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VEGETATION CARBON STOCKS OF 2 – 12 YEAR RESTORED MANGROVES IN NORTHERN SUMATRA COAST

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Abstract – Restored mangroves at 2, 4, 6, 8, 10 and 12 year old were studied through non-destructive method by measuring stem diameter and tree height of each tree. The objective of this study was to estimate vegetation carbon stocks and its sequestration estimated by three different allometries. The carbon values of restored mangroves were significantly different when it was estimated by different allometries. Average carbon stocks (2 – 12 years) in pond and riverine estimated by $D_{30}{}^2H$ had a higher value than its estimated by D_{30} and Destructive Allometry (DA). The carbon stock range in riverine(34.4 – 51.1 MgC ha^{-1}) was higher than the stocks in pond (33.6 – 42.4 MgC ha^{-1}). Carbon sequestration in riverine estimated by D_{30} increased 34.7% from 18.4 to 50.3 $MgCO_2e\ ha^{-1}\ yr^{-1}$ as the trees growing older. Restored mangroves in this site were able to succeed naturally and grow perfectly in ideal space (1,325 ind ha^{-1}). In contrast, carbon sequestration in pond showed a decreasing trend (-4.4%) from 21.9 to 17.1 $MgCO_2e\ ha^{-1}\ yr^{-1}$. Decreasing trend may relate to competitive factors among individual trees for phosysnthetic process when they grow in dense population (2,596 ind ha^{-1}). The decrease of carbon sequestration of high density restored mangroves is related to the factor of competition between each tree for photosynthesis. The dried twigs leading to dead trees mostly occured at the middle of dense mangroves in pond started at 8-10 years. Combined factors of less nutrient, unstable soil pH, very low salinity and high tree density may influence why the carbon sequestration in pond going to decrease when trees growing older. It is concluded that the carbon sequestration are more influenced by individual tree phenology, species, ideal space (400 – 500 ind ha^{-1}) between trees and their adaptation to different environment rather than by high density (>2,500ind ha^{-1}).

INTRODUCTION

Carbon sequestration is the process that involves carbon capture and long-term storage of carbon dioxide (CO_2) to mitigate or defer global warming (Sedjo *et al.,* 2012). Mangrove restoration is one of the rational options to mitigate the impacts of global climate change caused by carbon emmission from deforestation (Murdiyarso *et al.,* 2010). Mangrove restoration is a process of helping degraded ecosystem to the recovery condition and well protected (Society for Ecological Restoration International Science & Policy Working Group, 2004). The CO_2 stocks of mangrove ecosystem are stored at above ground and below ground biomass. Biomass measurement of each mangrove forest components is necessary to determine the above ground carbon stocks by multiflying the above-ground biomass component with the percentage carbon concentration that ussually less than 50% (Kauffman and Donato, 2012).

Mangroves have C4 pathways in carbon fixation process for photosynthesis (Clough *et al*., 1982), in which mangrove biomass productivity increases with increasing atmospheric CO_2 concentrations (Warrick *et al*., 1987). Restored mangroves at optimal hydrological and geomorphological sites create biomass, vegetation structure and productivity of mangrove forests up to 20 – 25 years old (McKee and Faulkner, 2000). The above ground biomass are stored in the stems, branches, fruits, flowers, above ground roots, litters and microbia. While the below ground biomass are stored at below ground roots and organic soil of sediments, and parts of them are decomposed on the food chain system (Hairiyah, 1997). The biomass of mangroves was influenced by age, species and locality (Komiyama *et al*., 2007). Above ground biomass is >500 Mg ha^{-1} for mangrove ecosystem at the riverine of Indo-Pacific (Kauffman *et al.,* 2011). The biomass of low density of mature mangroves will grow faster concomitant with increasing age (Ellison, 2008).

Mangrove restoration has been conducted in many sites in the world with various results. Restoration program in the study areas included *reforestation* – to replant mangroves at the degraded mangrove ecosystem and *afforestation* – to build new mangrove ecosystem at previously non-mangrove areas. The mangrove ecosystem restoration program in Northern Sumatra (Aceh, North Sumatra and Riau) has been validated and verified internationally as carbon credits for climate change mitigation.

Although the carbon stocks of mangroves have been described by many studies, most studies were carried-out mostly on natural mangrove forests and very rare studies on planted mangroves. Moreover, there is little known about carbon sequestration of serial age restored mangroves for climate change mitigation. A few studies were carried in the single age of restored mangroves. Ong *et al*. (1995) studied the productivity of a 20 year-old *Rhizophora apiculata*. The tree growth dynamics and productivity of mature mangroves were also studied in Malaysia (Putz and Chan, 1986). The 12 year-old planted *Rhizophora mucronata* in Kenya producing the standing biomass of 106.7 ± 24.0 ton $ha^{-1}$with accumulation rate of 8.9 ton ha^{-1} yr^{-1} (Kairo *et al*., 2008).

The inability to study the carbon sequstration at differents ages of mangroves is limited due to lack of age series of mangroves. To improve this understanding it is important to collect samples of different ages of restored mangroves. Started 2005, the restoration of degraded mangroves was carried in Northern Sumatra at a large scale and in a sustainable manner. Two species of *Rhizophora mucronata* and *R. apiculata* were used for restoration program. After 2 years planting, natural species regeneration of *Bruguiera sexangula, Avicennia marina, A. officionalis, Excoecaria agallocha, Xylocarpus granatum, Sonneratia alba* and *S. Caseolaris* occurred in restoration sites. Since the date of planting, the initial study of carbon stocks was carried on 2008 - 2009 in Northern Sumatra coast (Suprayogi *et al*., 2010).

The carbon sequestration of restored mangroves as an increase of mangrove ages was investigated. The specific objective was to determine the carbon stocks and its sequestration of restored mangroves at 2, 4, 6, 8, 10 and 12 years old. The data were analysed using three different allometries:(a) combined quadratic stem Diameter and tree Height variable Reference ($D_{30}{}^2H$), (b) stem Diameter variable Reference (D_{30}), and (c) Destructive Allometry resulted from destructive study (DA). This study also determined significant differences of carbon stocks and its sequestration of restored mangroves living in pond and riverine sub-ecosystems.

MATERIALS AND METHOD

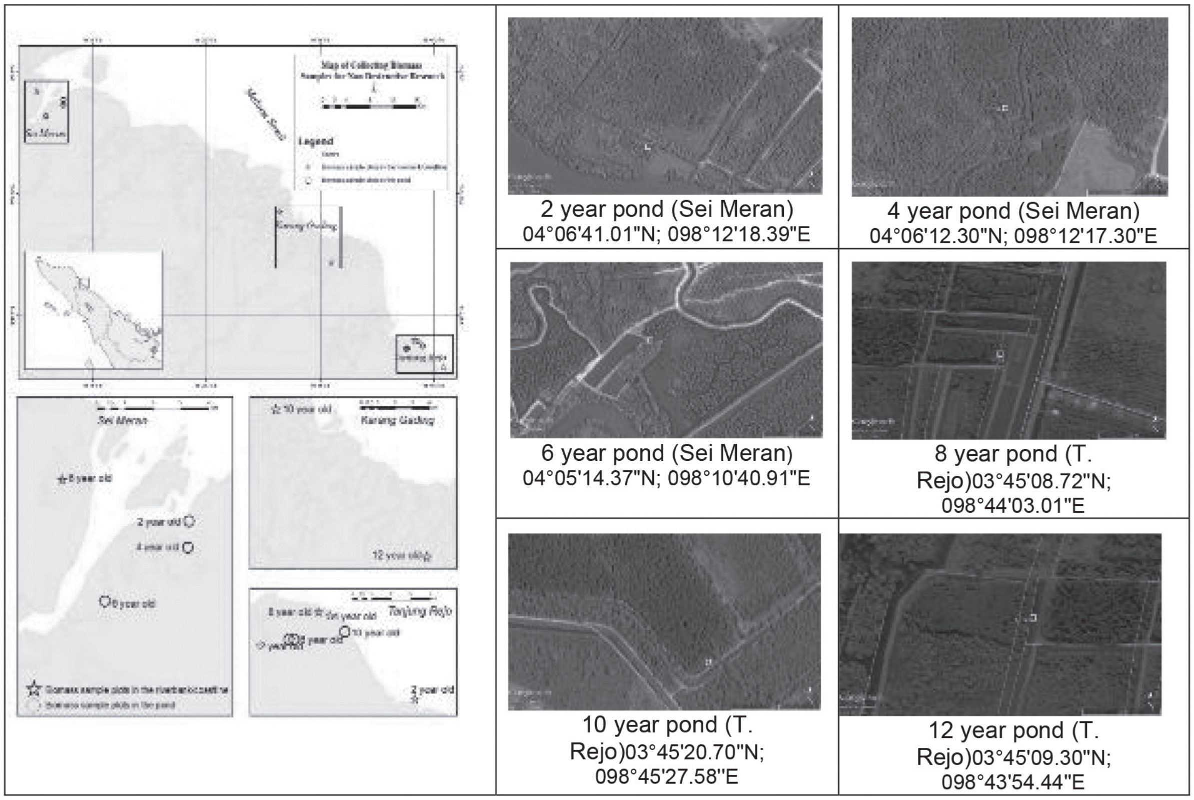
Study sites

Non-destructive study in pond sites was carried at the Northern Sumatra coast, located at the Tanjung Rejo village – Deli Serdang district, and Sei Meran village and Karang Gading village – Langkat district, representing 2, 4, 6, 8, 10 1nd 12 year planted mangroves (Annex 1). While, the non-destructive study at riverine sites representing similar ages of restored mangroves was also carried at the Northern Sumatra coast: Percut village and Tanjung Rejo village of Deli Serdang district, and Pangkalan Siata village, Jaring Halus village and Pangkalan Gading village of Langkat district.

