the carbon calculation obtained in this study could be used as instrument to protect mangrove area. Besides, database of carbon stock and stored carbon potential generated in this study will support the carbon emission reduction policy through the REDD Policy. In addition, the entire calculation result of each type of ecosystem could become consideration material for Semarang City government in formulating policy of coastal area management in Tapak particularly, and coastal area of Semarang in general.

Material and Method

Description of the study sites. This study was conducted May to October 2016 at mangrove ecosystems of Tapak Sub-village, Semarang, Indonesia (Figure 1), which consist of various lansdcape such as mangrove vegetation, fish pond, sandy beach and estuary. Tapak Sub-village is located at 110º17’15”-110º22’4”E and 6º56’13”-6º59’14”S (Martuti et al 2017). It is one of administration area of Tugurejo Sub-district, Semarang.

Determination of research station location. The research stations were classified based on ecosystem type and density of mangrove species in Tapak area. The mangrove species included *Avicennia marina* (station I, II, III, IV, V and VI), *Rhizhophora mucronata* (station II and IV), and *Rhizophora stylosa* (station IV). Purposive sampling method was adopted emphasizing mangrove species and landscape type represented (Kauffman & Donato 2012); resulting in six (6) research stations marked out as: station I - mangrove ecosystem; stations II and IV - river ecosystems; and stations III, V and VI - fishpond ecosystems.

Preparation of research plots. The research plots were 20 m in diameter representing each type of ecosystem (n = 9). Underground biomass data were also collected by random sampling method with priority given to the areas around the research plots (n = 18) (Kauffman & Donato 2012).

Data collection. Data were collected once in July 2016. The research sites are always inundated by sea water at 20-30 cm high, so the soil samples was taken from 0-20 cm depth, depending on level of standing water in the mangrove forest. The soil samples were then placed in a labelled plastic bag and stored in a cooler for laboratory analysis.

Allometric method of measurement of tree diameter at breast high (DBH) was employed in carbon calculation above the water surface. The tree diameter and height in all plots were measured, from small to large diameter, e.g., DBH class 6.4-35.2 cm (Mitra et al 2011; Kauffman & Donato 2012).

