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Carbon Stocks in Mangrove Ecosystems of Musi and Banyuasin Estuarine Waters, South Sumatra Province

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Abstrak

Hutan mangrove di daerah estuari mampu menghasilkan stok karbon yang sangat besar sebagai daerah perlindungan dan pemulihan yang efektif sebagai strategi mitigasi perubahan iklim yang efektif. Pemilihan ekosistem pesisir dalam strategi mitigasi memerlukan kuantifikasi stok karbon untuk menghitung emisi atau penyerapan berdasarkan waktu. Penelitian ini menghitung stok karbon pada ekosistem Musi Estuari Waters (MEW) dan Banyuasin Estuari Water (BEW), Provinsi Sumatera Selatan pada tipe vegetasi yang berbeda dan hubungan variabel lingkungan dengan stok karbon. Di tujuh lokasi dalam MEW dan BEW sampel vegetasi dan tanah. Hasil yang didapatkan adalah nilai yang lebih tinggi dari stok karbon di vegetasi dari lokasi III/MEW (7.600,92 mg.ha^{-1}), stok karbon dalam tanah dari lokasi II/MEW (61.081,87 mg.ha^{-1}) dan stok karbon di ekosistem dari lokasi II (64.548,54 mg.ha^{-1}). Mangrove A. marina merupakan yang paling baik menyimpan stok carbon termasuk antara vegetasi dan tanah karena toleransi salinitas yang rendah.

Kata kunci: *mangrove, karbon, estuari, Musi, Banyuasin*

Abstract

Mangrove forests in estuarines can have exceptionally large carbon stocks and their protection and restoration would constitute an effective mitigation strategy to climate change. Inclusion of coastal ecosystems in mitigation strategies require quantification of carbon stocks in order to calculate emissions or sequestration through time. This study quantified the ecosystem carbon stocks of the Musi Estuarine Waters (MEW) and Banyuasin Estuarine Water (BEW), Province of South Sumatra into different vegetation types and examined relationships of environmental variables with carbon stocks. At seven sites within MEW and BEW of vegetation and soil samples. The results that the higher value of carbon stock in vegetation from Site III/MEW (7.600,92 mg.ha^{-1}), the carbon stock in soil from Site II/MEW (61.081,87 mg.ha^{-1}) and carbon stock in ecosystem from Site II (64.548,54 mg.ha^{-1}). Mangrove of A. marina the best to explain carbon stocks included both vegetation and soil because they can tolerate lower salinity.

Keywords: *mangrove, carbon, estuarine, Musi, Banyuasin*

Introduction

Mangroves have among the highest rates of deforestation of any forest ecosystem, land conversion has resulted in the loss of over one third of all mangroves over the past 20–50 years (Alongi, 2002). Dominant causes of deforestation and degradation include: agriculture and aquaculture conversion, pollution, coastal development, and hydrological disruptions (Alongi, 2002; Spaulding *et al.,* 2010). Besides the loss of aboveground biomass following mangrove disturbance, decomposition of organic material causes the release of considerable amounts of CO_2 to the atmosphere (Lovelock *et al.,* 2011).

Mangrove wetlands exist in the transition zone between terrestrial and marine environments and as such were historically overlooked in discussions of terrestrial and marine carbon cycling. In recent decades, mangroves have increasingly been credited with producing and burying large quantities of organic carbon (OC) (Breithaupt *et al.,* 2012).

Given the large carbon stocks of mangroves, the emissions arising from conversion are likely exceptionally high and a significant source of greenhouse gasses (Donato *et al.,* 2011). Furthermore, global climate change may affect

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mangrove cover and distribution through an increase in sea-level rise, changes in tropical storm intensity, and changes in stream and groundwater flows that discharge into mangroves (Gilman *et al.,* 2008). Because of their large ecosystem carbon stocks, their vulnerabilities to land use, and the numerous other ecosystem services they provide, coastal wetlands are of increasing interest for participation in climate change mitigation strategies (Murdiyarso *et al.,* 2009). In to order participate in climate change mitigation strategies, such as Reduced Emissions from Deforestation and Degradation (REDD+) (Masripatin *et al.,* 2010), it is necessary to determine carbon stocks and emissions baselines, especially in mangrove ecosystems.

