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Carbon Stock Evaluation of Selected Mangrove Forests in Peninsular Malaysia and its Potential Market Value

ABSTRACT

Mangrove forest has a big potential to become a new market for carbon trading. The purpose of this study was to estimate the amount of carbon stored and its potential carbon market value in undisturbed mangrove forest; Kuala Selangor Nature Park (KSNP) and degrading mangrove forest; Sungai Haji Dorani (SHD) thereby create awareness on how preserving the natural mangrove forest in Malaysia really pays. The carbon content of seasonally-sampled selected mangrove living vegetation and soil was determined using the LOI furnace method followed by a conversion factor. The carbon content for the soil and above-ground biomass in the undisturbed forest was greater than in the degrading forest; while the carbon stored below-ground surprisingly showed a reversed pattern. The total ecosystem carbon stock in undisturbed KSNP was estimated at 246.21 t ha^{-1} C which is relatively higher than that in the degrading forest in SHD with 151.40 t ha^{-1} C. It was also estimated that the minimum carbon credit value for the mangrove forest in the SHD and KSNP was USD 3,314.23 ha^{-1} and USD 5,89.83 ha^{-1} respectively, based on the market price in the voluntary market. The undisturbed mangrove forests have a higher potential for economic return in carbon credits.

Key words: *mangroves, biomass, carbon sink, carbon market*

Liu Chai Hong[1]
Zhila H. Hemati[2]
Rozainah M. Zakaria[3*]

[1] Institute of Biological Sciences, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2] Key Laboratory of Tropical Forest Ecology, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla, Yunnan 666303, China
[3] Institute of Ocean & Earth Sciences, University of Malaya, 50603 Kuala Lumpur, Malaysia

*Corresponding author:
rozainah@um.edu.my

INTRODUCTION

According to the *WWF-Australia Blue Carbon Report* (*2012*), coastal ecosystems, including sea grass, mangrove and salt marsh, are known as the blue carbon sinks. Mangrove forests are effective in storing organic carbon 3-5 times higher than terrestrial forests (*Donato et al. 2011*). In fact, this storage of Blue Carbon can potentially occur for millennia. The two main carbon pools in the forest ecosystem are: the living vegetation and the soil (*Kauffman et al. 2011; Chen et al. 2012*). The soil ecosystem is often the largest pool in the mangrove ecosystem, and measuring it is important for determining the long-term dynamics associated with climate change and/or land management. The soil carbon pools usually constitute over 50%, and sometimes over 90%, of the total ecosystem carbon stock of mangroves (*Donato et al. 2011; Kauffman et al. 2011*). Among the main sources of organic carbon for soil are litter production and dead wood debris from the plant. The decomposition and decay of organic material caused by bacteria increases the accumulation of organic matter in the soil sediment. This process usually takes place in the soil surface layer, which is known as the organic-rich layer. It is also important to highlight that mangrove forests can be carbon sinks but, if the ecosystem is disturbed, they can become a carbon source as well. The clearing of mangrove forests causes the drying up of mangrove sediments, which increase the microbial activity following the loss of anaerobic environment. This in turn causes an oxidation for the soil and leads to the release of stored carbon into the atmosphere. Thus, it is essential to acknowledge the importance of the mangrove forests and to value their conservation.

Malaysia ranks as the third country in the world to hold largest mangrove forest at 469,100 ha in 2014 after Indonesia and Brazil, but sadly subjected to a reduction in 0.19% since 2000 (*Hamilton and Casey 2016*). In larger view, Southeast Asia is a region of concern with mangrove deforestation rates between 3.58 – 8.08%, while across the globe, mangrove reduction was estimated between 0.16 – 0.39% (*Hamilton and Casey 2016*).

Several publications have acknowledged that mangrove forests are a globally important source of carbon storage due to their high carbon assimilation and flux rate (*Bouillon et al. 2008; Komiyama et al. 2008;*

Kristensen et al. 2008). According to Jennerjahn and *Ittekkot* (*2002*), mangrove forests account for 11% of the total input of terrestrial carbon into the ocean although it only covers 0.1% of the earth's continental surface. Yet, only a few researchers have quantified the total carbon stock in the mangrove ecosystem, with so much lacking of carbon stock reporting in mangrove forests especially in Malaysia, even though Malaysia is the third largest mangrove holding nation across the world. Therefore, it is very crucial that monitoring of carbon stocks and baseline inventories of local mangrove forest being seen as one of the drivers in mangrove research agenda especially in payment for ecosystem service initiatives. This paper attempts to highlight the importance of quantifying carbon in mangrove forest in Malaysia, with potential for carbon trading.