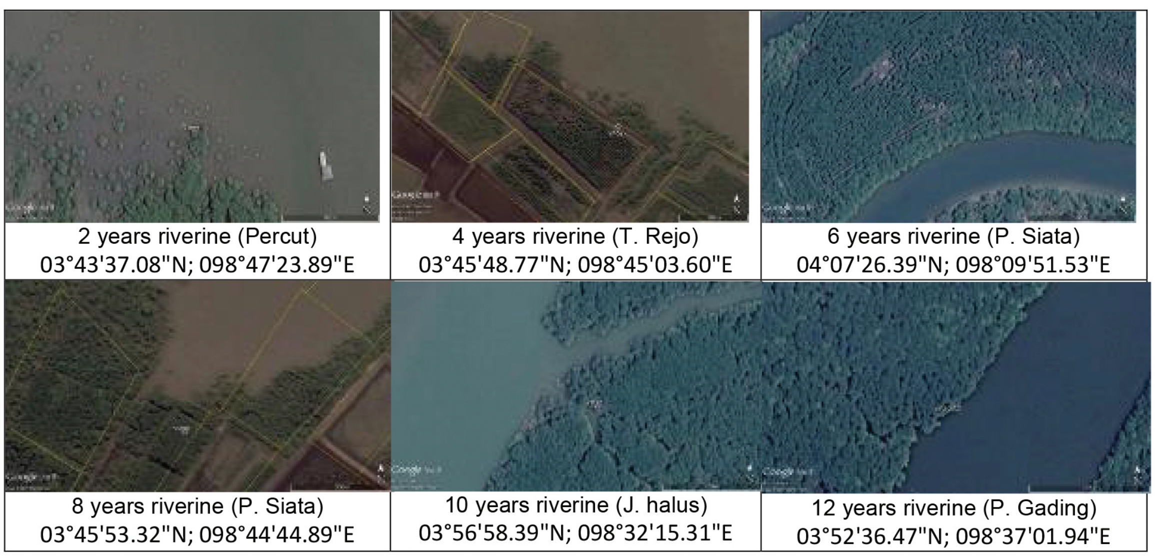
Plant culture

Propagules of *R. apiculata* and *R. mucronata* were collected from the nearest planting sites. When seedlings were 3 – 4 months old, they were transplanted in the study sites. Equal age *R. apiculata* mangrove seedlings were transplanted into pond, while *R. apiculata* and *R. mucronata* seedlings also planted at riverine sites. All planted mangroves were placed in the middle of pondand riverine to ensure all plants covered by intertidal zones. The planting was designed in the same distance between one to another to ensure each plot have simmilar density at the beginning of planting time.

To represent each mangrove age, five plots were

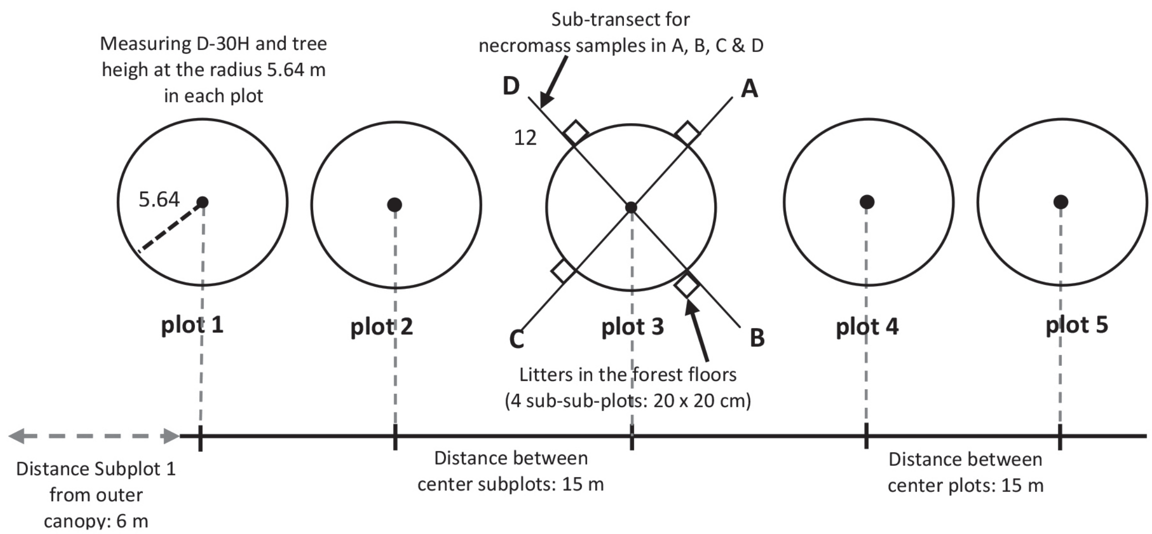


Annex 1. Non-destructive in pond sites



Annex 2. Non-destructive in riverine sites

established along a randomly transect in which each plot size was 100 m^2 (5.64 m radius), as seen in Annex 3. Species composition, tree density, basal area and important value index were quantified at each plot. All trees (2, 4, 6, 8, 10 and 12 years old) inside the plots were measured for stem diameter and tree height using non-destructive method. The stem diameter 30 cm above the highest prop-roots (D_{30}) were recorded for each tree in which each multi-stemmed tree was treated indivually. The height of each tree from the land-base to the top of canopy was also measured.



Annex 3. Non-destructive transect for biomass measurement

Sampling, measurement and data analysis

The field study was designed to measure the biomass of restored mangroves. The data collection was applied on restored mangroves of *Rhizophora apiculata* and *R. mucronata*, and the natural species regeneration such as *Avicennia marina, A. officionalis, Bruguiera sexangula, Excoecaria agallocha, Sonneratia alba, S. Caseolaris* and *Xylocarpus granatum*.

All data on stem diameter and tree height collected from the field were calculated using Excel software package. Linear and multiple regression were established for further data discussion. Comparisons between mean data ($p<0.05$) were analysed using the Excel Statistical package.

The aboveground and belowground carbon of each mangrove species were estimated using allometric equation of our destrutive study and then compared to carbon stocks exstimated by two allometric equations based on diameter (D_{30}) and quadratic diameter–tree height (D_{30}^2H) variables from previous studies, as seen in Annex 4.

Wood density of each mangrove species is*R. apiculata* 1.047, *S. alba* 0.800, *R. mucronata* 1.027 *E. agallocha* 0.509, *B. sexangula* 0.917, *A. marina* 0.817, *S. caseolaris* 0.509, *A. officinalis* 0.605, *X. granatum* 0.567 and *B. parviflora* 0.760 g cm^{-3} (ICRAF, 2010; Zanne *et al*., 2009).

The aboveground and belowground C-stocks (kg) of each mangrove species were determined by multiplying biomass content with precentage of carbon concentration (Kauffman and Donato, 2012). This study consistently used the default value of 0.47 carbon concentration for aboveground C-stocks (Kauffman and Cole, 2010) and 0.39 for belowground carbon stock calculation (Komiyama *et al*., 2008). All carbon stock estimation will be converted from kg into Mg (ton) per hectar (MgC ha^{-1}). Then, the C-stocks will be converted into CO_2e by multiflying C stocks with default value of 3.67 ($CO_2e = 3.67 * C$) based on the ratio of CO_2 (44) and C (12) molecular weights (Kauffman and Donato, 2012).

RESULTS AND DISCUSSION

Species composition

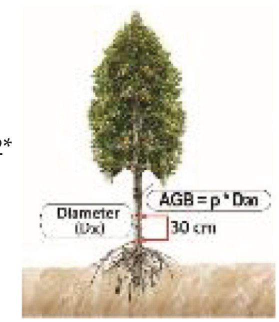
After growing several years, the planted *R. apiculata* in pond and *R. apiculata* and *R. mucronata* in riverine had a variety vegetation composition and structure. There were 6 species of natural growth found in pond sites, such as: *Avicennia marina*, *Bruguiera sexangula*, *Excoecaria agallocha, Sonneratia alba* and *S. caseolaris;* while 7 succession species found in riverine sites, such as: *Avicennia marina*, *A. officinalis, Bruguiera sexangula*, *B. parviflora, Xylocarpus granatum*, *Sonneratia alba* and *Excoecaria agallocha.* Open space and tidal pattern may give better access for non-*Rhizophora* species floating to the riverine sites. The species composition and vegetation structure are influenced by the sediment factors (Blasco, 1984).

