

Carbon pools and fluxes in *Bruguiera parviflora* dominated naturally growing mangrove forest of Peninsular Malaysia

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Abstract Estimation of carbon pools and fluxes were conducted in *Bruguiera parviflora* dominated naturally growing protected mangrove forest in Kuala Selangor Nature Park of Peninsular Malaysia. Above and below-ground carbon pools in seedlings were estimated from destructive methods. While, carbon pools and fluxes in saplings and trees were estimated from the derived allometric biomass equations. Carbon concentrations in different parts of seedlings, saplings and trees; and litter were measured during the dry, wet and intermediate seasons. Soil cores up to 1 m were analyzed to measure carbon concentrations and bulk densities at different depths. Litter standing crop of the study area was measured at the dry, wet and intermediate seasons and the range of total amount of litter standing crop was from 0.66 to 0.88 Mg/ha. Carbon concentration found to vary with the plant and litter parts; and also with the seasons and the range of mean weighted carbon concentration was 40.19 ± 0.87 – 56.52 ± 1.01 %. The carbon pools in seedling, sapling, tree and litter were 0.69, 0.51, 82.62 and 0.41 Mg C/ha respectively. However, 13.95 Mg C/ha/year of carbon flux was associated with saplings, trees and litter. The estimated carbon pool in the soil (up to 1 m) of the study area was 488.04 Mg C/ha. The findings of this study are the first estimation of carbon pools and

fluxes in *B. parviflora* dominated sites and suggests the potential of this site as a carbon pool.

Keywords Carbon flux · Carbon pool · Biomass · *Bruguiera parviflora* · Litter · Mangroves

Introduction

At the beginning of industrial revolution, atmospheric CO₂ concentration increased from 290 to 370 ppm by the year of 2002 (Keeling et al. 1989; Kimmins 2004). The future prediction of CO₂ concentration in the atmosphere is highly variable and depends on the trends of population increase, per capita use of fossil fuels, land use changes and rate of deforestation (Kimmins 2004). Elevated concentration of CO₂ in the atmosphere leads to global warming and results in climate change. Climate change and its consequences are the major threats towards sustainable development. Scientific communities are concerning about the climate change problems and looking for different mitigation technologies and measures. The most promising measures are to reduce the emission of CO₂ and conservation of forest. Forestry can make significant contributions to mitigate this global risk with adaptation and sustainable development (IPCC 2007). Most of the carbon studies were focused on the terrestrial forests. But, the role of mangroves and

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wetlands in carbon sink were ignored previously (Rattan 2008; Komiyama et al. 2008; Kridiborworn et al. 2012).

Mangrove forests are serving as carbon sink; and these forests provide feeding, breeding, and nursery ground for a variety of fish and wild life, recreational opportunities, and protection from coastal storms and extreme weather events (Ellison 2008; Alongi 2009). These forests support the dissolved and particulate form of carbon to the aquatic ecosystem which is important for the benthic and pelagic communities in the adjacent waters (Bouillon et al. 2008). The mangrove forests have high root-shoot ratios (Fujimoto et al. 1999; Page et al. 2002; Komiyama et al. 2008), and have the capacity to store great amount of carbon in soil at several meters depth (Bouillon et al. 2003). Mangroves have more carbon in their soil alone than most tropical forests have in all their biomass and soil combined (Kristensen et al. 2008; Donato et al. 2011). In spite of their ecological, economic and social importance, the mangrove forests are threatened by land use changes. Rates of deforestation/conversion are among the highest of all tropical forests, far exceeding rates in upland forests (Valiela et al. 2001; Langner et al. 2007).

Malaysia contributes about 4 % of the world mangrove forest and these are under sustainable yield management practices. Peninsular Malaysia contains only 17 % of the country's total mangrove forests, which mostly concentrates on the sheltered west coast, and almost continues from Kedah to Singapore. Of these forests, only 0.3 % of mangrove areas are legally gazetted as protected areas (Spalding et al. 1997). Total mangroves area in Malaysia was about 650,000 ha during 1982 (Ong 1982) and this area coverage was reduced to about 641,000 ha at the end of 1993 (ISME 1993). During this time, about 9,000 ha of mangrove forest were destroyed, which constituted 1.26 % of yearly destruction and remains higher than the world average destruction rate. The destruction of mangrove areas in Malaysia is mainly due to the construction of sea ports, airports, and industrial estates and agricultural land use. The depletion of mangroves results in serious environmental and economic constraint in the coastal region (Ong 1982). These forests may be of high value in terms of carbon storage, which is particularly relevant to climate change mitigation strategies focusing on reducing carbon emissions through reduction of