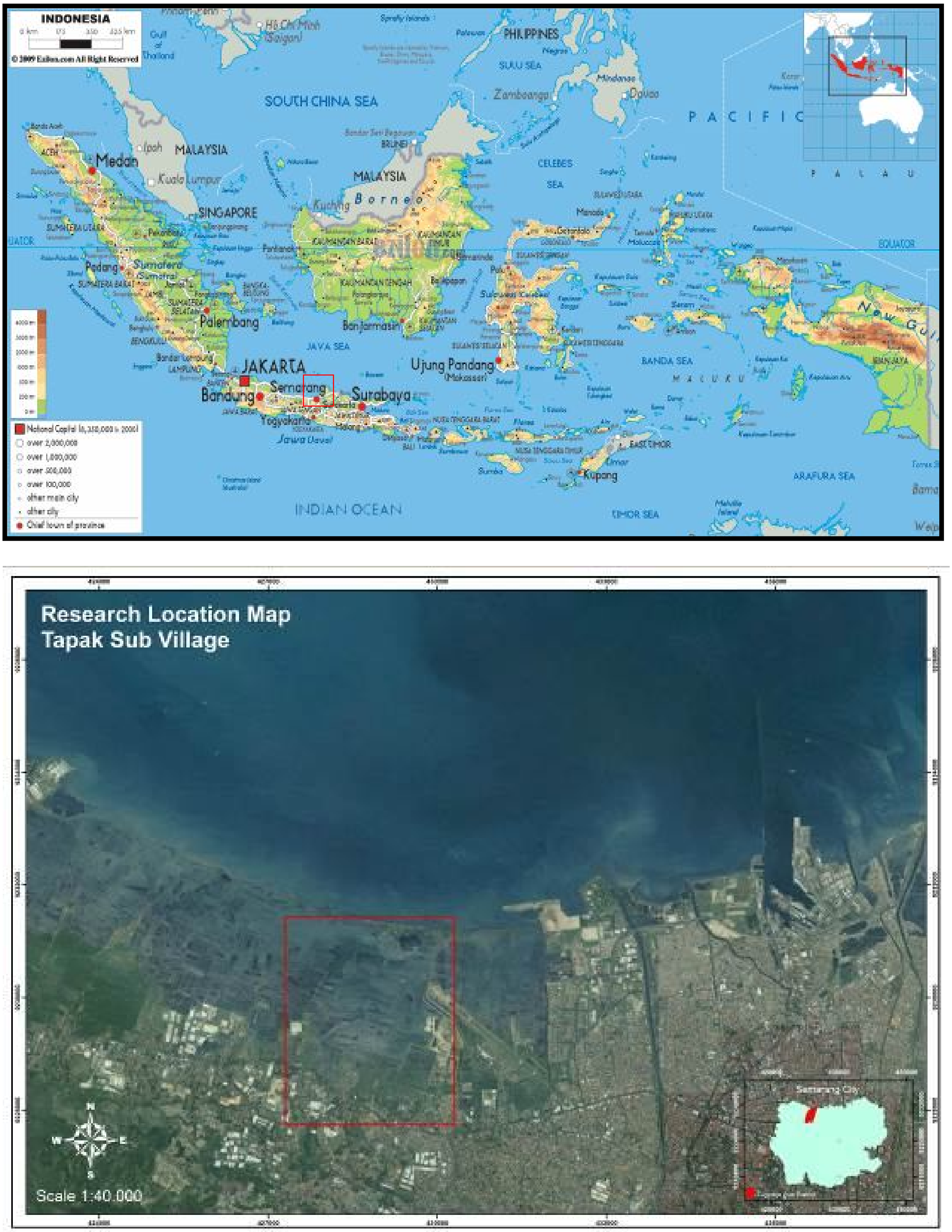

Figure 1. Research location (source: ezilon.com 2009 and google earth maps 2016).

Data analysis. The data collected in this study were analyzed based on data type, including soil carbon content analysis, biomass amount measurement and carbon stock calculation. Biomass measurements were analyzed by two approaches, i.e. allometric equation and destructive method (Prasetyo et al 2011). According to Hairiah et al (2001) destructive method was generally used for underground biomass measurement and stand types which do not yet have allometric values. Some allometry models of some mangrove trees species are showed in Table 1 (Research and Development Agency of Forestry Department 2013).

Table 1

Allometric models used in mangrove tree biomass estimation

Type of tree	*Allometric model*	*DBH*	R^2
Avicennia marina	$BBA = 0.1848\ D^{2.3524}$	6.4-35.2	0.98
Bruguiera gymnorrhiza	$\log BBA = -0.552+2.244 \log D$	5.0-60.9	0.99
Rhizophora apiculata	$\log BBA = -1.315+2.641 \log D$	2.5-67.1	0.96
Xylocarpus granatum	$\log BBA = -0.763+2.23 \log D$	5.9-49.4	0.95

Biomassa Bagian Atas (BBA) = Upper Part Biomass; D = Diameter at breast high (DBH) (Source: The Forestry Agency of Research and Development - BALITBANG (2013)).

Carbon stock estimation in stands/trees were calculated by first deriving the biomass value, and then multiplying by carbon fraction (appropriate value for the ecosystem type) to convert to carbon stock value (Smith et al 2006; Schöngart et al 2011). Where the specific carbon fraction value from an ecosystem type does not exist, the default IPCC value of 0.47 was used:

$$\text{Carbon stock} = \text{Carbon fraction} \times \text{biomass}$$

In this research we also calculated CO_2-equivalent using following equation:

$$CO_2\text{-equivalent} = (44/12) \times \text{carbon stock}$$

In addition, the bulk density and organic carbon measurement of the soil was analysed in the Balai Pengkajian Teknologi Pertanian (BPTP) (Center for Assessment and Study of Agricultural Technology) Laboratory of Central Java using Walkley & Black Method (Walkley & Black 1934).

Results and Discussion

Biomass content, carbon stock, CO_2 absorption by mangrove in Tapak Sub-village. The research results indicate total biomass value, carbon stock and CO_2 absorption of mangrove vegetation in Tapak Sub-village, Tugurejo Sub-district, Semarang in Table 2.