Avicennia officinalis, *Xylocarpus granatum* and *Bruguiera parviflora* in study sites were naturally growing at riverine (fringe species) that are tolerance to high salinity and tidal pattern. *Sonneratia caseolaris* and *S. alba* were better growing

Annex 4. Three allometries used for above- and belowground carbon stocks of restored mangroves

a. The aboveground carbonbased on destructive study:
   - AGC (kg) = 0.0368*(D_{30}, cm)^2.5996 for *R. apiculata* aboveground carbon (kg)
   - Using biomass references * 0.47 from previous studies for aboveground carbon of other species (kg)
   - BGC = AGC/(shoot/root ratio) for belowground carbon (kg).

b. The aboveground carbon based on diameter variable from previous studies
   - *R. apiculata*carbon estimation(AGC, kg)from Kauffman dan Cole (2010):
     - if D_{30}<5.1 cm; AGC= 0.47*(0.0000695*((D_{30})^2.64412)*WD + 10^(-1.8571 +(2.1072* (LOG(D_{30})))) + 0.0000695*((D_{30})^2.64412)*WD*0.101
     - if D_{30}5.1 – 10.1 cm, AGC= 0.47*(0.0000695*((D_{30})^2.64412)*WD + 10^(1.8571+(2.1072* (LOG(D_{30})))) + 0.0000695*((D_{30})^2.64412)*WD*0.204
     - if D_{30} 10.1 – 20.1 cm, AGC =0.47*(0.0000695*((D_{30})^2.64412)*WD + 10^(-1.8571 +(2.1072* (LOG(D_{30})))) + 0.0000695*((D_{30})^2.64412)*WD*0.273
     - if D_{30}>20.1 cm, AGC=0.47*(0.0000695*((D_{30})^2.64412)*WD + 10^(-1.8571 + (2.1072* (LOG(D_{30})))) + 0.0000695*((D_{30})^2.64412)*WD*0.21
   - Aboveground carbon of other species using biomass references * 0.47(kg)

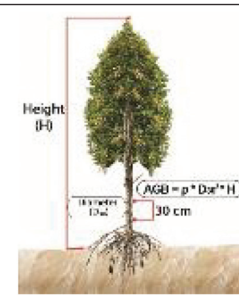


	Aboveground biomass (AGB, kg)		
Species	Leaf biomass	Stem and branch biomass	Referensces
B. sexangula	10^(-1,1679+(1,4914*(LOG(D_{30}))))	WD*0,0000754*(D_{30}^2,5)	Kauffman&Cole (2010)
X. granatum	10^(-1,1679+(1,4914*(LOG(D_{30}))))*WD	WD*0,0000754*(D_{30}^2,5)	Kauffman&Cole (2010)
B. parviflora	10^(-1,1679+(1,4914*(LOG(D_{30}))))*WD	WD*0,0000754*(D_{30}^2,5)	Kauffman&Cole (2010)
S. alba	10^(-1,1679+(1,4914*(LOG(D_{30}))))	WD*0,0003841*(D_{30}^2,1)	Kauffman&Cole (2010)
R. mucronata	10^(-1,8571+(2,1072*(LOG(D_{30}))))	WD*0,0000695*((D_{30})^2,64412) +	Kauffman&Cole (2010)
	if (D_{30}<5,1),	WD*0,0000695*((D_{30})^2,64412)*0,101	
	if (D30>5,D_{30}<10,1),	WD*0,0000695*((D_{30})^2,64412) *0,204,	
	if (D30>10,1,D_{30}<15,1),	WD*0,0000695*((D_{30})^2,64412)*0,356,	
	if (D30>15,D_{30}<20,1),	WD*0,0000695*((D_{30})^2,64412)*0,273,	
	jika (D_{30}>20,1)	WD*0,0000695*((D_{30})^2,64412)*0,21	Kauffman&Cole (2010)
E. agallocha	10^(-1,1679+(1,4914*(LOG(D_{30}))))	WD*0,0003841*(D_{30}^2,1)	Kauffman&Cole (2010)
S. caseolaris	10^(-1,1679+(1,4914*(LOG(D_{30}))))	WD*0,0003841*(D_{30}^2,1)	Kauffman&Cole (2010)
A. marina		0,308*D_{30}^2,11	Comley&McGuinness (2005)
A. officinalis		0,308*D_{30}^2,11	Comley&McGuinness (2005)

- Belowground carbon of species using biomass references * 0.39(kg)

Species	Belowground biomass (BCG, kg)	References
B. sexangula	0.0188*((D_{30}^2)*(D30/(((0.025*D_{30})+0.583)))^0.909	Tamai *et al.* (1986)
X. granatum	0.0188*((D_{30}^2)*(D30/(((0.025*D_{30})+0.583)))^0.909	Tamai *et al.* (1986)
B. parviflora	0.0188*((D_{30}^2)*(D30/(((0.025*D_{30})+0.583)))^0.909	Tamai *et al.* (1986)
S. alba	0.199*WD^0.899*$D_3$0^2.22	Komiyama *et al.* (2008)
R. mucronata	0.199*WD^0.899*D_{30}^2.22	Komiyama *et al.* (2008)
E. agallocha	0.199*WD^0.899*D_{30}^2.22	Komiyama *et al.* (2008)
S. caseolaris	0.199*WD^0.899*D_{30}^2.22	Komiyama *et al.* (2008)
A. marina	1.28*D_{30}^1.17	Comley&McGuinness (2005)
A. officinalis	1.28*D_{30}^1.17	Comley&McGuinness (2005)

c. Biomassof all species (AGB, kg) based on quadratic diamater and tree height variables:
   - AGB = 0.0509*ñ*(D)^2*H (Chave*et al.*, 2005) for aboveground biomass (kg)
   - BGB, = 0.39*0.199*WD^0.899*D_{30}^2.22 (Komiyama *et al*., 2008) for belowground biomass(kg).



in pond that leads to the maindland (hinterland). Both *Sonneratia* species were only found 35 individuals in riverine because theywere resintance to the salinity and tidal pattern.

As seen in Annex 5, the importance value index (IVI) of 2 – 12 years restored mangroves in pond sites s were *R. apiculata* (233.7%), *S. alba* (28.7%), *S. caseolaris* (22.0%, *A. marina* (6.5%), *B. sexangula* (4.1%), *R. mucronata* (2.6%) and *E. agallocha* (2.4%). While the restored mangroves in riverine created more new species with the importan value index of R. *apiculata* (215.0%), *R. mucronata* (34.5%), *E. agallocha* (13.5%), *A. officionalis* (12.4%), *B. sexangula* (8.7%), *Xylocarpus granatum* (4.9%), *Bruguiera parviflora* (4.5%), *S. alba* (3.7%) and *A. marina* (6.5%). The total IVI of *Rhizophora apiculata* in riverines (215.0%) was lower than in ex-ponds (233.7%). The IVI of *R. apiculata* in both sub-ecosystems was the highest compared to the other species because this species was used as main species on mangrove restoration both in pond and in riverine.

The importance value index of each species differed between in pond and riverine. The differences of IVI on the vegetation structure may relate to evapotranspiration physical process and mangrove canopy adaptation to the precipitation, and ability of absorbing CO_2 and sun radiation for photosynthetic process (Lima, 2013).

An increase of extreme air temperature may affect changes in species composition and plant phenology patterns as well as decrease propagul production required for mangrove breeding. This increase in salinity also affect declining biomass productivity, inhibiting the growth and resilience of mangrove seedlings, leading to competition among species as well as diminish mangrove ecosystem diversity and even the extinction of some mangrove species (Field, 1995; Ellison, 2000).

Number of trees and growth parameters

Number of trees, basal area, stem diameter and tree height may influence to mangrove carbon stocks in pond and riverine. Number of trees in pond (2,596 ind ha^{-1}) were almost twice compared to the trees in riverine (1,325 ind ha^{-1}). Number of trees in pond decreased as an increase of tree age (P<0,001). Fertilizer compounds used for aquaculture farming may affect better growth for restored mangroves in

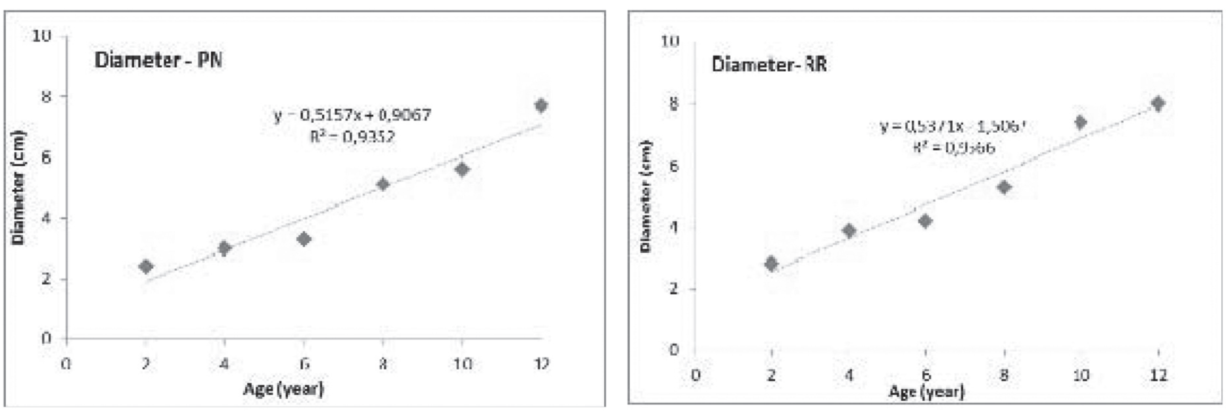


Fig. 1. Stem diameter growth of restored mangroves in pond and riverine

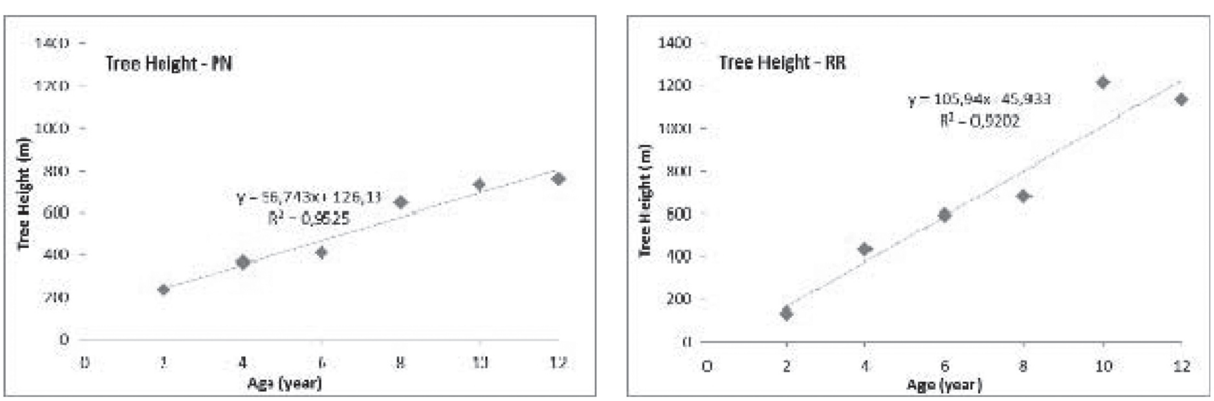


Fig. 2. Tree high growth of restored mangroves in pond and riverine

pond. The different on survival rate at both sub-ecosystems shows each individual tree need special density for their growth.