Carbon Trade Policy in Malaysia

Malaysian government has been proactive to drive the nation towards sustainability by implementing carbon credit income tax since 2008. Such policy could promote green practice among corporate and private sectors as well as the development of green technology (*CSR Malaysia 2008*). Nevertheless, awareness among Malaysians is still lacking, coupled with the rapid economic growth and industrialization that has placed heavy demand on resources and energy consumption. Just like other developing countries, some of the forestland and peat land have been exploited for agriculture and other urban use (*Amran et al. 2013*). In fact, peat and mangrove forests are the important carbon sinks in which they will emit significant amount of carbon when destroyed; which is contradict to the effort of government to promote carbon credit income.

Carbon Payments for Mangrove Conservation

A regulated cap-and-trade scheme is one of the most promising schemes implemented for Blue Carbon. This scheme aims to control greenhouse gas (GHG) emission by providing economic incentives to achieve a target. Two parties are involved in this scheme: the entities that reduce GHGs for credits and the entities that pay credits to emit GHGs. The European Union Emissions Trading System (EUETS) is the largest cap-and-trade scheme providing offsets from agriculture, forestry, and other land use. Due to the large market size of the EUETS, the potential for including Blue Carbon as one of the offsets and incentives is great (*Ullman et al. 2013*). The other market-based funding system is the voluntary market for carbon credits. This market provides much smaller amounts than the regulated markets, which may make it influence on global wetland conservation less significant. In 2012, the total volume of emitted GHGs obtained via voluntary markets was about 131 Mt CO_2e, and the average price per tonne was only USD 6.0 compared to the regulated markets, where the average price was USD 19.18 (*Ullman et al. 2013*).

The objective of this study is to quantify the ecosystem carbon stock in both undisturbed and degrading mangrove forests through field-based measurements, and to estimate the carbon market value based on regulated and voluntary markets. The purpose of including the price for carbon is to inform decision-makers in Malaysia about the potential economic income that can be obtained through mangrove conservation. The data collected would provide useful information of the potential of economic loss due to greenhouse emissions, when these habitats are being disturbed, as well as to provide some insights and platform for carbon trading in Malaysia.

MATERIALS AND METHODS

Experimental Sites

This study concentrated on two mangrove forests in the state of Selangor, Sungai Haji Dorani (SHD) and Kuala Selangor Nature Park (KSNP) (**Figure 1**). Both sites lie on the same stretch of coast, facing the Straits of Malacca and are about 70 km apart. Both study areas have been described in *Hemati et al.* (*2014, 2015*). KSNP is a healthy, established mangrove forest of 323 ha, which has been managed by the Malaysian Nature Society (MNS) since 1987 (*MNS 2013*). The park was originally opened for education, research and conservation, and later became an eco-tourism site attraction as it is located only about 70 km from the capital, Kuala Lumpur (*Asmawi et al. 200*9). In contrast, the SHD mangrove forest is a degrading wetland along coastal areas in the village of SHD. In 2006, the Department of Irrigation and Drainage (DID) recognized that the mangrove forests here were critically eroded due to excessive exploitation of the mangrove forests and mismanagement (*Hashim et al. 2010*). In addition, the high erosion rate in the coastal areas had also contributed to the high deterioration rate of the wetlands. The area is now the site of a pilot study for a mangrove rehabilitation and reestablishment project involving several government agencies.

Ecosystem carbon stocks comprising aboveground, belowground and soil up to 30 cm deep were quantified in both study sites in three seasons. The seasons were classified according to the monthly rainfall data obtained from the Malaysian Meteorological Department, which