The research result showed that biomass content, carbon stock and CO_2 absorption of mangrove vegetation in Tapak Sub-village, in order of descending magnitude were in stations I, II, IV, V, III and VI. The carbon deposits per hectare obtained from each research station covering 314 m^2 yielded mangrove biomass content of 1507.91 ton ha^{-1} carbon stock was 708.2 ton C ha^{-1}, and able to absorb CO_2 of 2598.65 ton ha^{-1}. The highest biomass value (913.94 ton ha^{-1},) per plot came from *Avicennia marina* which is equal to a carbon content of 429.55 ton C ha^{-1}; because this mangrove species was distributed across all six research stations and covered the widest area, among the others.

Table 2 also indicates the biomass potential of the mangrove in Tapak Sub-village at each different station. Station I had the highest biomass potential (449 ton ha^{-1}), while Station VI had the lowest potential (30.4 ton ha^{-1}). This could be attributed to the fact that station I was located near the estuary, had a high density compared to other stations and had older stands. Correlation analysis reveal a strong relationship (r = 0.67) between mangrove density and mangrove biomass content (Figure 2).

Table 2

Biomass content, carbon stock, and CO_2 absorption in Tapak Sub-village

Station	*Mangrove species*	*Number of species*	*The stands biomass (ton ha^{-1})*	*Carbon stock (ton ha^{-1})*	*CO_2 - equivalent (ton ha^{-1})*
I (mangrove ecosystem	AM	113	449	211.03	773.78
II (river ecosystem)	RM	46	289.44	136.04	498.80
	AM	14	59.51	27.97	102.56
	Σ	60	348.95	164.01	601.36
III (fishpond ecosystem)	AM	28	113.43	53.31	195.48
IV (river ecosystem)	RM	64	247.48	116.32	426.49
	RS	13	57.05	26.81	98.32
	AM	9	43.02	20.22	74.14
	Σ	86	347.55	163.35	598.95
V (fishpond ecosystem)	AM	48	218.58	102.73	376.69
VI (fishpond ecosystem)	AM	51	30.4	14.29	52.39
Total		386	1507.91	708.20	2598.65

AM = *Avicennia marina*; RM = *Rhizhophora mucronata*; RS = *Rhizophora stylosa* (Source: Data analysis 2016).