destruction. Reduced Emissions from Deforestation and Forest Degradation (REDD+) in developing countries has emerged as a likely component of the next international policy effort addressing climate change, to be implemented when the Kyoto Protocol expires in 2012 (Kanninen et al. 2007). This programme would offer economic incentives for conserving forests and associated carbon stocks, intended to offset the short-term economic factors that promote deforestation. Malaysian mangrove forests can be ideal candidates for REDD+ strategies. However, the viability of such a programme depends heavily on having sound information on carbon storage in forests, and how much carbon may be released when these forests are converted. The quantification of carbon emission from deforestation and conversely their values as carbon reservoirs, it is important to quantify the total ecosystem carbon stock. Only one study (e.g. Ong 1993) has quantified the carbon stock (above-ground and below-ground) in Malaysian mangroves. Recent reviews of coastal carbon dynamics and energetics contained little or incomplete data on the total ecosystem carbon storage of mangroves (Bouillon et al. 2008; Alongi 2009; Laffoley and Grimsditch 2009). Therefore, the aims of this study were to estimate the carbon pools and fluxes (above and below ground) in the naturally growing protected mangrove forest in Peninsular Malaysia.

Materials and methods

Description of the study site

The study area is *Bruguiera parviflora* Wight & Arn. dominated naturally growing mangrove forest in Kuala Selangor Nature Park (Latitudes 3°19'–3°20'N and 101°14'–101°15'E) on the west coast of the Malay Peninsula. It is a fringing mangrove growing at the mouth of the Selangor River, which has an average width of 200 m between sea and land interface. This mangrove forest belongs to Watson's (1928) tidal inundation class 4 (the maximum tidal height is 4 m above the datum). *Bruguiera parviflora*, *Avicennia alba* Blume, *Rhizophora apiculata* Blume, *R. mucronata* Lam and *Sonneratia caseolaris* (L.) Engl. are the common species in this forest. The mean annual rainfall is about 1,790 mm. The wet season (September–December), intermediate season (January–April)

and dry season (May–August) contribute about 46, 31 and 23 % of the annual rainfall respectively. The mean minimum and maximum temperatures are 24 and 32 °C respectively. Soil texture is clay and pH varies from slightly acidic to neutral (6.77–7.07). Soil salinity varies from 39.03 to 59.03 m.e./100 g and cation exchange capacity varies from 34.53 to 38.23 m.e./100 g (Mahmood 2004).

Standing biomass and annual biomass increment

Above- and below-ground biomass of *B. parviflora* seedlings was estimated from destructive sampling method. A total of eighteen plots (1 m × 1 m) were selected randomly and seedlings of *B. parviflora* inside the plots were collected with their root system. Low-pressure water jet was used to loosen the soil from the collar region of seedlings and the surrounding areas at 50 cm radius. Once the soil was sufficiently loosened, the seedlings were uprooted. The collected seedlings from each plot were then separated into leaves, stems and roots. The fresh mass of each part was measured and recorded in the field at plot basis. Sub-samples from each part (about 0.25 kg) were brought back to the laboratory to obtain fresh to oven dry mass conversion ratios at 80 °C. The oven-dry mass (kg) of seedling parts was calculated from the respective fresh to oven-dry mass (kg) conversion ratios. The above and below-ground biomass and annual biomass increment of *B. parviflora* saplings and trees were taken from Mahmood et al. (2008).

Litter standing crop and litter production

Natural litter bed (leaves, small branches, bracts and propagules) of the study area was observed from 18 randomly selected plots (1 m × 1 m) during the wet, intermediate and dry seasons. All litter from the individual plot was collected. The collected litter was washed thoroughly to remove all the dirt and sediment particles and sorted into leaves, small branches (diameter <2 cm), bracts and propagules. Leaves were again sorted into intact and broken leaves. The sorted litter was oven dried at 80 °C until constant mass. Total amount of litter standing crop and their parts in different seasons were compared by one way analysis of variance followed by Duncan Multiple Range (DMRT) Test by using SAS (6.12) statistical

software. The amount and rate of litter production of the study area was taken from Mahmood et al. (2005).