Mangroves are found in Musi estuarine waters as many as four species, among others *S. alba, A. marina, A. alba,* and *N. fruticans.* There are five species of mangrove in Banyuasin estuarine waters i.e *A. marina, S. alba, B. gymnorrhiza, R. mucronata* and *N. fruticans.* The results showed that *A.marina* has the highest number of species and the highest importance value index of 300 (Melki and Isnaini, 2014).

This study measures whole-ecosystem carbon stocks of different mangrove ecosystems within the Musi and Banyuasin Estuarine Waters, South Sumatra Province. This study determine and compare ecosystem carbon stocks of different vegetation types, and to determine abiotic factors that could affect their carbon storage potential.

Materials and Methods

Study site and field sampling

Field samplings were done on June 2014 at seven sites (Musi Estuarine Waters/MEW such as site I, II, III, IV and Banyuasin Estuarine Waters/BEW such as site V, VI and VII) Province of South Sumatra (Figure 1 dan Table 1), site IV is control (no mangroves). Melki and Isnaini (2014) reported a total of seven species found, four species in Musi estuarine waters *i.e. S. alba, A. marina, A. alba, N. Fruticans,* and five species at Banyuasin estuarine waters *i.e. A. marina, S. alba, B. gymnorrhiza, R. mucronata* and *N. fruticans.*

At each site, data necessary to calculate total carbon stocks derived from standing tree biomass and soil were collected. Soils were also colelcted for analysing of water quality which include salinity, pH, temperature and soil charateristic at different depths (0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-100 cm). Soils were strained using a 20 ml syringe to collect pore water, and refractometer was used to measure salinity, while temperature was measured by using a thermometer.

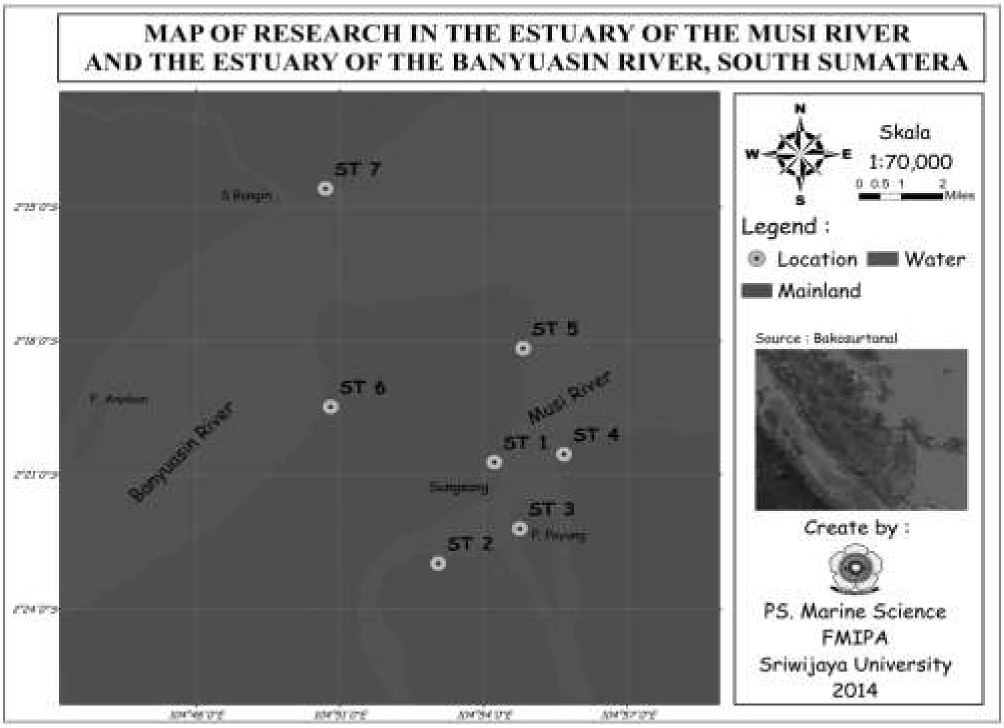

Figure 1. Location map of study area of Musi Estuarine Waters and Banyuasin Estuarine Waters, South Sumatra

