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ORIGINAL ARTICLE

Biodiversity and biomass of a natural and degraded mangrove forest of Peninsular Malaysia

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Abstract Anthropogenic activities have always been the cause of most environmental degradation, and mangrove disappearance is no exception. A comparative assessment on the biodiversity of natural and degraded mangrove forests has been undertaken, looking at the biomass, both above-ground and below-ground. The natural and the degraded mangrove forests were situated at Kuala Selangor and Sungai Haji Dorani, respectively, both on the West coast of Peninsular Malaysia. A random sample scheme with quadrate sample plots (10 m × 10 m) was adopted for the measurement of the diameter at breast height and total height of individual tree species at both forests. Diversity indices and above- and below-ground biomass were estimated from this inventory. Eight mangrove tree species were identified at both study areas, namely: *Bruguiera parviflora, Avicennia officinalis*, *Rhizophora mucronata*, *Sonneratia alba*, *Avicennia marina, Bruguiera cylindrica*, *Xylocarpus mekongensis* and *Excoecaria agallocha*. The mangrove species in Sungai Haji Dorani showed high diversity with a Shannon–Weiner Index (H′) value of 0.91, compared to the natural mangrove of Kuala Selangor which has a lower value, H′ = 0.55. The dominant species in the natural mangrove area was *B. parviflora*, with the highest Important Value Index (IVI) of 70.96 %, as opposed to *A. marina* which was the most common species in the degraded mangrove area, with IVI of 49.16 %. An estimate of 305.46 t/ha of above-ground biomass was calculated for the natural mangrove, while 122.78 t/ha was obtained for the degraded mangrove forest. This contrasts with the below-ground biomass estimates, which were 14.09 t/ha for the natural mangrove and 36.35 t/ha for the degraded mangrove.

Keywords Biodiversity · Mangroves · Biomass · Structure · Allometry · *Avicennia* sp · *Bruguiera* sp

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Introduction

Mangroves are woody plants that grow at the interface between land and sea on tropical and sub-tropical sheltered coasts. Therefore, mangrove trees grow in soil that is more or less permanently water logged (Peter 1999). A wide diversity of aquatic and terrestrial species of different taxonomic groups resides in mangrove ecosystems (Dinerstein et al. 1995). Mangroves provide timber, firewood and charcoal, fishing poles, pulp and tannin (Hamilton and Snedaker 1984; Nagelkerken et al. 2008; Walters et al. 2008). Mangroves reduce coastal erosion, flooding and run-off, and provide nutrients (Lugo and Snedekar 1974; Mahmood et al. 2003). They also play an important role in carbon fixation and stocking, control of the quality and quantity of water, and the flux of organic particles to the aquatic ecosystem (Dinerstein et al. 1995). Mangroves are important to estuarine fisheries because of their contribution of detritus and dissolved organic carbon within the food webs, and their roots provide shelter for juvenile

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fish (Mahmood et al. 2005; Mumby et al. 2004; Husch et al. 2003; Machiwa and Hallberg 2002; Alongi et al. 2000).