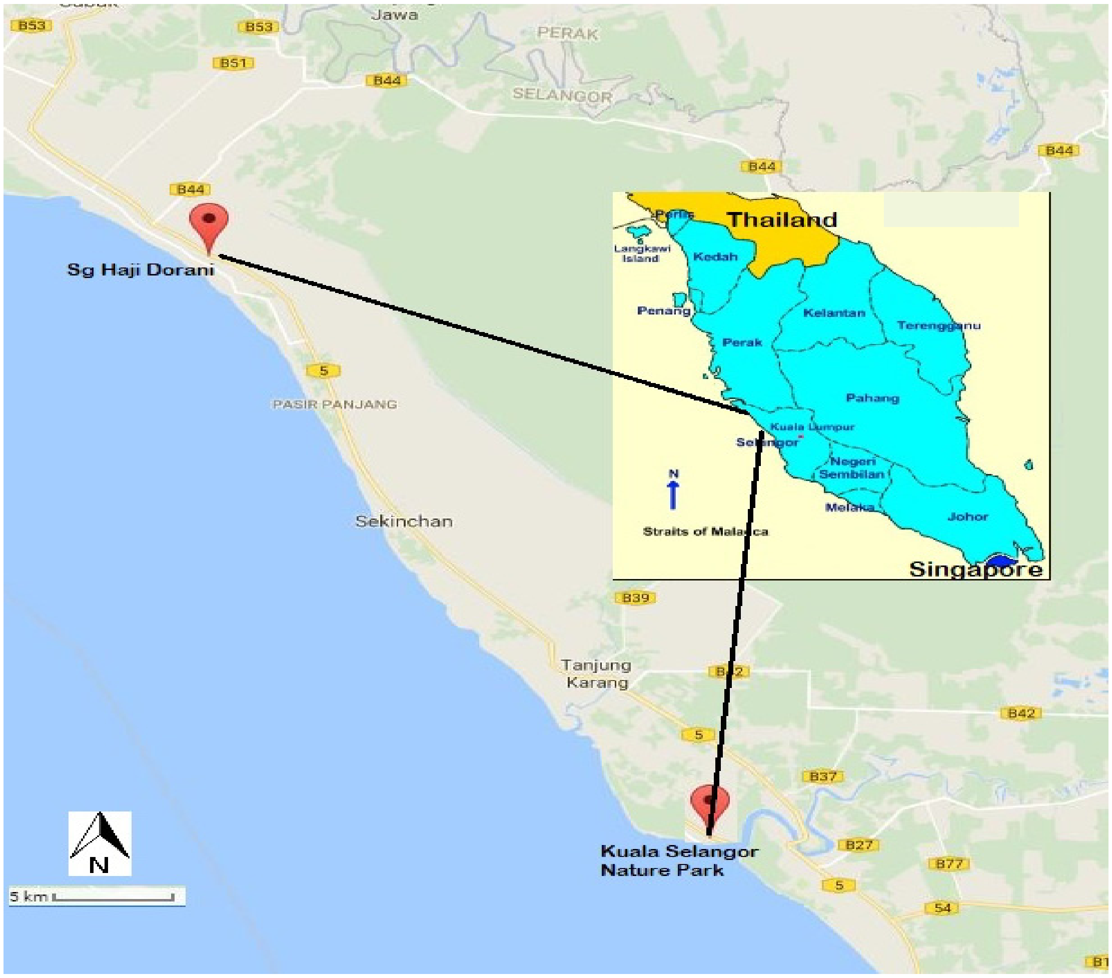

Figure 1. Map locating both study sites (Scale: 1:10 km)

classifies the seasons into wet season (September to December), intermediate season (January to April) and dry season (May to August).

Mangrove species and study setting

The species composition and biomass estimation at both study areas have been reported in *Hemati et al.* (*2014*). In each site, a total of 18 sample plots (100 m^2 each) were established following a line transect from seaward to landward. All species more than 4 cm in diameter at breast height were identified and measured for its diameter. Basically, the mangrove species found in KSNP are *Sonneratia alba*, *Avicennia officinalis*, *Brugueira parviflora* and *Rhizophora mucronata*, whereas those recorded in SHD are *Sonneratia alba*, *Avicennia marina*, *Brugueira cylindrica*, *Xylocarpus mekongensis* and *Excoecaria agallocha*. However, *Sonneratia alba* was not sampled due to the small number of representatives and was excluded from the carbon study. Three replicates were obtained for each of the mangrove species available, with mean diameter ranged between 5.64 ± 0.25 - 13.58 ± 1.25 cm. The same individual trees were sampled in a non-destructive way in each season to reduce sampling error. The sampled trees were separated into their respective parts: leaves, branches, stems, barks, -and roots. Leaves and branches were plucked by hand or by using tree cutter. The barks were removed using a knife while the stems were obtained using a battery powered driller. Similarly, visible roots were sampled using a knife. Total samples of vegetation parts obtained in this study were 315. The respective tree parts were weighed and oven-dried for 3-4 days at 75°C to remove the remaining moisture content. The dried samples were weighed again and processed into clay-sized pieces using a 1-Liter Waring Laboratory Blender (7009L/7009G) with a SS110 Pulverizer Stainless Steel Container. The samples were then determined for their carbon content following LOI method as described in 2.3 below.

Ten plots were selected randomly for sediment sampling in each site, in each season for which an AMS Stainless Steel 2" X 6" Core Sampler was used. After the soil sediment was obtained, the soil depth was divided into 0-10 cm, 10-20 cm and 20-30 cm layers. A total of 180 soil samples were collected from both study sites. Inthe laboratory, the soil sediment was left to dry at room temperature until it was completely dry, then processed into clay-sized pieces and analysed for carbon content following LOI method as described below.