Table 1. Location of study area

Site	Latitude/Longitude	Location
Site I	104º 53' 1,54" BT / 2º 22' 53,13" LS	Musi Estuarine
Site II	104º 54' 53,11" BT / 2º 22' 31,88" LS	Payung Island
Site III	104º 55' 36,97" BT / 2º 20' 34,59" LS	Tanjung Buyut
Site IV	104º 54' 58,21" BT / 2º 18' 0,71" LS	Tanjung Carat/no mangrove
Site V	104º 50' 37,95" BT / 2º 17' 32,60" LS	Banyuasin Estuarine
Site VI	104º 49' 40,3" BT / 2º 21' 42,7" LS	Tanjung Api-api
Site VII	104º 50' 13,9" BT / 2º 14' 76,3" LS	Bungin River

Vegetation carbon

Girth is measured in cm at the tree height of 30 cm for *Rhizophoraceae* and at 1.3 m for all other mangroves. The tree diameter (D) is then calculated by multiplying the girth with a factor of 0.318 of all trees rooted within each plot of each transect. Measurements of Diameter at Breast Height (DBH) can be used to calculate above ground biomass using allometric relationships between DBH and the biomass of individual plant parts (Putz and Chan, 1986; Clough and Scott, 1989).

Coefficients for these allometric relationships for a number of species are summarized by Clough (1992). Recently a common allometric equation for estimating the tree weight of mangroves has been proposed (Komiyama *et al.*, 2005) as follows:

a. The biomassa are estimated using the following allomatric equations
   Shoot biomass (SB) = $0.251 \times \rho \times D^{2.46}$
   Root biomass (RB) = $0.199 \times \rho^{0.899} \times D^{2.22}$
   Total biomass (X) = SB+RB (kg/plant)
   D= tree diameter; ρ = wood density in ton per m^3 (Table 2)
b. Carbon Biomass (kg/plant) = Total biomass x 0.42

Table 2. Wood Density (ρ) of Mangroves

Jenis mangrove	ρ
Rhizophoraceae	
Bruguiera cylindrica	0.749
Bruguiera gymnorrhiza	0.699
Ceriops tagal	0.746
Ceriops decandra	0.960
Rhizophora apiculata	0.770
Rhizophora mucronata	0.701
Rhizophora mangle	0.830
Others	
Avicennia alba	0.506
Avicennia marina	0.670
Avicennia officinalis	0.670
Sonneratia alba	0.475
Sonneratia caseolaris	0.340
Xylocarpus granatum	0.528

Soil Organic Carbon

At each sites, soil samples for bulk density were collected using a corer of 100 cm height and 5 cm diameter. The soil samples collected at the five depth (0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-100 cm) will be transferred to laboratory immediately in sterile polythene bags. Samples of a known volume were collected in the field and then oven-dried to a constant weight at 60ºC for 48 hours. A partion of the dried sample is measured for its volume by immersing it in to a jar with a known volume of water and measuring the volume of water displaced. Then, the bulk density is determined by dividing the weight of oven-dried soil sample by the volume of the sample.

Total organic carbon in sediment was estimated by adopting the method of El Wakeel and Riley (1956). The procedure involves chromic acid digestion and subsequent titration with ferrous ammonium sulphate solution in the presence of phenanthroline indicator, as follows:

a. Total Organic Carbon (TOC) in sediment soil (g $C.g^{-1}$) (X) = (1.15 x 0.6) x volume ferrous ammonium sulphate consumed
b. Total Organic Carbon in sediment soil (TOC) (%) = X/10
c. Total Carbon in sediment soil (TC) (%) = TOC ÷ 2
d. Carbon Stock in sediment soil ($Mg.ha^{-1}$) = Bulk density x TC x soil depth interval
e. Carbon Stock in one meter depth of soil: Carbon stock in different depths (0-10 cm, 10-30 cm, 30-50 cm, 50-70 cm, 70-100 cm) of soil will be summed up to get total carbon stock of sediment soil for one meter depth.