Sonneratia albav was uncutted species and remaining left during restoration process in ponds, therefore this species had a second number of trees (120 ind ha^{-1}) after *R. apiculata* and its basal area (25.4 m^2 ha^{-1}). While in riverine, *Rhizophora mucronata* was as asecond number of trees (120 ind ha^{-1}) and basal area (14.9 m^2 ha^{-1}) because this species was used for restoration materials. The differences on tree density and basal area from one area to the others are mostly influenced by human harverting factors rather than abiotic factors, salinity and tidal pattern (Menezes *et al*., 2003).

The growth parameters of restored mangroves were significant ($P<0.001$) indicated by increasing of stem diameter, tree height and canopy width. Average stem diameter in pond (4.5±0.1 cm) was lower than the diameter in riverine (5.6±0.4 cm). An increase in stem diameter in pond of 0.52 cm yr^{-1} (yD-EP = 0.5151x + 0.9067) didn't differ greatly from those grown on riverine 0.54 cm yr^{-1} (yD-RR = 0.537x + 1.5067).

The growth range of mangrove stem diameter of this study (0.52 – 0.54 cm yr^{-1}) was higher than *Rhizophora mangle* stem (0.33 cm yr^{-1}) growing at exposed sea tides in Braganca Peninsula, Northern Brazil (Menezes, *et al*., 2003). Growth diameter of mangrove stem in Northern Brazil reached the lowest point (0.12 cm yr^{-1}) at monthly rainfall <50 mm. This suggests that mangrove growth is not only influenced by abiotic factors and competition among individuals and species but it is also influenced by local climate factors.

Average tree height of 2-12 year trees in riverine (6.96 m) was higher than the height in pond (5.24 m). In general, the tree high growth of restored mangroves located in pond and riverine increase along with the increase in plant life. An increase of tree height on riverine (1.06 cm yr^{-1}) is almost 2 times of tree high increase in pond (0.57 cm yr^{-1}). Finding of Cintron *et.al*. (1978) mentioned that the tree high growth of mangrove forest in Puerto Rico was inversely related to an increase of sediment salinity through the allometric equation: $Y = -0.2 X + 16.58$ ($R^2 = 0.72$) and no-mangroves can live in salinity 70-80 ppt.

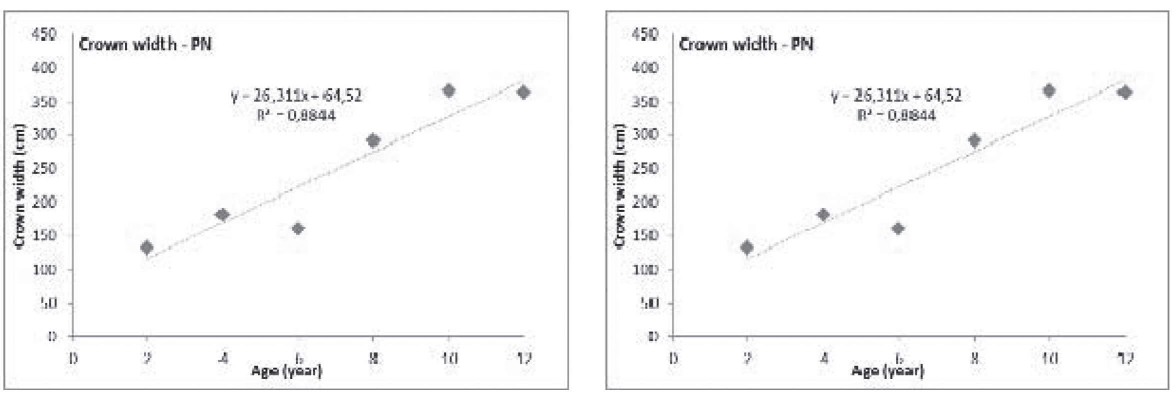


Fig. 3. Crown width growth of restored mangroves in pond and riverine

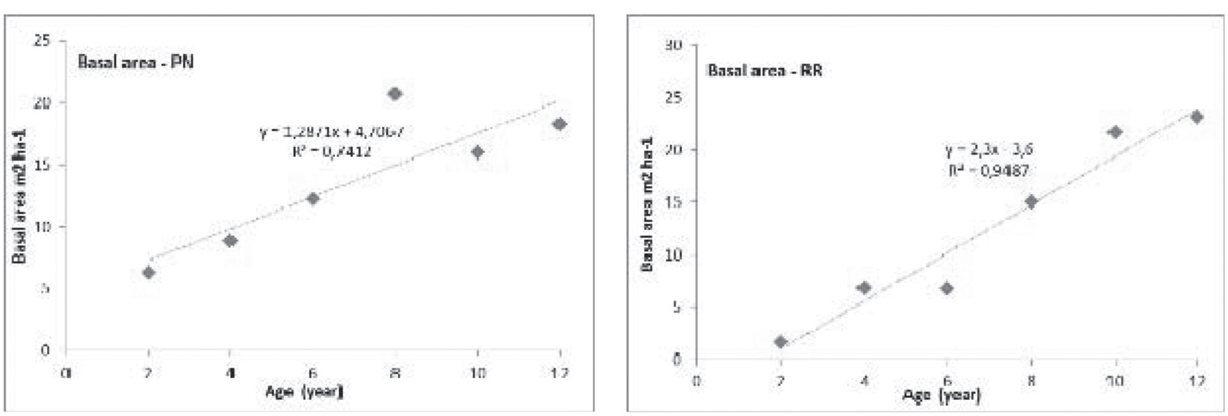


Fig. 4. Basal area growth of restored mangroves in pond and riverine

Annex 5. Number of Trees (NT), Basal Area (BA) and Important Value Index (IVI) of each species restored mangrove in pond and riverine

No	Spesies	NT (ind ha^{-1})				BA (m^2 ha^{-1})		IVI(%)	
		Po	%	Rr	%	Po	Rr	Po	Rr
1	*R. apiculata*	2,383	91.8	1,068	80.6	363.7	327.2	233.7	215.0
2	*S. alba*	120	4.6	1	0.1	25.4	6.6	28.7	3.7
3	*R. mucronata*	4	1.2	154	11.6	2.6	14.9	2.6	34.5
4	*E. agallocha*	3	0.1	27	2.0	2.2	7.5	2.4	13.5
5	*B. sexangula*	7	0.3	26	2.0	1.1	4.2	4.1	8.7
6	*A. marina*	7	0.3	1	0.1	3.5	3.1	6.5	2.8
7	*S. caseolaris*	72	2.7			13.2		22.0	
8	*A.officinalis*			40	3.0		6.8		12.4
9	*X. granatum*			5	0.4		2.8		4.9
10	*B. parviflora*			3	0.2		1.9		4.5
	Total	2,596	100	1,325	100.0	411.7	375.1	300.0	300.0

Po = Pond; Rr = Riverine; NT = Number of trees (ind ha^{-1}); BA = Basal Area (m^2 ha^{-1}); IVI = Important Value Index(%); n-plot = 60

Eventhough stem diameter and tree height increased as increasing of tree age, the crown widegrowth varied and didn't follow the rules of tree age. In opposite to stem diameter and tree height, the crown width at 2-12 year restored mangroves in riverine (242.0 cm) was little bit lower than that in ponds (248.7 cm). Moreover, an average increase of canopy width in pond 26.3 cm yr^{-1} (yTH-RR = 26.311x + 64.52) was more than 2 times crown width increase on riverine 11.1 cm yr^{-1} (yTH-EP = 11.08x + 164.51).

Average basal area in pond (13.7m^2 ha^{-1}) was statistically not different with the basal in riverine (12.5 m^2 ha^{-1}), however an increase of basal area at riverine(23.3 m^2 $ha^{-1}yr^{-1}$; y= 2.3x – 3.6) was higher than in pond(13.3 m^2 $ha^{-1}yr^{-1}$; y= 1.2871x + 4.4067). Average increase of basal area in this study was higher than an increase basal area of *Sonneratia alba* (7.0 – 79.6 cm^2 yr^{-1}) and *Bruguiera gymnorhiza* (4.8 – 27.4 cm^2 yr^{-1}) living at natural mangrove forest in Micronesia (Krauss *et al.*, 2007).