However, mangroves are disappearing from all over the world at an alarming rate. Estimates indicate that the mangrove area worldwide fell below 15 million ha by 2000, down from 19.8 million ha in 1980. The world has thus lost about 5 million ha of mangroves over that 20-year period, or 25 % of the extent found in 1980. Estimates also indicate that mangrove deforestation continued, on a slightly lower rate in the 1990s (1.1 % per annum) than in the 1980s (1.9 % per annum) (FAO 2003). About 90 % of global mangroves are growing in developing countries, and they are critically endangered and nearing extinction in 26 countries. Malaysia contributes approximately 12 % of Southeast Asia's mangrove area, along the coasts of Sabah (57 %), Sarawak (26 %) and Peninsular Malaysia (17 %). However, about 1 % of the mangrove area in Peninsular Malaysia is being lost each year since 1990 due to conversion to aquaculture, agriculture, deforestation and urban land uses (FAO 2003; Ong 1982). With the intention that such conversions enhance economic empowerment, enable infrastructural development and create conducive leisure/recreational environment as desired by present day lifestyle, little is known on the magnitude of what is lost. Therefore, understanding the importance of mangrove to the costal ecosystem is very important. Though a number of studies have documented forest diversity, structure and biomass, yet little has been related to its role in carbon pool as it pertains to the productivity of mangrove trees. Moreover, a comparative scenario of natural and degraded mangrove is expected to correct the ignorance/negligence on mangrove management, wherein some changes go on within mangrove eco-diversity without clear detection. Mangroves within forest ecosystems in Malaysia are vulnerable to climatic changes; however, it serves as a veritable study area on above-ground and below-ground biomass research across diversity of tree species. In view of that, the present study aimed to evaluate the associated above- and below-ground biomass of the mangrove tree species within the natural and degraded forest of Kuala Selangor and Sungai Haji Dorani, respectively. At the same time, the diversity and similarity of tree species in both areas, with their contrasting degradation status, were also investigated. The generated data will be very beneficial to Malaysian forest management and conservation strategies.

Materials and methods

Study area

Both study areas, Kuala Selangor (03°20′N and 101°14′E) and Sungai Haji Dorani (03°40′N and 100°58′E) are situated in Selangor state, on the West coast of Peninsular Malaysia, bordering the Straits of Malacca (Fig. 1). These areas are under the influence of the northeast monsoon and southwest monsoon, with mean annual temperature of 27.3–27.7 °C. The relative humidity average is 77 % and the mean annual rainfall in the study areas is about 1,701–1,710 mm, where the mean monthly rainfall is 142–164 mm (Department of Meteorology 2012). Kuala Selangor's mangrove forest is known as a healthy natural mangrove while the mangrove in Sungai Haji Dorani is identified as a degrading type (Roslan 2006). The mangrove of Kuala Selangor is fully inundated only during the spring high tides, while the mangrove of Sungai Haji Dorani is a macro tidal beach with a semi-diurnal tidal regime. The soil texture for both study areas is clayey.

Kuala Selangor is a very healthy vast mangrove forest and is currently being managed by the Malaysian Nature Society (MNS), an NGO which was given a task to manage this protected forest. On the other hand, Sungai Haji Dorani is a degrading mangrove forest experiencing a gradual thinning process due to anthropogenic activities and coastal erosion.

Sampling and data collection

A total of eighteen sample plots (10 m × 10 m) were randomly established in both sites from three predetermined transects across the coastline in January 2012. All trees within the plots were identified up to species level and tagged. Diameter at breast height (DBH) of trees inside the plots was measured, while trees with DBH <4 cm were not recorded as they are considered as saplings. Height of trees was also measured and recorded, using a pole.

Vegetation structure

The structural characteristics of the trees, including density, relative density, frequency and relative frequency, mean DBH, mean height, basal area, relative dominance and importance value index of trees were calculated using the relationship given by Cintron and Novelli (1984).

Species diversity

A number of different measures of species diversity have been calculated in this study. This exercise explored three methods for species diversity indices and similarity (Shannon–Weiner Index, Simpson's Index and Sorenson's Similarity Index).

Shannon–Weiner Index

Species diversity is described according to the value of Shannon–Weiner Index (H′) based on the relative

Fig. 1 Locations of study areas

abundance (proportion) of the *i*th species in the community, and natural log (ln). H′ is calculated using the following formula by Mac Arthur (1969):

$$H' = -\sum p_i \ln p_i.$$

The Shannon Index is used to measure habitat quality. Its range is from 0.0 to approximately 4.6. A value of 0.0 means that every organism in the sample is of the same species and 4.6 means the number of individuals are evenly distributed among numerous species.