Carbon in plant and litter parts; and soil

Six seedlings were randomly selected, uprooted and separated into parts as described earlier. Six saplings were randomly selected and uprooted by low pressure water jet and portable winch. Collected saplings were then separated into different parts (leaves, buds, branches, bark, stems and roots). Six trees were selected randomly and sub-samples of leaves, buds, and small branches (diameter <2 cm) were collected by using sharp knife attached with long pole. Bark samples were collected by using sharp knife and stem samples were collected by using stem borer. One buttress root was selected randomly from each tree and roots were excavated followed by the buttress root by using water jet. Sub-samples (about 100 g) of different parts of seedlings, saplings and trees were collected randomly during the dry, wet and intermediate seasons. Sub-samples were then oven-dried at 80 °C until constant mass. Eighteen litter traps (1 m × 1 m) were suspended under the tree canopy at a height of 1.5 m above the ground level (beyond the reach of high tides). The trapped litter was collected at monthly to get the litter samples during the dry, wet and intermediate seasons. Season wise litter samples were sorted into leaves, small branches, bracts, flowers and propagules and oven dried at 80 °C until constant mass. Nine samples of soil were collected randomly for the determination of bulk density and carbon concentration at the following depths: 0–15, 15–30, 30–50 and 50–100 cm by using core sampler of 5 cm diameter. The different samples of seedlings, saplings, trees and litter parts; and soil were processed according to Allen (1974). Carbon concentrations in the samples were measured by using Leco CR—12 Carbon determinator, USA. Carbon concentration in different parts of seedlings, saplings and trees and litter at different seasons were compared by one way analysis of variance followed by DMRT ($p < 0.05$) by using SAS (6.12) statistical software. Carbon pool in plant parts was estimated from their weighted mean carbon concentration and the respective oven-dry biomass. Carbon pool in each soil layer was estimated as the product of the carbon concentration and their corresponding bulk density of each layer.

Results

Biomass and annual biomass increment

The above and below-ground biomass of seedlings, saplings and trees of *B. parviflora* were 1.12, 0.89 and 142.46 Mg/ha; 0.25, 0.14 and 18.93 Mg/ha respectively (Table 1). Mahmood et al. (2008) reported the yearly average biomass increments for saplings and trees were 0.58 and 16.51 Mg/ha/year respectively (Table 2).

Litter standing crop and litter production

The amount of different parts of litter standing crop showed significant ($p < 0.05$) variation among the seasons. Comparatively ($p < 0.05$) higher amount of leaf litter standing crop was observed during the intermediate seasons and lower amount during the dry seasons. The amount of total litter standing crop was ranged from 0.66 to 0.88 Mg/ha (Table 3). Litter production was 10.35 t/ha/year and the rate of leaf litter, small branches, bracts, flowers, propagules and total litter production varied from 1.63 to 3.07, 0.08 to 0.38, 0.13 to 0.39, 0.01 to 0.23, 0.03 to 2.29 and 2.31 to 4.46 g/m²/day respectively (Mahmood et al. 2005).

Carbon concentration in plants and litter parts; carbon pool and fluxes

Seasonal fluctuation in carbon concentration in different parts of seedlings was observed and stems (48.64 ± 0.08 – 56.24 ± 0.03) contained relatively ($p < 0.05$) higher carbon followed by leaves and roots (Fig. 1). In saplings parts, stems (46.53 ± 0.06 – 52.40 ± 0.08 %) and branches (48.05 ± 0.03 – 50.28 ± 0.06 %) showed comparatively ($p < 0.05$) higher carbon concentrations at different seasons and leaves contained lower carbon (Fig. 2). In trees, stems (45.26 ± 0.01 – 57.52 ± 0.02 %) and roots (46.06 ± 0.01 – 53.68 ± 0.03 %) contained comparatively ($p < 0.05$) higher carbon concentration during different seasons (Fig. 3). However, comparatively ($p < 0.05$) higher carbon concentration (48.77 ± 0.07 – 54.92 ± 0.02 %) was found in leaves of litter production in different seasons (Fig. 4) and all the parts of litter standing crops showed wide range in carbon concentration among the seasons (Fig. 5). Most of the parts of seedlings, saplings, trees and litter were found to contain higher carbon concentration during the dry