The basal area in riverine (23.3 m^2 ha^{-1}) in this study was slightly different with basal area (23.97 m^2 ha^{-1}) of other 2 – 12 year non-destructive study in Maluku, Eastern Indonesia (Komiyama *et al*., 1988); basal area (23.97 m^2 ha^{-1}) in Ranong – Southern Thailand (Tamai *et al*., 1986); and basal area (29.5 m^2 ha^{-1}) in Talidendang–Riau, Eastern Sumatra (Kusmana *et al*., 1992). The differences of basal area are significatly influenced by the hydro-geomorphology sites where mangrove grow. Vegetation structure, growth parameters and basal area were influenced by salinity level of mangrove sediment (Cintron *et al*., 1978).

The shoot/root ratio was inversely with growth parameters in which it decreased when the trees growing older. Shoot/root ratio of restored mangroves in pond 1.07±0.02 (y = 1.6648$x^{0.256}$) was higher than in riverine 0.98±0.03 (y = 1.6401$x^{0.276}$). It means that rooting system in pond is more intensive

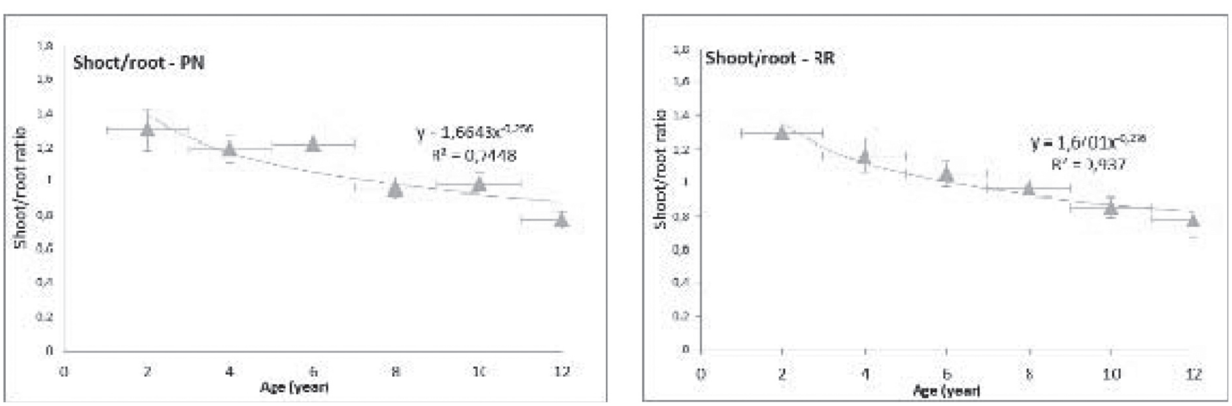


Fig. 5. Shoot/root ratio growth of restored mangroves in pond and riverine

Table 1. Average carbon stocks of 2- 12 year restored mangroves in ideal and actual condition estimated by three allometries in pond and riverine

Allometries	Average carbon stocks (MgC ha^{-1})					
	Ex-ponds			Riverines		
	Ideal	Actual	Lost	Ideal	Actual	Lost
$D_{30}{}^2H$	49.5	46.9	2.6	58.4	56.7	1.6
D_{30}	45.3	41.5	3.8	46.2	44.3	2.0
DA	36.6	33.6	3.0	36.0	34.4	1.6
D_{30}-DA	8.7	7.9		10.2	9.9	
$D_{30}{}^2H$-DA	12.9	13.3		22.4	22.3	

n-plot = 60

and expansive than in riverine. The expansive root system in pond because of change land cover from open space into vegetative space in which mangrove trees easily take nutrients with wider rooting system.

The shoot/root ratios of restored mangroves in pond significantly decreased 6.7% per year during the life span of 2 – 12 years: from 1.30±0.12 at 2-yearto 1.19±0.08 at 4-year; 1.22±0.03 at 6-year; 0.96±0.06 at 8-year; 0.98±0.07 at 10-year and 0.77±0.05 at 12-year old. Similarly, the shoot/root ratio in riverine also significantly decreased 6.5%: from 1.29±0.04at 2-year to 11.16±0.10 at 4-year; 1.05±0.08 at 6-year; 0.96±0.01 at 8-year; 0.85±0.06 at 10-year and 0.78±0.11 at 12-year old.

Vegetation carbon stocks

Vegetation components (leaves, fruits, flowers, twigs, branches, stems, stumps and proof-roots), and mangrove soil are very effective at absorbing and storing CO_2 (Hairiyah, 1997). Therefore, carbon stocks are available at above ground and belowground of mangrove ecosystem. The above ground carbon stocks were estimated based on three different allometries (Annex 4). Those three allometries had high correlations (>90%) of carbon

Annex 6. Number of trees and basal area ofof restored mangroves in pond and riverine

Age	Number of trees (ind plot^{-1})			Basal Area (m^2 ha^{-1})		
(years)	Po	Rr	SL	Po	Rr	SL
2	105 a ± 29	23 b ± 3	**	6.3 b ±3.1	1.6 a ±0.5	*
4	98 a ±19	50 b ±11	**	8.8 a ±2.1	6.8 a ±2.7	TN
6	131 a ±18	43 b ±13	**	12.2 a ±1.4	6.7 b ±2.4	**
8	94 a ±23	63 b ± 09	**	20.7 a ±4.1	15.0 b ±2.5	**
10	55 a ±11	43 a ±15	TN	16.0 b ±2.0	21.7 a ±5.5	**
12	38 a ±12	43 a ±12	TN	18.3 b ±5.4	23.2 a ±1.7	**
Average	87 a ±7	44 b ±4	**	13.7 a ±1.5	12.5 a ±1.7	TN

Po = Pond; Rr = Riverine; n-plot = 60; SL = Significant Level; NS = Not Significant; * = Significant level at α 5%; ** = Significant level at α 1%

Annex 7. Stem diameter and tree height of of restored mangroves in pond and riverine

Age	Stem diameter (cm)			Tree height (m)		
(years)	Po	Rr	SL	Po	Rr	SL
2	2.4 a ± 0.3	2.8 a ± 0.3	TN	2.3 a ±1.1	1.3 b ±0.4	**
4	3.0 a ± 0.1	3.9 a ± 0.4	TN	3.6 b ±1.0	4.3 a ±0.6	**
6	3.3 b ± 0.2	4.2 a ± 0.3	*	4.1 b ±0.9	5.9 a ±0.5	*
8	5.1 a ± 0.7	5.3 a ± 0.2	TN	6.4 a ±1.1	6.8 a ±0.9	TN
10	5.6 b ± 0.5	7.4 a ± 0.6	**	7.3 b ±1.8	12.1 a ±0.6	**
12	7.7 a ± 0.5	8.0 a ± 2.0	TN	7.6 b ±0.5	11.3 a ±4.2	**
Average	4.5 b ± 0.1	5.6 a ± 0.4	**	5.2 b ± 0.4	7.0 a ±1.5	**

Po = Pond; Rr = Riverine; n-plot = 60; SL = Significant Level; NS = Not Significant; * = Significant level at α 5%; ** = Significant level at α 1%

stocks to the independent variables of stem diameter and tree height. The above- and below ground carbon stocks of restored mangroves in pond and riverine can be seen in Annex 9, Annex 10 and Annex 11.

The cabon stocks of 2, 4, 6 and 8 year restored mangroves using Destructive Allometry (DA) significatly increased from 15.5 to 23.1; 26.9; 49.1 MgC ha-1, but after 10 and 12-years decreased to 40.2; and 46.6 MgC ha^{-1}. While the trend of carbon stocks at riverine significantly increased as an increase of tree age from 3.7 to 17.5; 16.0; 40.0, 63.6 and 65.5 MgC ha^{-1}.

The carbon stocks of 2 – 12 year restored mangroves estimated by three allometries showed significant different values. The riverine stocks of 2, 4, 6 and 8 year old were lower than in pond, however the stocks after 8-years in riverine are bigger compared to the stocks in pond. Field evidences showed that the 8 – 12 year restored mangroves living on the middle ponds had higher density but its diameter were smaller compared to those mangroves in riverine. In contrast, the restored mangroves at riverine grew naturally that allow natural succession among individual trees and between the species. For longterm management, it is suggested to conduct a selective cutting to the restored mangroves in pond after 8-10 years in order to maintain each tree having enough space for their growth.

The percentages of belowground carbon stocks in this study were 55.35% in pond and 57.56% in riverine. These belowground precentages were consistent with belowground mangrove forest precentages from Tamooh *et al*. (2008) study that ranging from 30 to 60%, but it was higher than *Avicennia marina* belowground carbon (26,41%) in Thane creek, Maharastra, India (Pachpande and Pejaver, 2015). The different balance of above ground and below ground biomass productivity may be influenced by individual and species composition sensitivity to the biotic and abiotic factors and local climate where the mangrove grow.