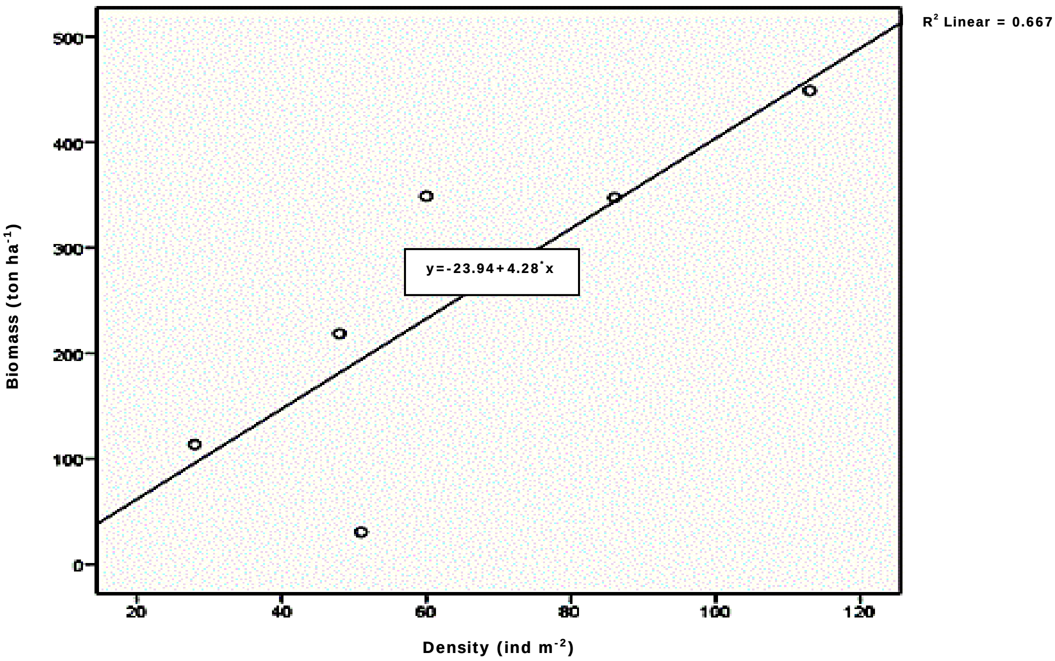

Figure 2. Correlation graph of mangrove density and the biomass content (Source: Data analysis, 2016).

Figure 2 explained that the mangrove density had positive correlation to the biomass content. In other words, the mangrove density is directly proportional to the biomass content of mangrove; the higher the mangrove density, the higher the biomass content.

Apart from tree density, the biomass value was also influenced by the diameter size of the tree, because the larger the tree diameter, the higher the biomass value (Mandari et al 2016). According to Syam'ani & Susilawati (2012), the biomass increased because the vegetation absorbs CO_2 in the atmosphere and transforms it to organic compound through photosynthesis process; resulting in vertical or horizontal growth, indicated by increased diameter and height. Through the photosynthesis process, CO_2 were absorbed by the vegetation with the help of sunlight. Thereafter, it was transformed into carbohydrate which was then distributed to the whole body of tree and stored in leaf, stem, branch, fruit and flower (Hairiah et al 2001).

Chanan (2012) stated that every addition of biomass content will be followed by the addition of carbon stock. This explains why carbon and biomass have positive relations; so anything which causes an increase or decrease in biomass will lead to an increase or decrease in carbon stock. High value of biomass at station I will be associatory with high carbon stock of mangrove, vice versa, low value of biomass at station VI will be accompanied with low carbon stock of mangrove. This is in line with Imiliyana et al's (2012) assertion that carbon stock percentage increases in line with the increase of biomass. This assertion is upheld in this study revealing positive maximum correlation value (r = 1.00) between biomass and carbon stock (Figure 3).