Table 1 Standing biomass of different parts of seedlings, saplings and trees of *Bruguiera parviflora*

Growing stage	Total above and below ground biomass (Mg/ha)	Total above ground biomass (Mg/ha)	Roots biomass (Mg/ha)	Stems with bark (Mg/ha)	Stems without bark (Mg/ha)	Bark (Mg/ha)	Branches (Mg/ha)	Leaves (Mg/ha)	Buds (kg/ha)	Flowers (kg/ha)
Seedlings	1.37	1.12	0.25	0.72				0.40		
Saplings ^a	1.03	0.89	0.14	0.69	0.61	0.08	0.12	0.08	5.01	
Trees ^a	161.39	142.46	18.93	92.39	81.28	11.11	38.23	10.91	518.85	412.66
Total	163.79	144.47	19.32	93.80		11.19	38.35	11.39	523.86	412.66

^a Values after Mahmood et al. (2008)

Table 2 Annual biomass increment in different parts of *Bruguiera parviflora* saplings and trees (after Mahmood et al. 2008)

Growing stage	Leaves (Mg/ha)	Bud (Mg/ha)	Branches (Mg/ha)	Stems (Mg/ha)	Bark (Mg/ha)	Roots (Mg/ha)	Total (Mg/ha)
Saplings	0.04		0.06	0.38	0.05	0.05	0.58
Trees	1.11	0.05	4.11	7.99	1.09	2.16	16.51

Table 3 Amount of litter standing crops at different seasons

Sampling season	Intact leaves (Mg/ha)	Broken leaves (Mg/ha)	Small branches (Mg/ha)	Bract (Mg/ha)	Propagules (Mg/ha)
Wet season	0.237 ± 0.005 ^b	0.238 ± 0.008 ^b	0.170 ± 0.019 ^a	0.011 ± 0.000 ^b	0
Intermediate season	0.296 ± 0.019 ^a	0.329 ± 0.032 ^a	0.169 ± 0.024 ^b	0.015 ± 0.000 ^a	0.01 ± 0.002 ^b
Dry season	0.176 ± 0.014 ^c	0.213 ± 0.005 ^c	0.146 ± 0.009 ^c	0.009 ± 0.000 ^c	0.334 ± 0.141 ^a

Mean values in each column identified with the same letter are not significantly ($p > 0.05$) different

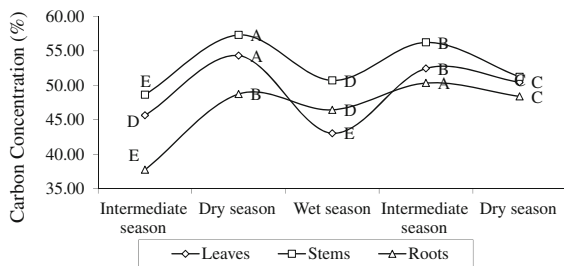


Fig. 1 Carbon concentration in different parts of seedlings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly ($p > 0.05$) different

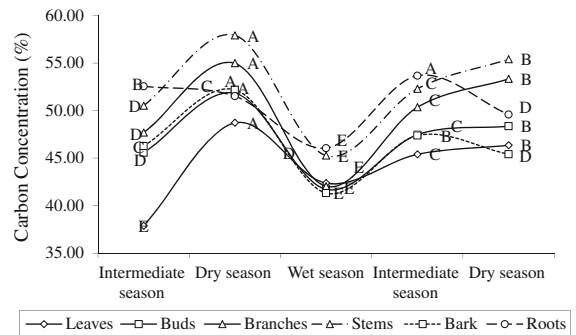


Fig. 3 Carbon concentration in different parts of trees at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly ($p > 0.05$) different

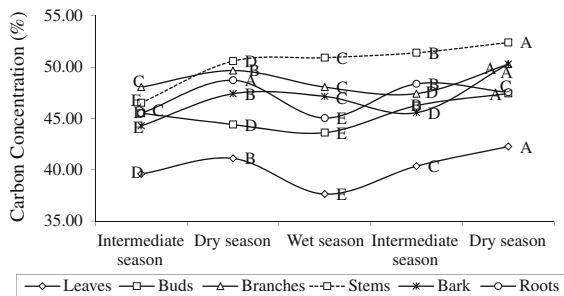


Fig. 2 Carbon concentration in different parts of saplings at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly ($p > 0.05$) different