Carbon analysis and carbon stock

The furnace method, also known as the Loss on Ignition (LOI) method is the cheapest and fastest method that can be used to determine organic carbon content (*Heiri et al. 2001*). Initially, samples were oven dried at 110°C for 24 hours. Then, samples were ignited at 660°C in a Digital Muffle Furnace (model F7FH Series) for 6 hours to obtain organic matter. The organic carbon content was estimated by multiplying the organic matter by a factor 0.4 (*Craft et al. 1991*). To calculate the amount of ecosystem carbon stock in the mangrove trees and soil sediment, equations modified from *Kauffman and Donato* (*2012*) shown below was used;

Total ecosystem carbon stock (t ha^{-1}) = $C_{treeAG} + C_{treeBG} + C_{soil}$, where:

C_{treeAG} = aboveground carbon pools of tree (stem part),
C_{treeBG} = belowground tree carbon pool (roots part),
C_{soil} = total soil carbon pool (30cm deep).
$C_{treeAG \text{ and } CtreeBG}$ = biomass of each species X their respective wood carbon content (%),
C_{soil} = ∑ (bulk density (gcm^{-3}) X soil depth interval (cm) X % C)

The stem part was selected for the calculation as it represents the primary indicator of the permanent biomass production of plants, whereas branches and leaves are more susceptible to litter fall and contribute to a lower biomass production (*Mitra et al. 2011*).

Carbon dioxide equivalent and carbon market price

In order to calculate carbon market value, the total ecosystem carbon stock was converted to carbon dioxide equivalents or CO_2e by multiplying the total ecosystem carbon stock with 3.67 (*Kauffman and Donato 2012*). *Peters-Stanley et al.* (*2011*) cited by *Ullman et al.* (*2013*) suggested that the average price ranged from USD 6.00 in the voluntary market to a maximum USD 19.18 in the regulated market (EU ETS) for every ton of CO_2e.

Statistical analysis

The results obtained focused on the amount of organic carbon stored within the mangrove tree parts and the soil layers at both locations (undisturbed and degrading forests), across seasons. An Independent Samples T-test was used to analyse the differences between locations and between the aboveground biomass and the belowground biomass of the vegetation. One-way ANOVA was used to determine the degrees of difference between seasons, species and vegetation parts at a 95% confidence level. Non-parametric tests (Mann-Whitney U Test and Kruskal-Wallis Test) were used to further validate the test results.

RESULTS

Vegetation carbon

Although SHD and KSNP contained different species, the average carbon content in the vegetation was not significantly different ($P>0.05$) (**Table 1**). The organic carbon content in SHD was in the order of *B. cylindrica* > *A. marina* > *X. mekongensis* > *E. agallocha*, and the average organic carbon content was 35.61 ± 4.35%. In KSNP, the order of organic carbon content was *A. officinalis* > *R. mucronat*a > *B. parviflora*, and the average content was 36.27 ± 4.02%.

Both areas showed very similar carbon allocations in terms of the vegetation parts, with the stem containing the most carbon while the roots contained the least (**Table 1**). The difference was significant using the Kruskal-Wallis Test. Not only that, the organic carbon content of the leaves was significantly lower than that of the stem parts ($P<0.05$). This trend has also been noted in several other publications, including *Boullion et al.* (*2008*), *Kauffman et al.* (*2011*) and *Mitra et al.* (*2011*).

Table 1. A summary of carbon content in vegetation at both study sites.

Vegetation	SHD	KSNP
Average carbon content (%)	35.61 ± 4.35	36.27 ± 4.02
Order of C (%) based on species	*B. cylindrica* > *A. marina* > *X. mekongensis* > *E. agallocha*	*A. officinalis* > *R. mucronata* > *B. parviflora*
Order of vegetation tree parts	stem > bark > branch > leaf > root	stem > bark > branch > leaf > root
Order of biomass partitioning	aboveground > belowground	aboveground > belowground
Order of seasonal changes	dry > wet > intermediate	intermediate > wet > dry

The vegetation biomass can be further divided into above-ground and below-ground biomass. The root is considered the below-ground part of the tree biomass, while the other vegetation parts are considered the above-ground part. Both sites show a similar trend; the mean organic carbon content of the aboveground tree biomass is significantly higher than that of the belowground biomass, confirmed by the Mann-Whitney U Test (**Table 1**).