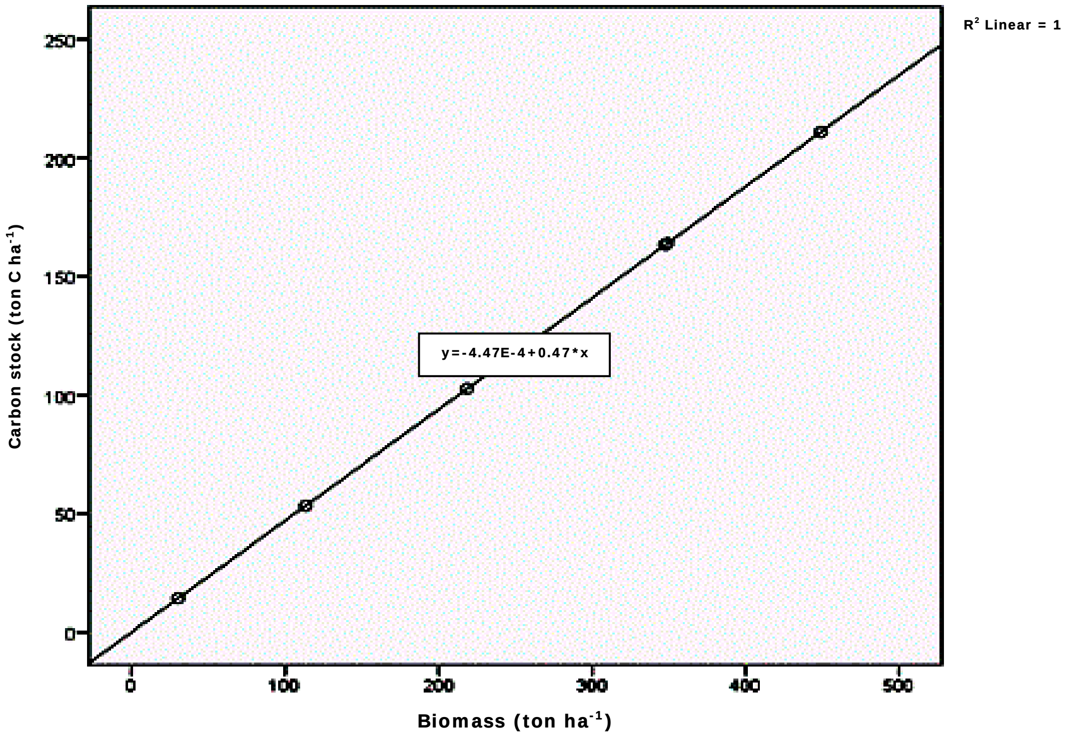

Figure 3. Correlation graph of biomass and carbon stock (Source: Data analysis, 2016).

Figure 3 elucidates the positive correlation between mangrove biomass and carbon stock content. In other words, biomass value is directly proportional to mangrove carbon stock. The higher the biomass value then the higher the carbon stock of mangrove.

Stem is part of wood and consists 50% of cellulose (Delmer & Haigler 2002). Cellulose is the main part of tough wall which covers vegetation cell and consists of linear sugar molecule in a long chain of carbon (Campbell et al 2008), so the higher the cellulose then the higher the carbon content value. It was estimated that the bigger the size of tree diameter the higher the potential that cellulose and other wood compounds will be larger. The high carbon in the stem is closely related to higher stem biomass when compared to other tree parts. This factor causes the larger diameter grade of the tree hence the carbon content will be larger.

Carbon is stored and incorporated into the forest vegetation in a process called sequestration process (C-sequestration). The carbon stock value incorporated in the life vegetation body (biomass) in a land describes the amount of CO_2 in the atmosphere absorbed by plants. CO_2 absorption is related to carbon stock (Heriyanto & Subiandono 2012). Research result of this study (Table 2), illustrates that mangrove ability to absorb CO_2 is directly proportional to carbon stock stored in the vegetation. The highest ability of mangrove to absorb CO_2 was recorded in station I (773.78 ton ha^{-1}), while the lowest ability was in station VI (52.39 ton ha^{-1}). Mangrove vegetation in station I recorded the highest CO_2 absorption capability owing to its high mangrove density supported by a large number of mangroves that had large stem diameters, while station VI recorded low mangrove density with incidence of mangroves with small stem diameters. In connection with this observation, Huy & Anh (2008) assert that vegetation's stem accounts for 62% of total accumulation of CO_2, branch 26%, bark/shell 10% and leaf 2%. Hence, CO_2 absorption is positively related to total number of mangrove biomass and carbon stock. This is further confirmed by the correlation analysis in this study which reveal maximum positive correlation value (r = 1.00), between carbon stock content with CO_2 absorption (Figure 4).