Result and Discussion

Vegetation Carbon

Vegetation carbon is the tree biomass of mangrove ecosystems in MEW and BEW varied ranging from 446,28 $Mg.ha^{-1}$ in mangrove species of *A. alba* (site II) to 7.600,92 Mg/ha in mangrove species of *A. marina* (site III). Total stocks of the vegetation carbon varied ranging from 876,76 Mg/ha in site I (MEW) to 7.600,92 ton/ha in site III (MEW). In Site IV is control (no mangrove) (Figure 2).

Table 3. Physico-chemical analysis, Bulk density, Total Organic Carbon (TOC), Total Carbon (TC), and Carbon Stocks (CS) of mangroves Soil in MEW and BEW

Site/Mangrove	Depth (cm)	Temperatur (°C)	pH	Salinity (ppt)	Bulk density (g.cm^{-3})	TOC (%)	TC (%)	CS (%)
Site I								
A. alba	10	30	4.8	5	2.50	0.97	0.48	12.08
	30	30	4.8	5	2.50	0.45	0.22	16.82
	50	29	4.7	5	2.63	1.22	0.61	80.35
	70	29	4.7	5	2.78	0.78	0.39	75.80
	100	29	4.8	5	2.63	0.48	0.24	62.64
	Total							247.69
N. fruticans	10	30	5.59	5	2.50	0.75	0.38	9.40
	30	30	5.59	5	1.67	0.75	0.37	18.63
	50	29	5.56	5	2.50	0.67	0.33	41.83
	70	29	5.56	5	1.67	0.68	0.34	39.85
	100	29	5.55	5	2.27	0.61	0.30	69.00
	Total							178.71
Site II								
A. marina	10	29	5.6	0	4.17	0.81	0.41	16.96
	30	29	5.56	0	5.00	0.76	0.38	56.93
	50	30	5.56	5	1.67	0.50	0.25	20.70
	70	29	5.56	10	2.50	0.71	0.36	62.19
	100	29	5.56	10	2.78	0.49	0.24	68.04
	Total							224.82
A. alba	10	28	5.6	0	2.50	0.55	0.27	6.81
	30	28	5.45	0	2.63	0.59	0.29	23.15
	50	29	5.55	5	2.50	0.77	0.38	47.87
	70	29	5.56	10	2.27	0.93	0.47	74.10
	100	29	5.55	10	2.50	0.73	0.37	91.43
	Total							243.36
N. fruticans	10	28	5.7	0	2.78	0.48	0.24	6.71
	30	28	5.9	5	2.78	0.61	0.30	25.30
	50	29	5.6	5	3.33	0.60	0.30	50.03
	70	29	5.9	5	4.17	0.00	0.00	5.03
	100	29	5.9	5	2.78	0.40	0.20	55.58
	Total							142.65
Site III								
A. marina	10	29	5.33	3	1.79	0.75	0.38	6.72
	30	29	5.23	3	2.78	0.97	0.49	40.54
	50	29	5.23	3	2.27	0.90	0.45	51.36
	70	29	5.22	3	2.50	0.93	0.47	81.51
	100	29	5.24	3	2.27	0.90	0.45	101.93
	Total							282.05
N. fruticans	10	32	5.4	2	4.17	0.00	0.00	0.72
	30	32	5.41	3	2.27	0.08	0.04	2.82
	50	32	5.42	3	3.85	0.20	0.10	19.24
	70	34	5.4	3	2.50	0.29	0.14	25.36
	100	31	5.44	3	2.50	0.40	0.20	50.03
	Total							98.16
Site IV								
No mangrove	10	29	6.15	3	1.00	0.59	0.29	2.93
	30	29	6.1	3	1.00	0.51	0.26	7.66
	50	29	6.1	3	1.00	0.31	0.16	7.76
	70	30	6.15	3	1.00	0.41	0.21	14.49
	100	30	6.2	3	1.00	0.35	0.17	17.25
	Total							50.09

Table 3. Physico-chemical analysis, Bulk density, Total Organic Carbon (TOC), Total Carbon (TC), and Carbon Stocks (CS) of mangroves Soil in MEW and BEW (next table)