Seasonal changes did not influence the organic carbon distribution in the vegetation, although the amount of organic carbon stored in KSNP was highest during the intermediate season, while SHD recorded its highest during the dry season.

Vegetation Biomass and Carbon stock

It is undeniable that the organic carbon stored is proportional to the biomass of the mangrove vegetation, and thus can be used to estimate the carbon stock (**Table 2**). Higher aboveground biomass value in *A. marina* (108.63 t ha^{-1}) and *B. parviflora* (266.74 t ha^{-1}) led tohigher amount of carbon stock. Below ground organic

Table 2. Vegetation biomass and carbon pools of mangrove forests in SHD and KSNP.

Season	Species	Wood Carbon Content (%)	Aboveground Biomass (t ha^{-1}) *Hemati et al.* (*2014*)	Above ground Organic Carbon Content (t ha^{-1}) *	Root Carbon Content (%)	Below ground Biomass (t ha^{-1}) *Hemati et al.* (*2014*)	Below ground Organic Carbon Content (t ha^{-1}) **
SHD							
Wet	*A. marina*	39.3	108.63	42.69	31.59	12.12	3.83
	B. cylindrica	35.82	12.95	4.64	31.37	12.12	3.80
	X. mekongensis	40.00	0.25	0.1	27.82	12.12	3.37
	E. agallocha	40.00	0.92	0.37	27.19	12.12	3.29
Total				47.80			14.29
Intermediate	*A. marina*	38.63	108.63	41.96	28.56	12.12	3.46
	B. cylindrica	40.00	12.95	5.18	33.80	12.12	4.10
	X. mekongensis	40.00	0.25	0.1	29.74	12.12	3.60
	E. agallocha	40.00	0.92	0.37	17.87	12.12	2.17
Total				47.61			13.33
Dry	*A. marina*	40.00	108.63	43.45	30.37	12.12	3.68
	B. cylindrica	40.00	12.95	5.18	34.95	12.12	0.47
	X. mekongensis	39.44	0.25	0.10	30.25	12.12	3.67
	E. agallocha	40.00	0.92	0.37	32.26	12.12	3.91
Total				49.1			11.73
Mean total C (t ha^{-1})				48.17			13.12
KSNP							
Wet	*A. officinalis*	40.00	37.22	14.89	37.06	4.06	1.50
	B. parviflora	40.00	266.74	106.70	27.97	4.06	1.14
	R. mucronata	37.19	1.07	0.40	26.25	4.06	1.07
Total				121.99			3.71
Intermediate	*A. officinalis*	40.00	37.22	14.89	26.98	4.06	1.10
	B. parviflora	40.00	266.74	106.70	30.86	4.06	1.25
	R. mucronata	40.00	1.07	0.43	36.19	4.06	1.50
Total				122.02			3.82
Dry	*A. officinalis*	38.52	37.22	14.34	n.a.	n.a.	n.a.
	B. parviflora	40.00	266.74	106.70	20.00	4.06	0.81
	R. mucronata	39.37	1.07	0.42	35.40	4.06	1.44
Total				121.46			2.25
Mean total C (t ha^{-1})				121.82			3.26

*Above-ground vegetation carbon pools were determined as the product of vegetation above-ground biomass multiplied by wood carbon content (stem part in percentage), following *Kauffman et al.* (*2011*).

**The belowground vegetation carbon pools were calculated as the product of vegetation below-ground biomass multiplied by root mean carbon content (%), following *Kauffman et al.* (*2011*).

carbon content in SHD is much higher than in KSNP as a result of a higher belowground biomass in SHD. Although SHD and KSNP share very similar values in terms of vegetation carbon stock (**Table 1**). The total mean organic carbon stored within the vegetation (aboveground and belowground) was only 61.29 t ha^{-1} C in SHD, significantly lower than in KSNP which was 126.52 t ha^{-1} C (**Table 2**). It is deduced that undisturbed forest in KSNP is significantly more efficient in storing organic carbon compared to degrading forest in SHD.

Soil Carbon

There is a similar finding in carbon content in soil as in the vegetation in both sites (**Table 3**). The mean organic carbon content in the mangrove soil of SHD was 90.11 t ha^{-1} C, lower than in KSNP with 119.69 t ha^{-1} C ($p < 0.05$). The ANOVA test revealed that the organic carbon content across seasons in both locations showed a significant difference ($p < 0.05$), unlike in the vegetation. Intermediate season was very pronounced in KSNP whiledry season showed the lowest carbon content. Conversely, intermediate season stored the lowest carbon content in SHD while wet and dry seasons showed the highest accumulation of carbon in SHD.