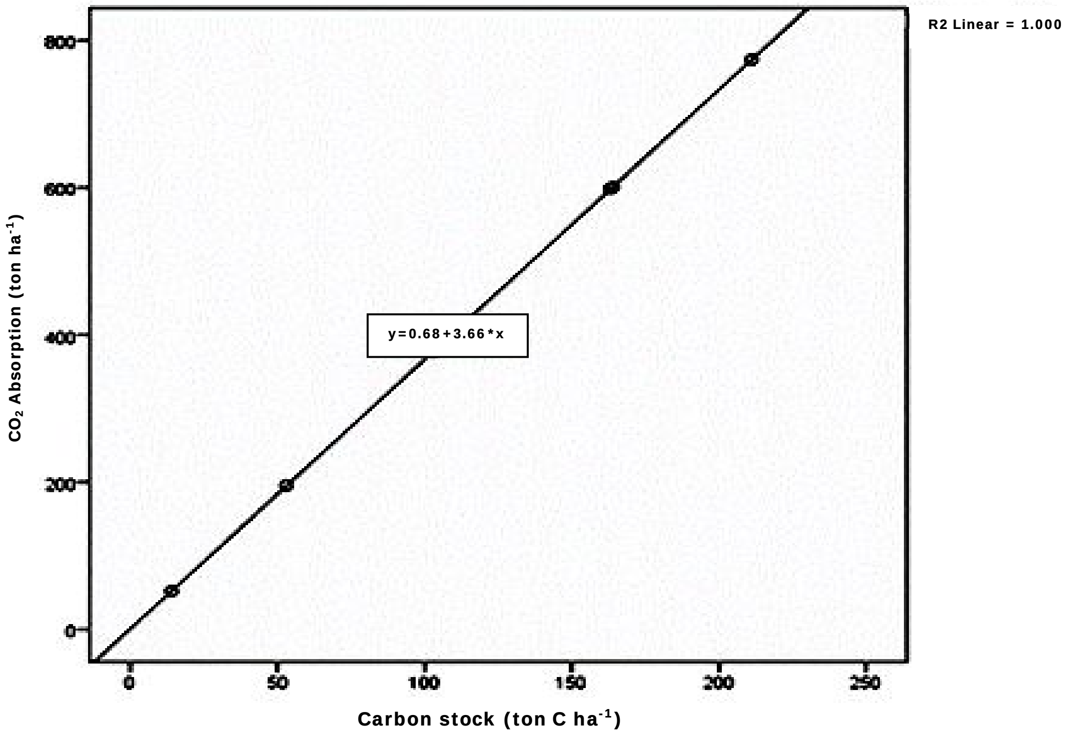

Figure 4. Correlation graph of carbon stock and CO_2 absorption (Source: Data analysis, 2016)

Figure 4 illustrates positive correlation between carbon stock content and CO_2 absorption of a mangrove stand. Thus it could be interpreted that CO_2 absorption will be large if the total stock was large. Vice versa, CO_2 absorption will be small if the carbon stock is small.

The average mangrove vegetation biomass in Tapak Sub-village from all of six research stations was 251.32 ton ha^{-1} contributing 118.03 ton C indicating that Kemujan Island, National Park of Karimunjawa with the highest mangrove vegetation biomass of 182.62 ton contributes about 91.31 ton C (Cahyaningrum et al 2014). The high output from the Kemujan Island could be linked to the environment quality of the area which favours its growth. Tapak Sub-village is a coastal area closed to industrial area that allows the existence of pollutants that can contaminate the environment. There are fourteen (14) industries around Tapak River which drain into Tapak Sub-village (Martuti et al 2016). Meanwhile, Xiao (2015) explained that industrial emissions consist of SO_2 (32%), NO_2 (18%), CO (20%), volatile organic compounds (VOC) (22%) and particulate matter (PM) (8%).

The CO_2 gas in atmosphere from industrial emission would be absorbed by the vegetation by photosynthesis process (Purba & Khairunisa 2012). Mangroves in coastal areas have high ability in reducing CO_2 emission. Hence, Nellemann et al (2009) stated that one of strategy to reduce CO_2 emission was the use of coastal ecosystem as CO_2 absorber which is known as *blue carbon*. Mangroves also play a role in reducing the amount of carbon in the air by absorbing CO_2 through the photosynthesis process, otherwise known as the sequestration process. The absorbed carbon is stored as tree biomass (Ardli 2012). The results of this study showed that the mangrove ecosystem in

Tapak Sub-village is effective in absorbing CO_2 in air, judging from the amount of biomass content and carbon stock stored in the vegetation.

Conclusions. In terms of ecosystem type, the highest mangrove biomass content was obtained from station I (449 ton ha^{-1}; mangrove forest), then station II (348.95 ton ha^{-1}; river ecosystem) and station III (115.35 ton ha^{-1}; fish pond ecosystem). Similarly, mangrove forest ecosystem recorded the highest carbon stock, then river ecosystem and the lowest was from fish pond ecosystem.

Acknowledgements. This research was funded by Ministry of Technology Research and Higher Education of Indonesia in 2016.

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Received: 14 September 2017. Accepted: 07 November 2017. Published online: 06 December 2017.
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How to cite this article:
Martuti N. K. T., Setyowati D. L., Nugraha S. B., Mutiatari D. P., 2017 Carbon stock potency of mangrove ecosystem at Tapak Sub-village, Semarang, Indonesia. AACL Bioflux 10(6):1524-1533.