Simpson's Index (D_s)

A measure that accounts for both richness and proportion (%) of each species is the Simpson's diversity Index. It has been a useful tool for understanding the profile of biodiversity across the zones. If a community with high diversity was randomly sampled twice, there is a good chance that the two samples will contain different species. However, if a low-diversity community was sampled twice, it is likely that both of the samples will be the same species (Simpson 1949). The study derived a formula based on the expected outcome of two random samples and had been adopted in the present study;

$$Ds = \frac{N(N-1)}{\sum n_i (n_i - 1)}$$

where N the total number of individuals of all species, n_i the number of individuals of species i.

Sorenson's similarity Index (S)

The Sorenson's similarity Index is used to indicate that the vegetation species found in the plot's analysis are similar to those vegetation species found in other plots. The range of Sorenson's similarity Index is from 0 to 1. A value of 0 indicates a complete dissimilarity while a value of 1 indicates a complete similarity (Goldsmith et al. 1986). The similarity Index is calculated by following formula:

$$S = \frac{2J}{A+B}$$

where J total species which is similar in both samples, A total species in sample A, B total species in sample B.

Above-ground biomass

A non-destructive method to estimate the above-ground and below-ground biomass was adopted in this study. DBH

and height of each tree was used to estimate the above-ground biomass of trees of the study sites by using different allometric equations derived by Clough and Scott (1989), Komiyama et al. (2000, 2005), Soares and Schaeffer-Novelli (2005), and Ong et al. (2004). Allometric equations describe the relationships for estimating leaf, branch, stem, and total above-ground biomass of species. The formula for the estimation of biomass is as follows:

$$\text{Log Biomass} = A + B \log_{10}\text{DBH}$$

where A and B are constants in the equation for log Biomass.

Below-ground biomass

The pitch method was adopted for the below-ground biomass estimated (Refaat et al. 2012). Therefore, three pitches (1 × 1 × 1 m) were dug 1 m away from any tree within the study area. All soil of each pitch was collected with roots, and the roots were sorted and washed. Roots were sorted into two groups, fine and coarse, depending on their diameter. The total fresh weight of each root category was measured in the field, and representative subsamples were taken to the laboratory where they were oven dried to constant weight at 80 °C. The total oven-dry weight of roots was calculated from the ratio of fresh to oven-dry weight.

Results

Vegetation structure

A total of 302 individual trees were recorded from the sample plots of Kuala Selangor and 402 individuals at Sungai Haji Dorani. A total of 8 species from four families has been reported from the two study sites.

Sonneratia alba possessed the highest DBH value in the Kuala Selangor; however, *Excoecaria agallocha* was only found in Sungai Haji Dorani and appears as biggest tree with average 11.90 ± 1.58 cm. However, the sparse distribution of *S. alba* (6 tree/ha) shifts importance towards *Bruguiera parviflora* which has about 84 % (1,406 tree/ha) of the total trees density in Kuala Selangor. Both *Bruguiera* species found on both study sites were taller than others in their discrete localities; with mean height value of *B. parviflora* at 12.56 ± 0.47 m in Kuala Selangor while *B. cylindrica* recorded 6.89 ± 0.12 m in Sungai Haji Dorani. *B. parviflora* possessed the highest IVI (70.96 %) as against 0.85 % shown by *S. alba.* However, the only similarity between both study areas in terms of tree diversity is the presence of *S. alba* (Table 1).

Species diversity

From the comparison of diversity between the two study areas, the Shannon–Weiner Index and Simpson Index result showed that the diversity Index was higher at Sungai Haji Dorani with value of 0.91 (H′) and 2.22 (D_S), respectively, than at Kuala Selangor with the value of 0.55 (H′) and 1.40 (D_S), respectively (Table 2). The Shannon–Weiner Index was 1.65 times greater (0.91/0.55 = 1.65) at the Sungai Haji Dorani compared to Kuala Selangor. Also, based on Sorenson's similarity Index result, the similarity of species in both areas was very low with a value of 0.22 (value from 0 to 1). This is because only one species, *S. alba,* was found at both study areas out of the total eight species (Table 2).