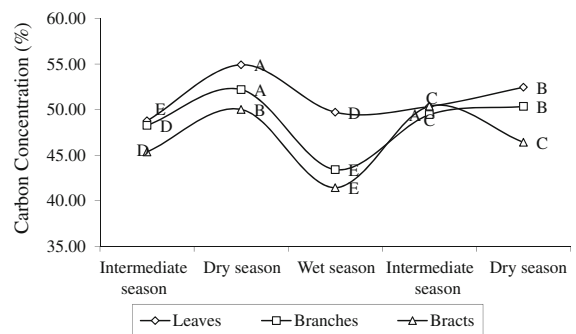


Fig. 4 Carbon concentration in different parts of litter production at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly ($p > 0.05$) different

seasons (Figs. 1, 2, 3, 4, 5). Considerable variations in weighted mean carbon concentrations (40.19 ± 0.87 – 56.52 ± 1.01) were observed for different parts of seedlings, saplings, trees and litter (Table 4). The carbon pools in above and below-ground plant material

were 74.45 and 9.78 Mg C/ha respectively. The estimated carbon pool in the soil (up to 1 m) of the study area was 488.04 Mg C/ha. However, 13.95 Mg C/ha/year of

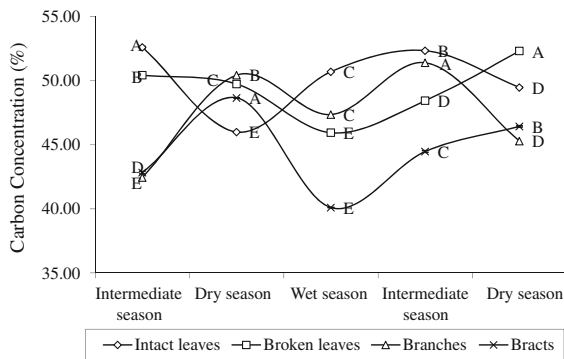


Fig. 5 Carbon concentration in different parts of litter standing crop at different seasons. Means with similar alphabet in the same line (according to seasons) are not significantly ($p > 0.05$) different

carbon flux was associated with different parts of saplings, trees and litter production (Table 5).

Discussion

Carbon concentrations in different parts of plant are strongly related with the biological activities of the plant parts (Santa Regina 2000) and structural components of plant cell (Kaakinen et al. 2004). This could be the reason for observing variation in carbon concentration in different parts of plants and litter components. Moreover, comparatively higher carbon concentrations were usually observed in woody parts of plants (Figs. 1, 2, 3, 4, 5) (Hart et al. 2003) because they contain higher concentrations of cellulose, hemicellulose and lignin (Schädel et al. 2009; Körner 2003). Plant species, types of plant parts and physiological age of the tissue and seasons (dry and wet) may influence the carbon concentration in plant parts (Salazar et al. 2010). Seasonal variation in carbon concentrations in plant parts was also reported and higher concentrations were observed during dry seasons (Figs. 1, 2, 3, 4, 5). Similar observation of carbon concentrations in different parts of *Sonneratia apetala*, *Excoecaria agallocha* and *Avicennia alba* were also described by Mitra et al. (2011) for the Sundarbans mangrove forest. The dry seasons of the study area were characterized by high salinity (30 ppt) of water and lower numbers of tidal inundation (25 tides, May–August) compared to wet seasons (25 ppt water salinity; 45 tides, September–December) (Mahmood 2004). Salinity may have positive relationship

with carbon assimilation in salt tolerant species (Asch et al. 2000) and tidal inundation showed negative relationship with net ecosystem exchange of CO_2 and carbon assimilation for the salt marshes (Kathilankal et al. 2008). Irrespectively, seasonal variation in carbon concentrations in different parts of plants and litter may be due to the variability in assimilation of CO_2 by plants in relation to solar irradiation, moisture, temperature (Kato and Tang 2008), and different stress factors like high salinity, arid environment, and low availability of nutrients (Bouillon et al. 2008; Barr et al. 2010). Higher amounts of net ecosystem exchange of CO_2 and net primary productivity are observed during the growing season and expecting higher increment of biomass and carbon concentration in plant parts (Zha et al. 2007; Ardö et al. 2008). Moreover, these variations of carbon concentration in plant parts may affect the carbon pools and fluxes at season as well as annual scales in mangroves as reported by Mitra et al. (2011).