Site/Mangrove	Depth (cm)	Temperatur (^oC)	pH	Salinity (ppt)	Bulk density (g.cm^{-3})	TOC (%)	TC (%)	CS (%)
Site V								
A. marina	10	29	6.2	3	2.00	0.91	0.46	9.11
	30	29	6.2	3	1.92	1.00	0.50	28.86
	50	29	6.25	3	1.79	1.00	0.50	44.67
	70	29	6.25	3	2.00	0.95	0.47	66.17
	100	20	6.25	3	2.50	1.06	0.53	132.83
	Total							281.63
Site VI								
B. gymnhorriza	10	29	6.2	5	6.25	0.51	0.26	15.96
	30	29	6.2	5	5.00	0.81	0.40	60.55
	50	29	6.25	10	2.63	0.56	0.28	36.77
	70	30	6.25	10	5.00	0.35	0.18	61.58
	100	30	6.25	10	5.00	0.26	0.13	63.83
	Total							238.68
S. caesoelaris	10	29	6.15	5	5.00	0.35	0.18	8.80
	30	29	6.15	15	2.78	0.66	0.33	27.31
	50	30	6.2	15	2.50	0.00	0.00	2.16
	70	30	6.2	15	2.27	0.03	0.01	2.20
	100	30	6.2	15	4.17	0.00	0.00	7.19
	Total							47.65
R. mucronata	10	29	6.1	5	1.67	0.31	0.16	2.59
	30	29	6.15	5	4.17	0.00	0.00	2.16
	50	29	6.15	5	2.50	0.00	0.00	2.16
	70	29	6.2	10	2.50	0.28	0.14	24.15
	100	30	6.2	10	2.50	0.09	0.04	11.21
	Total							42.26
A. marina	10	29	6.35	5	2.50	0.70	0.35	8.71
	30	30	6.35	10	1.67	0.69	0.35	17.25
	50	30	6.35	10	3.85	0.83	0.41	79.62
	70	30	6.35	15	1.67	0.77	0.38	44.68
	100	30	6.35	15	2.50	0.58	0.29	72.45
	Total							222.70
Site VII								
A. marina	10	28	5.31	28	2.50	1.07	0.53	13.37
	30	28	6.06	28	4.17	0.92	0.46	57.36
	50	28	6.05	28	2.63	0.90	0.45	59.47
	70	28	5.59	27	2.78	0.66	0.33	63.73
	100	28	5.58	27	4.17	0.90	0.45	188.31
	Total							382.23

The contribution of *A.marina* to vegetataion carbon stock is greater biomass between others species mangroves. The vegetation composition and structure of coastal wetlands is determined by a suite of environmental parameters, including salinity, pH, temperatur, and sediment type. Mangroves in MEW and BEW is largely dominated by *A. marina* which pointing to its wide adaptability in different environments (Melki and Isnaini, 2014). From the present observations, it is revealed that most of the species occupy a zone to which it is best adapted, however, there are overlapping occurrences of different species although with varying ecological optima along salinity and pH gradients.

Soil Organic Carbon

The carbon contents in the soil of mangrove ecosystems in MEW and BEW varied ranging from