The findings on soil organic carbon content based on soil depth revealed that in general, the soil organic carbon decreased with depth, with the bottommost layer (20-30 cm) having the lowest organic carbon content. The Tukey HSD post hoc test revealed that there was a significant difference in soil organic carbon content for each depth in SHD ($p < 0.05$), between 0-10 cm and 20-30 cm, but similar finding was not observed for KSNP.

Ecosystem Carbon Stocks and Economic Valuation

The total ecosystem C stock in SHD was 151.40 t ha^{-1} C and 246.21 t ha^{-1} C in KSNP (**Figure 2**). This study revealed that the soil carbon content made up 60% of the total ecosystem carbon stock in SHD and 49% of the stock in KSNP. After conversion to CO_2e, it was revealed that SHD had the potential to emit as much as 555.64 t ha^{-1} CO_2e while KSNP had a CO_2e of 898.31 t ha^{-1}.

Estimates have been made, based on per ha area since no valid data on actual mangrove coverage for SHD can be found (**Table 4**). For both study areas; SHD could be valued from USD 3,333.84 – 10,657.18 ha^{-1}, whereas KSNP could have a value in the range of USD 5,389.83-17,229.59 ha^{-1}. This finding reflects that there could be a huge difference in economic value between undisturbed and degrading mangrove forests, as well as how important it is to preserve such a large area for ahuge potential economic return. Looking at KSNP with a coverage of 323 ha, the potential economic return would be a minimum of USD 1.74 M.

Table 3. Soil carbon storage of mangrove forests in SHD and KSNP.

Location	Season	Soil depth (cm)	OC (%)	Bulk Density (g/cm^3)*	Soil Carbon Storage (t ha^{-1})	Total Soil Carbon Storage by season (t ha^{-1})	Average Total Soil Carbon Storage (t ha^{-1})
SHD	Wet	0-10	7.26	0.57	41.38	100.99	90.11
		10-20	5.22	0.57	29.76		
		20-30	5.24	0.57	29.85		
	Inter-mediate	0-10	4.55	0.57	25.93	69.95	
		10-20	3.97	0.57	22.61		
		20-30	3.76	0.57	21.41		
	Dry	0-10	5.97	0.57	34.01	99.38	
		10-20	6.59	0.57	37.56		
		20-30	4.88	0.57	27.81		
KSNP	Wet	0-10	6.05	0.65	39.35	111.09	119.69
		10-20	5.93	0.65	38.52		
		20-30	5.11	0.65	33.22		
	Inter-mediate	0-10	7.70	0.65	50.03	152.95	
		10-20	8.76	0.65	56.91		
		20-30	7.08	0.65	46.01		
	Dry	0-10	5.41	0.65	35.18	95.03	
		10-20	4.82	0.65	31.36		
		20-30	4.38	0.65	28.49		

Note: The soil carbon pools were determined as the product of mean carbon percentage of each season for each depth multiplied by soil bulk density and the soil depth interval, following Kauffman et al. (2011).
*The bulk densities were 0.65 and 0.57 g/cm^3 for KSNP and SHD, respectively (*Hemati et al. 2015*).