Quantification of mangrove carbon pools and its monitoring over time can be important information for formulating climate change mitigation strategies. The total carbon pool (572.27 Mg C/ha) (above and below-ground plant material and soil carbon to 1 m) in the study area was comparatively higher than the carbon pool (411–414 Mg C/ha) in Palau and Yap site of Micronesian mangrove forest dominated by *S. alba*, *R. apiculata* and *B. gymnorhiza* (Kauffman et al. 2011). Moreover, the much lower carbon pools (119.3 Mg C/ha) in *Kandelia obovata* dominated mangrove stand at Okinawa Island of Japan was reported by Khan et al. (2007). While comparatively higher carbon pool (993.3 Mg C/ha) and higher carbon flux (20 Mg C/ha/year) were recorded from the Indonesian mangrove forests (Murdiyarso et al. 2009) and Matang mangrove forest of Malaysia (Ong 1993) respectively. The variation in carbon pool in different mangrove forest arises from carbon storage in above-ground biomass, forest structure (Bradford et al. 2010), forest age (Kridiborworn et al. 2012; Cerón-Bretón et al. 2011), disturbance history (Goodale et al. 2002), dominant species (Ksawani et al. 2007) and below-ground carbon pool. Below-ground pools contribute to a significant proportion (88–98 %) to the total pool of carbon of mangroves (Murdiyarso et al. 2009). This below ground carbon pool largely depends on the depth of the organic soil, carbon concentration in soil, vegetation cover (Conant et al. 1998). Significant

Table 4 Weighted mean carbon concentration in different parts of seedlings, saplings, trees and litter of *Bruguiera parviflora*

	Carbon concentration (%) of dry weight							
	Leaves	Buds and Bract	Flowers	Propagules	Branches	Stems	Bark	Roots
Seedlings	49.18 ± 0.98	–	–	–	–	52.83 ± 0.87	–	46.33 ± 1.14
Saplings	40.19 ± 0.87	45.44 ± 1.03	–	–	48.70 ± 1.23	50.37 ± 1.32	46.94 ± 0.88	47.04 ± 1.36
Trees	44.14 ± 1.02	46.99 ± 0.99	47.30 ± 0.88	–	49.68 ± 0.97	52.29 ± 0.86	56.52 ± 1.01	50.68 ± 0.79
Litter production	51.24 ± 0.75	46.72 ± 1.12	51.09 ± 1.14	51.00 ± 0.95	48.74 ± 0.85	–	–	–
Litter Standing crop	49.80 ± 1.14	44.50 ± 1.07	–	50.40 ± 1.23	47.40 ± 1.62	–	–	–

Table 5 Carbon pool and carbon flux in *Bruguiera parviflora* dominated mangrove forest

Category	Unit
Carbon pool (Mg C/ha)	
Live above-ground	
Seedlings	0.57
Saplings	0.44
Trees	73.03
Live below-ground	
Seedlings	0.12
Saplings	0.07
Trees	9.59
Forest floor	
Litter standing crops	0.41
Soil carbon (cm)	
0–15	62.96
15–30	77.77
30–50	100.41
50–100	246.90
Carbon flux (Mg C/ha/year)	
Live above-ground	
Saplings	0.26
Trees	7.35
Live below-ground	
Saplings	0.02
Trees	1.09
Forest floor	
Litter production	5.23

differences in carbon flux in mangrove forests depend on soil conditions (Oren et al. 2001), climatic conditions (Barford et al. 2001), variations in rate of biomass increment among the species and litter production (Bradford et al. 2010). These factors and relationships are essential for understanding the control over forest carbon pools and fluxes over large areas (Waring and Running 1998; Kennedy et al. 2006).

Estimation of carbon pools as well as carbon flux in naturally growing mangrove forests give more insight into the ecological services and role of mangroves. Moreover, this study helps to develop the rapid assessment and monitoring of the carbon pool in Malaysian mangroves. Mangroves appear to be one of the most carbon dense types of tropical forest. The information generated from this study will help in evaluating their values and benefits from conservation

and restoration of mangroves. Moreover, mangroves could benefit from REDD+ and should be considered among strategies for climate change mitigation.

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