Biomass

Above-ground biomass of *Avicennia officinalis* and *B. parviflora* were 37.22 and 266.74 t/ha, respectively, and 305.46 t/ha of total above-ground biomass was recorded for Kuala Selangor. On the other hand, the total above-

Table 1 Stand structure of the study sites

Species	Mean DBH (cm) ± SE		Mean Height (m) ± SE		Density (trees/ha)		IVI (%)	
	KSNP	SHD	KSNP	SHD	KSNP	SHD	KSNP	SHD
A. officinalis	13.58 ± 1.25	–	10.45 ± 1.11	–	200	–	23.20	–
A. marina	–	7.90 ± 0.25	–	5.64 ± 0.25	–	1,150	–	46.16
B. parviflora	10.25 ± 0.27	–	12.56 ± 0.47	–	1,406	–	70.96	–
B. cylindrica	–	7.67 ± 0.24	–	6.89 ± 0.12	–	955.5	–	40.59
R. mucronata	7.31 ± 1.36	–	8.07 ± 1.07	–	67	–	4.99	–
S. alba	22 ± 0	6.50 ± 0	4.21 ± 0	4.21 ± 0	6	5.5	0.85	1.03
E. agallocha	–	11.90 ± 1.58	–	6.01 ± 0.58	–	72.2	–	3.60
X. mekongensis	–	6.68 ± 0.3	–	6.52 ± 0.39	–	44.4	–	5.62

KSNP Kuala Selangor Nature Park, *SHD* Sungai Haji Dorani

– Species not present in the study areas

Table 2 Biodiversity Index of the study areas

Species	No. of individuals	H′	Ds	S
Kuala Selangor		0.55	1.40	0.22
A. officinalis	36			
B. parviflora	253			
R. mucronata	12			
S. alba	1			
Sungai Haji Dorani		0.91	2.22	
A. marina	207			
B. cylindrica	172			
E. agallocha	13			
X. mekongensis	8			
S. alba	1			

H′ Shannon–Weiner Index, *Ds* Simpson Index, *S* Sorenson's Index

Table 3 Above-ground biomass of mangroves tree in both study area

Species	Above-ground biomass (t/ha)	
	KSNP	SHD
A. officinalis	37.22	–
B. parviflora	266.74	–
R. mucronata	1.07	–
S. alba	0.43	0.02
A. marina	–	108.63
B. cylindrica	–	12.95
E. agallocha	–	0.92
X. mekongensis	–	0.25
Total	305.46	122.78

– Species not present in the study areas

ground biomass was 122.78 t/ha for Sungai Haji Dorani. *A. marina* and *B. cylindrical* contributed the major portion of this biomass (Table 3).

The above-ground biomass of *B. parviflora* was found to be 61.62, 30.01 and 8.37 % for the stem, branch and leaf, respectively, in the Kuala Selangor mangrove forest, while the percentage of above-ground biomass of *Avicennia marina* in Sungai Haji Dorani was found to be 49.66, 43.79 and 6.55 % for the stem, branch and leaf, respectively (Table 4).

Below-ground biomass showed a variation between the two study areas. A comparatively higher amount of root biomass (12.12 t/ha) was observed for Sungai Haji Dorani, while 4.60 t/ha of root biomass was estimated for Kuala Selangor (Table 5).

Discussion

The degraded study site of Sungai Haji Dorani is higher in species diversity compared to Kuala Selangor. This may be due to the degradation of the mangrove forest through agricultural land clearing or tidal movement of water into the inner parts of the mangrove, which allows for the mixing or inter-woven nature of the trees breeding, hence increasing the density. These are the major differences across the sites over the monitored parameters which might be due to the environmental conditions and even standing age (Ong 1982).