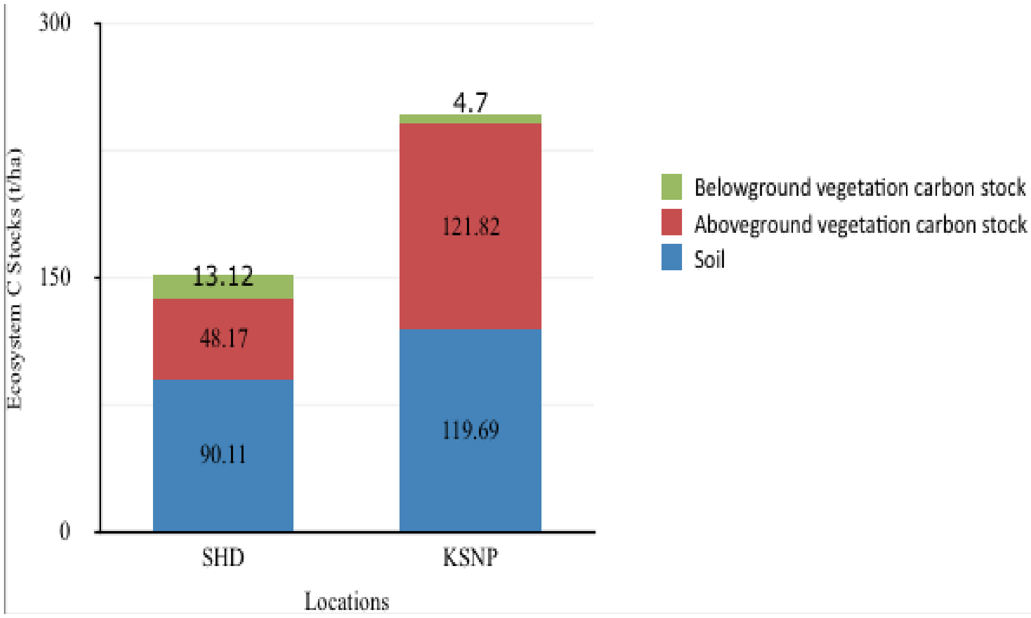

Figure 2. Ecosystem carbon stocks in SHD and KSNP

Table 4. Estimated price of carbon stocks in SHD and KSNP, based on various global market sources (modified from *Ullman et al. 2013*).

Study site	Total carbon stock of the sampled stand (t ha $^{-1}$)*	Total CO_2e (t ha^{-1})	Carbon market value (USD ha^{-1})$	
			Voluntary market price (USD 6.00)	EU emissions trading scheme price (USD 19.18)
SHD	151.40	555.64	3,333.84	10,657.18
KSNP	246.21	898.31	5,389.83	17,229.59

Note *Total CO_2e is calculated by multiplying the total carbon stock (t ha^{-1}) with 3.67.
$ calculated by multiplying total CO2e with the market price.

Discussion

The current study showed that higher aboveground biomass reflects higher carbon content. *Wang et al. (2013)* also discovered that forest organic carbon density increases with biomass growth and stand age of the mangrove forests. As a mature established forest, KSNP recorded a higher biomass, largely contributed by *B. parviflora* with estimation of 266.74 t ha^{-1} (*Hemati et al. 2014*). In this study, KSNP is an undisturbed managed mangrove forest with an aboveground organic carbon accumulation of 121.82 t ha^{-1} C, more than twice compared to degrading SHD with 48.17 t ha^{-1} C. Similar results were obtained by *Gleason and Ewel* (*2002*) in their study of a Micronesian mangrove forest, as well as by *Sun* (*2011*) and *Zhang et al.* (*2012*) in their studies of a mangrove forest in South China. In their studies, the organic carbon content was positively correlated to the living vegetation aboveground biomass. *Sun* (*2011*) also reported that the organic carbon in mature forest (105.73 t ha^{-1}) was higher than that in young (74.43 t ha^{-1}) and middle-aged mangrove forest (87.69 t ha^{-1}).

Mature forest would have a larger vegetation biomass and greater net productivity, as well as more plant litter and dead root input as organic matter for the soil, which would explainthe carbon rich thick sediment formed in the 0-50 cm soil layers (*Forrester et al. 2013*). Hence, mangrove forests constitute efficient sinks for organic C and N, and even essential nutrients that ensure increased rate of plant growth (*Holguin et al. 2001*).

The organic carbon in the soil could be autochthonous (a mangrove production) or allochthonous (imported from other water bodies or from adjacent water bodies) (*Bouillon et al. 2004; Chen et al. 2012*). The distribution and dynamics of the soil organic carbon content may differ due to the influence of the tide, vegetation biomass and productivity, species composition and sedimentation (*Sherman et al. 2003*). Furthermore, *Lacerda et al.* Mature forest would have a larger vegetation biomass and greater net productivity, as well as more plant litter and dead root input as organic matter for the soil, which would explainthe carbon rich thick sediment formed in the 0-50 cm soil layers (*Forrester et* *al. 2013*). Hence, mangrove forests constitute efficient sinks for organic C and N, and even essential nutrients that ensure increased rate of plant growth (*Holguin et al. 2001*).

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Findings of this study also discovered that season plays an important role in storing carbon in soil. Findings by *Cerón-Bretón et al.* (*2011*) and *Raza et al.* (*2011*) showed that the highest soil organic carbon content was during the dry season, concurred by this study in SHD but the opposite of KSNP. Perhaps intermediate season was the optimum condition for KSNP where the freshwater input is constant and not too much rampant tidal flooding occur which leads to anaerobic condition to the soil. Such condition improves the rate of accumulation and decay of the organic matter, which then causes the uprising of carbon storage in KSNP. This seasonal change from dry to wet could be related to the presence of organic matter in the soil sediment. *Eslami-Andargoli et al.* (*2009*) reported that the precipitation pattern may affect the distribution of mangroves by providing a greater fluvial sediment supply and lower sulphate content, and by reducing salinity (*Ellison 2000*). In fact, during the rainy season, the occurrence of tidal flooding is more frequent, which makes the soil sediment more susceptible to being washed away by the current.