In general, the carbon stocks of restored mangroves at all age level estimated by the Diameter-Height Reference (D_{30}^2H) in pondand riverine were mostly highest compared to the stocks estimated by Diameter Refence (D_{30}) and Destructive Allometry (DA). However, the stocks at 2-year mangroves estimated by D_{30}^2H in pond (12.7± 0.2MgC ha^{-1}) and in riverine (2.6± 0.1MgC ha^{-1}) were lower than the stocks estimated by D_{30}in pond (16.6±

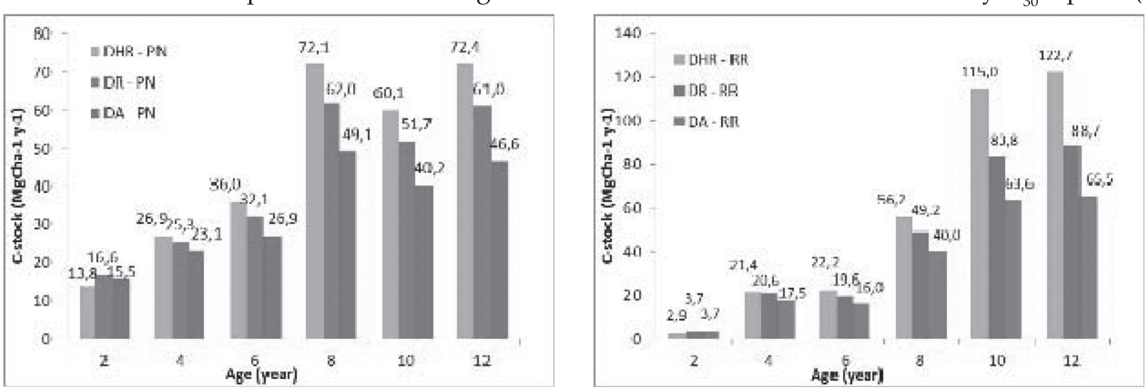


Fig. 6. Carbon stocks in pond and riverine

Annex 8. Crown width and shoot/root ratio of restored mangroves in pond andriverine

Age (years)	Crown width (cm)			Shoot/root ratio		
	Po	Rr	SL	Po	Rr	SL
2	131.8 a ±44.7	88 b ±30.6	**	1.30 a ±0.12	1.29 a ±0.04	NS
4	181.1 b ±63.0	299.5 a ±59.9	**	1.19 a ±0.08	1.16 a ±0.10	NS
6	159.2 b ±31.6	269.8 a ±11.0	**	1.22 a ±0.03	1.05 b ±0.08	*
8	291.6 a ±89.1	264.5 b ±61.5	**	0.96 a ±0.06	0.96 a ±0.01	NS
10	365.4 a ±6.0	266.8 b ±130.7	**	0.98 a ±0.07	0.85 b ±0.06	**
12	363.1 a ±37.8	263.8 b ±132.2	**	0.77 a ±0.05	0.78 a ±0.11	NS
Average	248.7 a ±28.4	242.0 b ±50.5	*	1.07a ± 0.03	1.02 b ± 0.04	**

Po = Pond; Rr = Riverine; n-plot = 60; SL = Significant Level; NS = Not Significant; * = Significant level at α 5%; ** = Significant level at α 1%

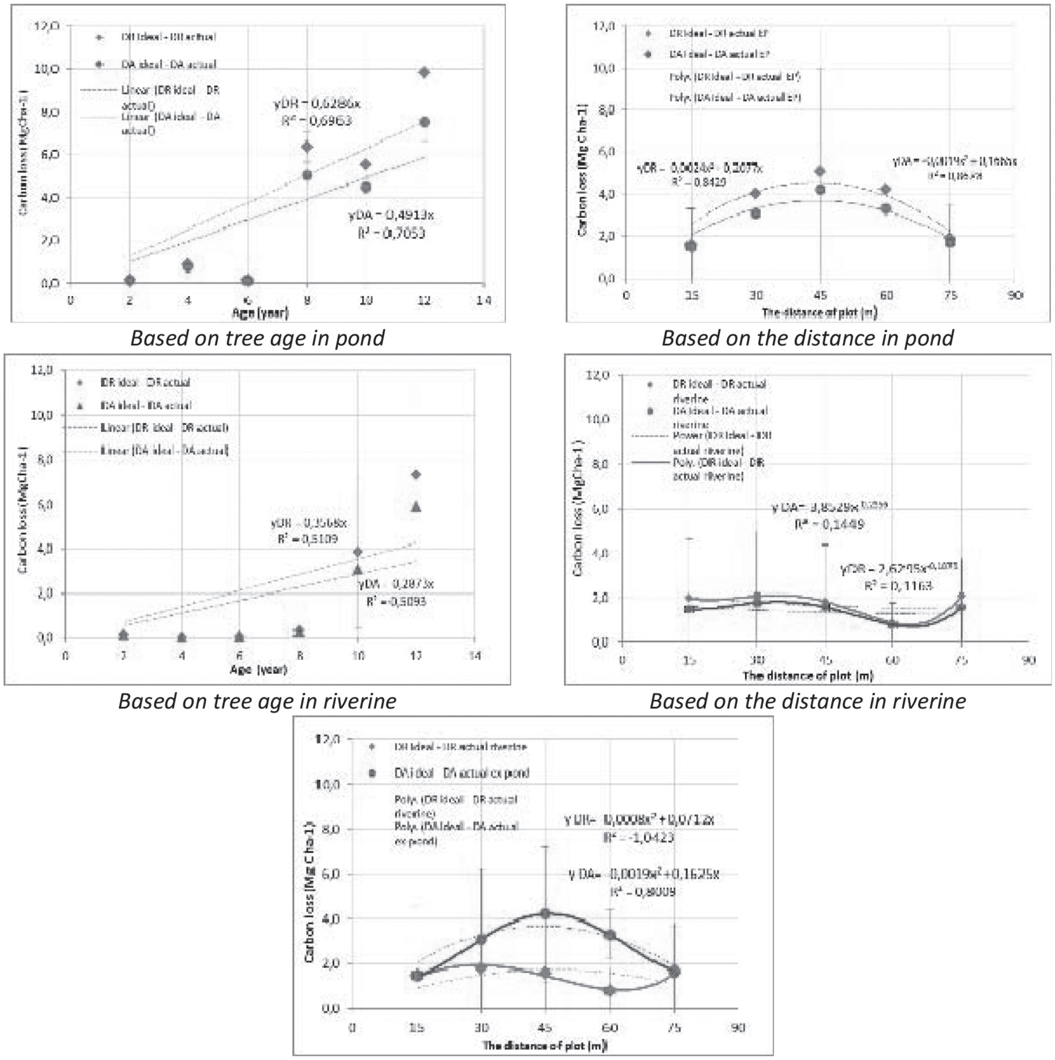


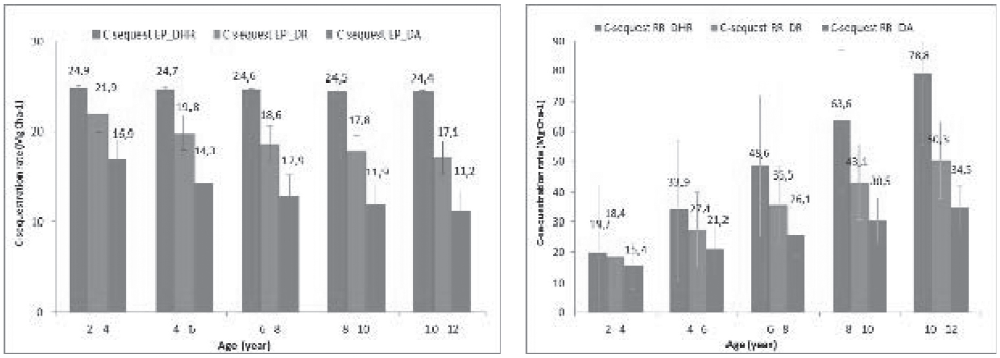
Fig. 7. Average lost of carbon based on tree age and distance in pond and riverine

0.1MgC ha^{-1}) and in riverine (3.7± 0.1MgC ha^{-1}). Average carbon stocks (2 – 12 years) in pond estimated by D_{30}^2H(42.4 ± 0.6Mg C ha^{-1}) was also higher than its estimated by D_{30}(41.5 ± 0.1Mg C ha^{-1}) and by DA (33.6 ± 0.4MgC ha^{-1}).

Similarly, the carbon stocks of restored mangroves at all age level estimated by the Diameter-Height Reference (D_{30}^2H) in riverine were mostly highest compared to the stocks estimated by Diameter Refence (D_{30}) and Destructive Allometry (DA). The average carbon stocks (2 – 12 years) in riverine estimated by D_{30}^2H(51.1 ± 1.5MgC ha^{-1}) was higher than its estimated by D_{30}(44.3 ± 0.4MgC ha^{-1}) and by DA (34.4 ± 1.0MgC ha^{-1}). Among three allometries used, the carbon stock range in riverine (34.4 – 51.1 MgC ha^{-1}) was higher than the stock range in pond (33.6 – 42.4MgC ha^{-1}).

An increase in vegetation carbon stocks that correspond to an increase of biomass was induced by the development of mangrove trees. The increase of mangrove carbon stocks in this study was also consistent with Alongi (2011) modified from Clough *et al* (1999) that show the biomass of *Rhizophora apiculata* in the Mekong delta, Vietnam still increase until 40-year old. The development of mangroves along the French Guiana was divided into 3 stages: early development (0-15 years), maturity (15-70 years) and senescence (after 70 years). Therefore mangrove ecosystem can effectively accumulate carbon until 70-year old (Alongi, 2011 modified from Fromard *et al.*, 1998).

The aboveground carbon stocks of this study



Pond Riverine

Fig. 8. Carbon sequestration of restored mangroves estimated by three allometries in pond and riverine

estimated by three allometries were much lower than the carbon stocks (123 MgC ha^{-1}) dominated *Rhizophora* mangrove forest in Hinchinbrook Chanel, Australia (Matsui, 1998). The differences of vegetation carbon stocks between this study and other references may be due to the different of tree ages being measured.

Carbon lost

In estimating the carbon lost, each tree component in the sampling plots was observed individually and then the plots divided into two categories: (1) ideal condition ifit was 100% no damage on tree components, and (2) actual condition if some tree components were damage or missing (97.5%if no leaves, 80% if no leaves and twigs, 30% from ideal condition if remaining stemonly).