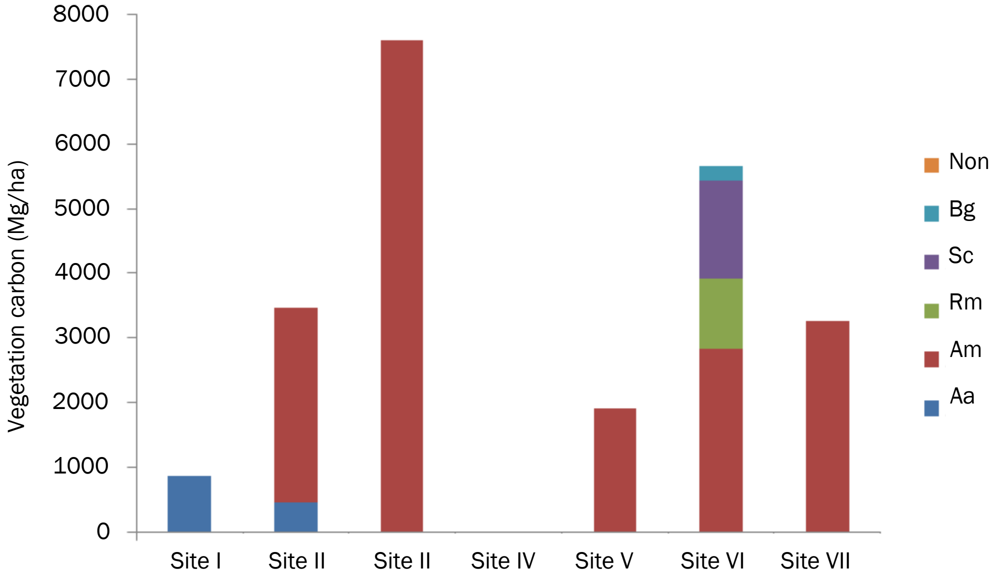

Figure 2. Carbon stocks in vegetation of mangroves in MEW and BEW.
Note : Aa *(Avicennia alba),* Am *(Avicennia marina),* Bg *(Bruguiera gymnorrhiza),* Rm *(Rhizophora mucronata),* Sc *(Sonneratia caseolaris),* Non (No mangrove)

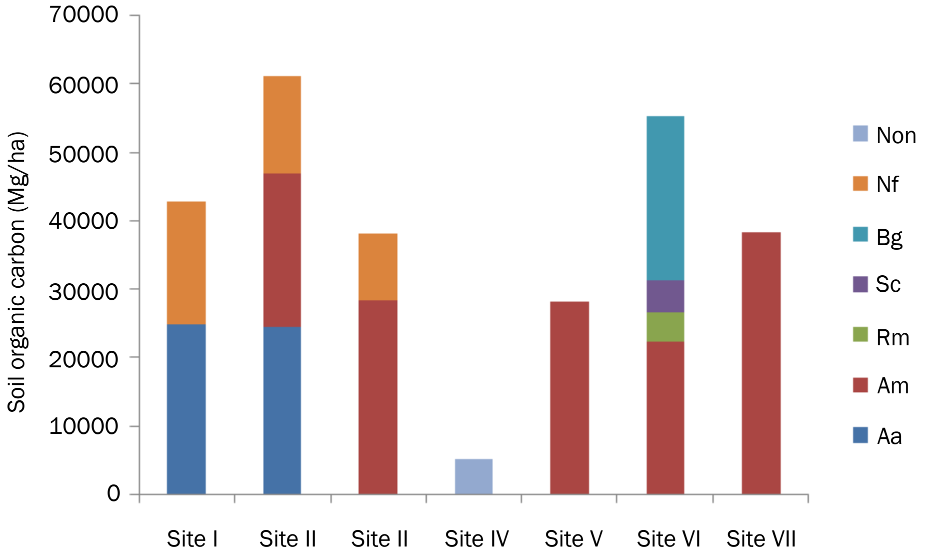

Figure 3. Carbon stocks in soil organic of mangroves in MEW and BEW.
Note : Aa *(Avicennia alba),* Am *(Avicennia marina),* Bg *(Bruguiera gymnorrhiza),* Rm *(Rhizophora mucronata),* Sc *(Sonneratia caseolaris),* Nf (*Nypa fruticans*), Non (No mangrove)

4.226,25 Mg.ha^{-1} in mangrove species of *R.mucronata* (site VI) to 38.223,38 Mg.ha^{-1} in mangrove species of *A. marina* (site VII). Total stocks of the soil organic carbon in mangrove ecosystems varied ranging from 5.009,40 Mg/ha in site IV (MEW) to 61.081,87 Mg.ha^{-1} in site II (MEW) (Figure 3).Physico-chemical analysis of mangroves soil for 1 m soil depth in MEW and BEW are found in wide ranges of soil temperature, pH and salinity. The soil temperature ranged from 28 ^{o}C to 32 ^{o}C, pH from 4.8 to 6.4 and the soil salinity ranged from 0 ppt to 28 ppt. Carbon stock of mangrove soil ranged from 50,09 Mg.ha^{-1} (Site IV/no mangrove) to 382,23 Mg.ha^{-1} (Site VII/species of mangrove *A.maria)* (Table 3).