According to *Zhang et al.* (*2009*), the organic carbon content of soil sediment is affected by the spatial variation of forests with coastal area. The sedimentation rate in SHD is low, mainly due to forest clearing activities which have led to rampant tidal erosion, causing the accumulation of organic matter to decrease. In addition, *Tam and Wong* (*1998*) concluded that low organic carbon content is probably due to frequent tidal wash away and the export of mangrove litter and organic matter. They discovered that >30% of organic matter could be found landward of the mangrove forest, which promoted higher organic carbon burial within the soil sediment. The accumulation of sediment and particulate matter is further enhanced by the presence of the stilt roots of *Rhizophora* sp. in undisturbed forest in KSNP (*Raza et al. 2011*). Despite the occurrence of tidal wash away in SHD, the tides and current assist in carrying additional organic carbon input into SHD, and the long term tidal inundation has greatly increased the rate of decomposition in SHD. The accumulation of organic matter also decreases, thereby lowering the decomposition rate, thus causing the carbon stored in the sediment to decrease.

Several studies and publications have highlighted the importance of mangrove forests as carbon sink. With the implementation of carbon credits, mangrove forest could potentially become a new market for carbon trading. Carbon sinks could help to offset the carbon emitted by absorbing the atmospheric carbon into the ecosystem; in which all the terrestrial and aquatic forests shared the function. For instances, in Malaysia, carbon sinks in oil palm plantations have been implemented in CDM under Kyoto Protocol. As one of the top producers in palm oil industry, Malaysia would have the potential to trade approximately RM 252 M per yr^{-1}

(USD 63M yr^{-1}) through composting and conversion of biomass to energy using the residues of palm oil (*Oh and Chua 2010*). But Malaysia does not need to stop at oil palm only; the vast green forest ecosystems which are already available and intact are potentially to give similar economic return. Mangroves are suitable for any PES schemes, although the ecosystem is very dynamic as a result of its location and management strategies upon it. In fact, the size of the CDM market is big and there lie a lot of opportunities for local corporate players to involve in the industry (*Amran et al. 2013*). Platforms are already available for Malaysian government to develop and implement a policy which treats all the sources of GHG equally but not only focus on specific industry and technology. Conservation of forested land and carbon-rich peat land as well as mangrove forests could be a significant step to reduce carbon emission. In other words, if the natural mangrove forest in Malaysia is well preserved, KSNP with a coverage area of 323 ha could provide a revenue of USD 1.7 million, based on voluntary carbon credit. As mangrove is a very sensitive ecosystem, minimal disturbance could lead to huge forest degradation, as what have been demonstrated by SHD.

However, *Alongi* (*2011*) argued that carbon payment must depend on carbon sequestration rate, and not the size of carbon stocks, as well as species diversity. Mature forest gains more carbon sequestration rate compared to rehabilitated forests, thus conservation by leaving the mangrove intact and minimal use is the key.

CONCLUSION

This study discovered that, although both sites contained different mangrove species, the carbon allocation within the vegetation parts were very similar, and both sites exhibited greater carbon storage in the aboveground biomass, especially in the stem parts. Seasonal changes do not affect the efficiency of carbon stored in vegetation. However, they differed significantly in terms of carbon stock in the soil according to the seasons, and both areas stored most of the carbon near the soil surface between 0-15 cm. The soil surface layer had the highest amount of organic carbon due to litter production, the high rate of decay and the decomposition process. In fact, this study recorded the soil biomass contributed about 49-60% of the stored ecosystem carbon stock. The carbon stock gathered from both undisturbed and degrading sites revealed that they were both capable of storing high amount of carbon. In fact, the total ecosystem carbon stock in KSNP was 246.21 t ha^{-1} C and in SHD was 151.40 t ha^{-1} C. However, this study only sampled 30 cm deep soil, which could be quite shallow and therefore, the results expressed here could be underestimated compared to other studies. This study also concludes that seasonal change will not affect the efficiency of the mangrove forest to store carbon in its vegetation but can influence the soil carbon stock. By using voluntary market mechanism, KSNP with its huge area and conservation status could return as minimal as USD 5,389.83-17,229.59 ha^{-1}, whereas a smaller and degrading mangrove forest at SHD can still worth USD 3,333.84-10,657.18 t ha^{-1} C. Clearly, carbon trading can be recognized as one of the most effective ways to reduce carbon emissions. Through valuation creation for mangrove forest, Malaysia should use its strength as the nation with rich biodiversity and tropical rainforest and strive towards sustainability.

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