Average actual carbon stocks (2 – 12 years) in pond estimated by $D_{30}{}^2H$ (46.9MgC ha^{-1}) was higher than its estimated by D_{30}(41.5MgC ha^{-1}) and by DA (33.6 MgC ha^{-1}). The average actual carbon stocks (2 – 12 years) in riverine estimated by $D_{30}{}^2H$(56.7 MgC ha^{-1}) was also higher than its estimated by D_{30}(44.3MgC ha^{-1}) and by DA (34.4 MgC ha^{-1}). Among three allometries used, the carbon stock range in riverine (34.4 – 56.7 MgC ha^{-1}) was higher than the stock range in pond (33.6 – 46.9 MgC ha^{-1}).

Graphs and tables of ideal-, actual and lost of carbon stocks of restored mangroves can be seen Annex 12, Annex 13, Annex 14 and Annex 15. The carbon stock difference at actual condition between D_{30} with DA estimation was 7.9 MgC ha^{-1} (19%) in pond and 9.9 MgC ha^{-1} (23%) in riverine; and between $D_{30}{}^2H$ with DA estimation was 13.3 MgC ha^{-1} (21%) in pond and 22.3 MgC ha^{-1} (33%) in riverine. It means that carbon estimation using destructive allometry has conservative value compared to the other references. This conservative value will be a strenght of destructive allometry that is able to illustrate the real condition in the field and

Annex 9. Above- and belowground carbon stocks of restored mangroves in expond and riverine using Destructive Allometry (DA)

Tree age	Belowground carbon stocks (BGC)(MgC ha^{-1})				Aboveground carbon stocks (AGC)(MgC ha^{-1})				Total carbon stocks (MgC ha^{-1})				
	Pond		Riverine		Pond		Riverine		Pond		Riverine		
	X	±sd	X	±sd	X	±sd	X	±sd	X	±sd	X	±sd	SL
2 years	6.6	± 3.2	2.0	± 0.6	8.9	± 5.6	1.7	± 0.6	15.5 a	±8.8	3.7 b	± 1.2	**
4 years	10.4	± 3.7	8.6	± 3.6	12.7	± 5.1	8.9	± 4.5	23.1 a	±8.8	17.5 b	± 8.0	**
6 years	14.1	± 1.7	7.8	± 2.7	12.8	± 1.5	8.2	± 3.1	26.9 a	±3.2	16.0 b	± 5.8	**
8 years	22.4	± 5.5	18.4	± 2.6	26.8	± 6.9	21.7	± 2.0	49.1 a	±12.4	40.0 b	± 4.5	**
10 years	17.3	± 2.8	25.6	± 5.0	22.9	± 1.7	38.1	± 7.7	40.2 b	±4.5	63.6 a	± 12.5	**
12 years	19.4	± 4.7	25.2	± 1.8	27.2	± 6.6	40.3	± 2.3	46.6 b	±11.2	65.5 a	± 4.0	**
Average (2-12 years)	15.0	± 1.4	14.6	± 1.5	18.5	± 2.4	19.8	± 2.5	33.6 a	±3.6	34.4 a	±3.9	NS

R. apiculata estimation AGC = 0.0368*(D_{30})^2.5996, AGC and BGC other species using references at Annex 4; X = average; sd = deviation standard; SL = Significant Level;
NS = Not Significant; * = Significant at α 5%; ** = Significant at α 1%; n-plot = 60

will be not over-prediction in estimating carbon stocks on specific site.

Carbon lost estimated by three allometrics in pond and riverine mostly increase when the restored mangroves growing up. The carbon lost of 2, 4 and 6 year restored varied from 0.0 – 0.7 MgC ha^{-1}, while carbon lost at 12 year old is the bigest (5.3 – 9.8 MgC ha^{-1}) among others. These evidences showed that the older restored mangroves were fragile from carbon lost because local communities prefered to cut trees after 12 year old for several purposes.

Acces to restored mangroves is one of important factors of lossing carbon where the mangroves within walking distance are fragile from illegal cutting. The average carbon lost based on D_{30} in pond (3.8 $MgCha^{-1}$or 8.39%) was almost twice significantly higher ($P<0.05$) than the lost in riverine (2.0 $MgCha^{-1}$ or 4.33%). Local communities prefered to cut the old trees at the distance of ±45 m from edge of pond and ±60m from edge of riverine. However, local people prefer to cut trees at the middle of pond or riverine community rather than its edge to eliminate evidences. These carbon lost can not avoided but it can be minimized through awareness program and law-enforcement.

Carbon stocks of necromass and litters

Mangroves produce necromass and litters from fallen dead branches, twigs, fruits, flowers and leaves to the ground. The litters will be as food sources for macro- and micro fauna and if are not consumed by fauna they will be decayed and become organic soil matrerials. However, around 50% litters will flow to the sea and contribute 10 – 11% carbon inputs at the sea (Alongi, 2014).

As seen in Annex 16, the necromass in pond increased as increasing of tree age, except at 12-year old. However, the increase of necromass in riverine didn't follow the tree age rule. Moreover, the carbon stocks of litters didn't increase as an increase of tree age and it was variable on each age group. Necromass and litter productivity from fallen twigs, leaves and other biomass were influenced by air humidity of mangrove ecosystem (Kaunang and Medellu, 2013). Average carbon stocks of 2 – 12 year necromass in pond and riverine were not significantly different with litter carbon stocks and their values were less than 1 MgC ha^{-1}. Due to very small amount, the carbon stocks of necromass and litters will not be included on the calculation of total carbon stocks of mangrove vegetation in this study.

Carbon sequestration of 2-12 year restored mangroves

Carbon sequestration (carbon absorption rate) is calculated based on difference or increment of carbon stocks divided by the time different to collect and store them in the ecosystem. Carbon sequestration in this study is an ability of mangrove tree to absorb and storage $CO_2$from the atmosphere into tree component and sediment that calculated annually ($MgCO_2e$ ha^{-1} yr^{-1}) for climate change mitigation measurement.

The three allometric estimations of carbon sequestration in pondshowed a decreasing trend. Carbon sequestration in pondon the age range 2-4; 4-6; 6-8; 8-10 and 10-12 year old estimated by $D_{30}{}^2H$ decreased from 24.9 to 24.4 $MgCO_2e$ ha^{-1} yr^{-1} (0.4%), while estimated by D_{30} also decreased from 21.9 to

Annex 10. Above- and belowground carbon stocks of restored mangroves in pond and riverine using Diameter References (DR)

Tree age	Belowground carbon stocks (BGC) (MgC ha^{-1})				Aboveground carbon stocks (AGC)(MgC ha^{-1})				Total carbon stocks (MgC ha^{-1})				
	Pond		Riverine		Pond		Riverine		Pond		Riverine		
	X	± sd	X	± sd	X	± sd	X	± sd	X	± sd	X	± sd	SL
2 years	7.2	± 3.4	2.0	± 0.6	9.4	± 5.7	1.7	± 0.6	16.6 a	± 9.0	3.7 b	± 1.2	**
4 years	11.5	± 3.8	10.1	± 4.2	13.7	± 5.1	10.5	± 5.3	25.3 a	± 8.8	20.6 b	± 9.4	**
6 years	16.8	± 2.0	9.5	± 3.4	15.3	± 1.8	10.1	± 3.9	32.1 a	± 3.8	19.6 b	± 7.3	**
8 years	28.2	± 7.2	22.6	± 4.1	33.8	± 9.2	26.6	± 3.7	62.0 a	± 16.4	49.2 b	± 7.7	**
10 years	22.2	± 4.3	33.6	± 7.1	29.5	± 3.7	50.1	± 10.8	51.7 b	± 8.0	83.8 a	± 17.8	**
12 years	25.4	± 6.1	34.0	± 2.8	35.7	± 8.7	54.7	± 3.8	61.0 b	± 14.7	88.7 a	± 6.6	**
(2-12 years)	18.6	± 1.9	18.6	± 2.1	22.9	± 2.9	25.6	± 3.4	41.5 b	± 4.6	44.3 a	± 5.4	*

AGC and BGC for all species using references at Annex 4; X = average; sd = deviation standard; SL = Significant Level; NS = Not Significant; * = Significant at α 5%;
** = Significant at α 1%; n-plot = 60

17.1 $MgCO_2e$ ha^{-1} yr^{-1} (4.4%) and with DA were from 16.9 to 11.2 $MgCO_2e$ ha^{-1} yr^{-1} (6.7%). The older restored mangroves living in pond may need more nutrient supply than the younger trees but its avaibility in the pond is limited. Excavation and surface displacement when to build pond may decrease soil fertility. Combined factors of less nutrient, unstable soil pH, very low salinity and high tree density may influence why the carbon sequestration in pond going to decrease when trees growing older.

The decreasing trend in pond may also relate to the competitive factors among mangrove trees for phosysnthetic process. Field observation showed stem diameter at the middle of pond tend to be smaller but towering compared to those who live at the edge of pond. The dead trees and dried twigs also ocurred at the middle of pond started at 8 year old. Therefore, it is suggested to conduct selective cutting in order to maintain an ideal space of mangroves living in pond.