We found that *A.marina* the best to explain C stocks included both soil and salinity. Most of mangrove species have varied salinity and optimum pH range like terrestrial plants, but they can tolerate lower salinity. Especially mangrove of *A. marina* occurred in varied salinity conditions from 0 ppt to 28 ppt. The complexity of vegetation increased with decrease in soil salinity. Low salinity in the sampling area is associated with some rivers. Kathiresan *et al.* (1996) generally mangroves ecosystem is good to

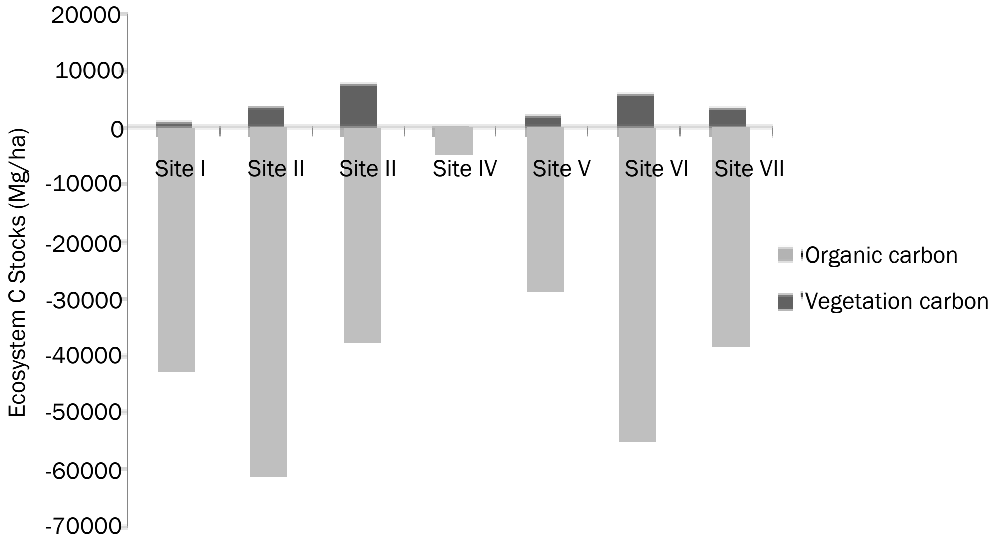

Figure 4. Ecosystem Carbon Stocks of mangroves in MEW and BEW

growth in soils with lower salinities. At Site VII we found that high salinity were associated with higher C ctocks in mangroves.

Ecosystem Carbon Stocks

Overall, there was a significant difference among ecosystem C stocks within organic sediment and vegetation. The highest ecosystem C stock (64.548,54 $Mg.ha^{-1}$) was measured at Site II (MEW), a site of organic carbon associated with vegetation carbon. The lowest ecosystem C stock (5.009,40 $Mg.ha^{-1}$) was measured at Site IV (MEW), this site there was no vegetation (Figure 4).

A comparison of this results with existing published C stocks for mangroves indicates that values are comparatively high average 41.577,65 $Mg.ha^{-1}$, 80-97% of which were directly associated with organic-rich soils. For example, mangroves sampled throughout the Indo-Pacific averaged 1023 $Mg.ha^{-1}$, 49%–98% of which were directly associated with organic-rich soils (Donato *et al.,* 2011). In western Micronesia, specifically Yap state and the Republic of Palau, mangrove C storage ranged from 479 (seaward) to 1385 (landward) $Mg.ha^{-1}$, with 70% of storage in soils (Kauffman *et al.,* 2011).The sink function occurs in mangroves if the rate of carbon entry to a system via photosynthetic transformation to plant material and eventually the soil, is greater than the rate at which it leaves via export or respiration (Twilley *et al*., 1992).

Conclusion

The study of carbon stocks in mangrove ecosystems of the two estuarines of dominance mangrove trees in study area showed that the positive potential from mangrove *A.marina* to sink of carbon. Generally, mangrove ecosystems in Musi Estuarine waters and Banyuasin Estuarine Waters haves effective climate change mitigation and adaptation strategies should aim at maintaining and restoring the exceptionally large carbon stocks as well as other ecosystem services provided by coastal wetlands.

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