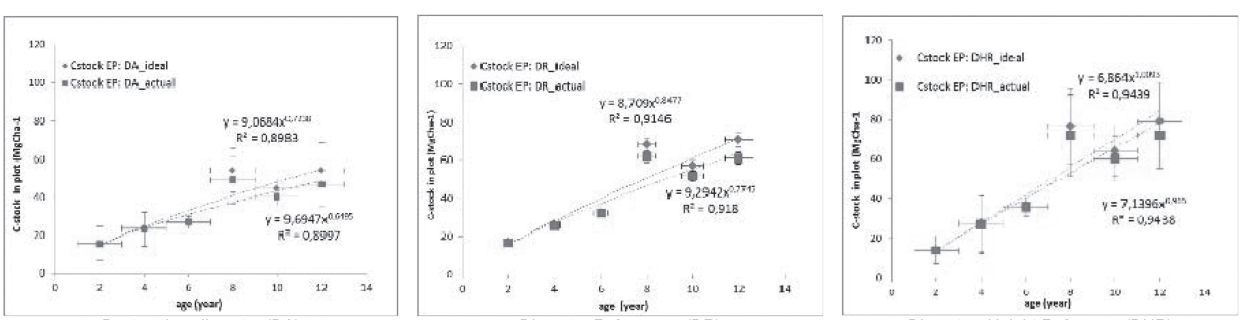
The opposite condition occurred in riverine in which the carbon sequestration shows an increase trend as mangroves growing up. The carbon sequestration in riverineon age range 2-4; 4-6; 6-8; 8-10 and 10-12 year old estimated by $D_{30}{}^2H$ increased from 19.7 to 78.8 $MgCO_2e$ ha^{-1} yr^{-1} (60.0%), while estimated by D_{30}also increasedfrom 18.4 to 50.3 $MgCO_2e$ ha^{-1} yr^{-1} (34.7%) and with DA were from 15.4 to 34.5 $MgCO_2e$ ha^{-1} yr^{-1} (24.8%).The restored mangroves in riverine were able to succeed naturally in which the trees can grow perfectly.The differences of carbon sequestration between age range in riverine (3.8 – 11.8 $MgCO_2e$ ha^{-1} yr^{-1})were higher than the carbon in pond (0.1 – 1.1 $MgCO_2e$ ha^{-1} yr^{-1}). Carbon sequestrations at age range vary depending on tree phenology living at different environment.

Using similar diameter allometric estimation, the average carbon sequestration of 2 – 12 restored mangroves estimated by D_{30}in pond (19.0 $MgCO_2e$ $ha^{-1}yr^{-1}$) in this study was smaller than IPPC (2014) default value (31.2 $MgCO_2e$ ha^{-1} yr^{-1}). However, the average carbon sequestration in riverine (34.9

Annex 11. Above- and belowground carbon stocks of restored mangroves in pond and riverine using Diameter- Height Reference (DHR)

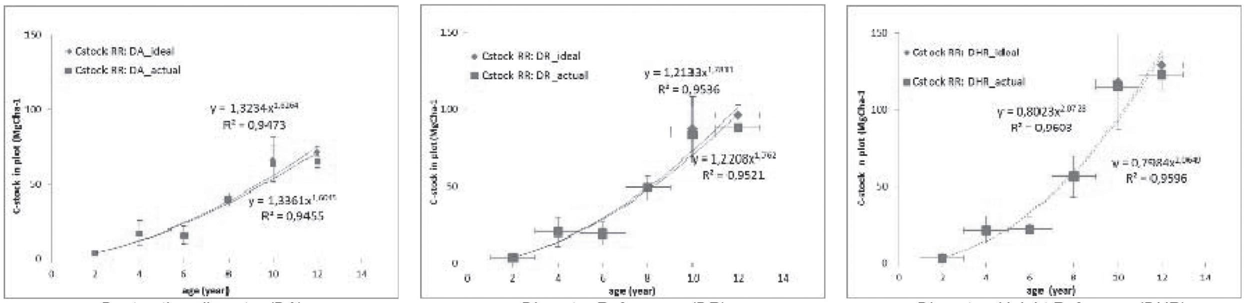
Tree age	Belowground carbon stocks (BGC)(MgC ha^{-1}) Pond X	± sd	Riverine X	± sd	Aboveground carbon stocks (AGC)(MgC ha^{-1}) Pond X	± sd	Riverine X	±sd	Total carbon stocks (MgC ha^{-1}) Pond X	±sd	Riverine X	±sd	EP SL
2 years	7.2	± 3.4	2.0	± 0.6	6.5	± 3.6	0.9	± 0.3	13.8 a	± 7.0	2.9 b	±0.9	**
4 years	11.5	± 3.8	10.1	± 4.2	15.4	± 10.6	11.3	± 5.1	26.9 a	± 14.3	21.4 b	± 9.2	**
6 years	16.8	± 2.0	9.5	± 3.4	19.2	± 2.5	12.6	± 4.6	36.0 a	± 4.4	22.2 b	± 8.0	**
8 years	28.2	± 7.2	22.6	± 4.1	44.0	± 13.5	33.6	± 9.1	72.1 a	± 20.6	56.2 b	± 13.2	**
10 years	22.2	± 4.3	33.6	± 7.1	37.8	± 7.4	81.3	± 21.7	60.1 b	± 11.6	115.0 a	± 28.7	**
12 years	25.4	± 6.1	34.0	± 2.8	47.0	± 11.3	88.8	± 8.1	72.4 b	± 17.2	122.7 a	± 10.8	**
Average (2-12 years)	18.6	± 1.9	18.6	± 2.1	28.3	± 4.4	38.1	± 7.3	46.9 b	± 6.1	51.1 a	± 9.2	**

AGC and BGC for all species using references at Annex 4; X = average; sd = deviation standard; SL = Significant Level; NS = Not Significant;
* = Significant at α 5%; ** = Significant at α 1%; n-plot = 60



Destructive allometry (DA) *Diameter References (DR)* *Diameter- Height Reference (DHR)*

Annex 12. Allometric model of ideal and actual condition of mangrove carbon stocks in pond



Destructive allometry (DA) *Diameter References (DR)* *Diameter- Height Reference (DHR)*

Annex 13. Allometric model of ideal and actual condition of mangrove carbon stocks in riverine

Annex 14. Mangrove carbon stocks (MgC ha^{-1}) at ideal and actual condition inpond

Tree age	Destructive allometry (DA)			Diameter References (DR)			Diameter- Height Reference (DHR)		
	Ideal	Actual	Lost	Ideal	Actual	Lost	Ideal	Actual	Lost
2 years	15.7	15.5	0.1	15.7	15.5	0.1	15.7	15.5	0.1
4 years	23.9	23.1	0.7	23.9	23.1	0.7	23.9	23.1	0.7
6 years	27.0	26.9	0.1	27.0	26.9	0.1	27.0	26.9	0.1
8 years	54.1	49.1	5.0	54.1	49.1	5.0	54.1	49.1	5.0
10 years	44.7	40.2	4.5	44.7	40.2	4.5	44.7	40.2	4.5
12 years	54.1	46.6	7.5	54.1	46.6	7.5	54.1	46.6	7.5
Average (2-12 years)	36.6	33.6	3.0	36.6	33.6	3.0	36.6	33.6	3.0

n-plot = 60

Annex 15. Mangrove carbon stocks (MgC ha^{-1}) at ideal and actual condition in riverine

Tree age	Destructive allometry (DA)			Diameter References (DR)			Diameter- Height Reference (DHR)		
	Ideal	Actual	Lost	Ideal	Actual	Lost	Ideal	Actual	Lost
2 years	3.8	3.7	0.1	3.8	3.7	0.1	3.8	3.7	0.1
4 years	17.5	17.5	0.0	17.5	17.5	0.0	17.5	17.5	0.0
6 years	16.0	16.0	0.0	16.0	16.0	0.0	16.0	16.0	0.0
8 years	40.3	40.0	0.3	40.3	40.0	0.3	40.3	40.0	0.3
10 years	66.7	63.6	3.1	66.7	63.6	3.1	66.7	63.6	3.1
12 years	71.4	65.5	5.9	71.4	65.5	5.9	71.4	65.5	5.9
(2-12 years)	36.0	34.4	1.6	36.0	34.4	1.6	36.0	34.4	1.6

n-plot = 60

Annex 16. Carbon stocks of necromass and litters of restored mangroves (MgC ha^{-1})

Tree age	Necromass					Litters				
	EP		RR		SL	EP		RR		SL
	X	±sd	X	±sd		X	±sd	X	±sd	
2 years	0.11b	±0.06	0.47a	±0.27	**	0.68b	±0.37	1.03a	±0.13	**
4 years	0.19b	±0.08	0.51a	±0.30	**	0.58b	±0.12	0.73a	±0.56	*
6 years	0.61a	±0.10	0.65a	±0.21	NS	0.45b	±0.18	1.26a	±0.18	**
8 years	0.49a	±0.23	0.28b	±0.12	**	0.72a	±0.37	0.74a	±0.10	NS
10 years	0.92a	±0.12	0.23b	±0.12	**	0.58a	±0.12	0.35b	±0.09	**
12 years	0.72a	±0.08	0.32b	±0.03	**	1.10a	±0.39	0.38b	±0.28	**
(2-12 years)	0.52a	±0.05	0.43a	±0.09	NS	0.69a	±0.15	0.73a	±0.13	NS

X = mean ; sd = deviation standard; n-plot = 60

$MgCO_2e\ ha^{-1}\ yr^{-1}$) was higher than those IPPC value but it was still lower than Alongi (2014) finding on carbon sequestration of un-identified age of mangrove natural forest in Australia (41.1 $MgCO_2e\ ha^{-1}\ yr^{-1}$). The differences may be due to different locations where individual trees have photosynthetic capability in producing annual carbon. Moreover, the sequestration ability of mangrove ecosystem was also influenced by respiration time when the high rate of carbon sequestration during spring tides rather than neap tides. Carbon cyclus model of mangrove ecosystem based on tidal pattern should be considered to anticipate sea rise problem in the future (Li *et al*., 2014).

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