Table 4 Percentage of above-ground biomass in component of tree

Component	Above-ground biomass (%)	
	B. parviflora	*A. marina*
Leaf	8.37	6.55
Branch	30.01	43.79
Stem	61.62	49.66

Table 5 Below-ground biomass of mangrove trees in both study areas

Component	Below-ground biomass (t/ha) Mean ± SE	
	KSNP	SHD
Coarse root	3.44 ± 0.34	7.61 ± 1.80
Fine root	1.26 ± 0.14	4.51 ± 1.36

Avicennia marina is the most important and dominant species with the highest Important Value Index (IVI) value in Sungai Haji Dorani. This agrees with Clough et al. (1997) that, unlike other species, *A. marina* can still thrive in windy situations and some other environmental conditions like high salinity and high temperature areas. On the other hand, Rhizophoraceae was the largest family in the Kuala Selangor, with two species, consistent with its widespread distribution worldwide; and this family is also very adaptable in extreme mangrove environments (Tomlinson 1986). *B. parviflora* with high IVI is dominant in the area of Kuala Selangor. This finding agrees with Mahmood et al. (2003). The dominance exhibited by *B. parviflora* in Kuala Selangor is based on the fact that it thrives more within mangrove areas located by river banks (Tomlinson 1986; Giesen et al. 2007). A high salinity level may not be easily tolerated by *B. parviflora,* unlike *A. marina* which is well known to grow and survive in extreme saline condition (Bagust and Tout-Smith 2005).

The results have shown that Kuala Selangor, being a natural mangrove, possesses not only larger but also taller mangrove trees when compared to Sungai Haji Dorani. Therefore, while the population density of trees is higher in Sungai Haji Dorani, individual tree size measured in terms of height and DBH is higher in Kuala Selangor mangrove area.

Although the density in Sungai Haji Dorani is higher, the value of the estimated above-ground biomass was lower in comparison to the natural mangrove in Kuala Selangor. The variation in above-ground biomass may be related to different local climatic conditions such as temperature, solar radiation, rain, and frequency of storms. Environmental factors such as soil properties and nutrient status may also affect the growth rate in mangrove biomass (Komiyama et al. 2008). Specifically, it is expected that species from degraded mangrove (Sungai Haji Dorani) show less above-ground biomass because of environmental interference that leads to much smaller size of trees. This is typical of mangrove forests where immature mangrove vegetation is exploited or experiences over-logging (Tomlinson 1986) which is the case at Sungai Haji Dorani. Publications on *A. marina* are very limited when compared to other mangrove tree species, as regards biomass estimation. Reasons for this, point towards the fact that *A. marina* shows lower biomass than other tree species within the mangrove ecosystem. Similarly, its irregular features and the multi-stemmed nature give less recognition (Onget al. 2004; Sherman et al. 2003). With the comparison of the biomass production in different parts of trees from both study areas, the result suggests that production of stem was higher than branch and leaf production. This agrees with Chandra et al. (2011) on higher biomass production of stems.

Surprisingly, the estimated value of below-ground biomass in Sungai Haji Dorani was higher compared to Kuala Selangor. Surveys of the mangroves in both study sites reveal that the density of root biomass at the top 10 cm is high, because some factors such as resilience, salinity, and softness might have played significant role in enhancing the degree of fine root biomass available within the top 10 cm profile (Briggs 1977; Komiyama et al. 2008). These findings concur with Lauff (1967) and Tamooh et al. (2008) that affirmed the concentration of *A. marina* roots at the top 30 cm below the ground level. According to Stafford-Deitsch (1996), anoxic environment might be responsible for the high root biomass in the upper profile because it halts root growth into deeper soil profiles. With many roots in the top profile, active transport of water and minerals are enhanced by the quality of roots in the top profile, and are characterized of accumulated organic matter and terrestrial forests nutrients (Claus and George 2005).

Conclusion

There is a gap in species diversity between Kuala Selangor and Sungai Haji Dorani, with the latter being higher. The relatively higher species diversity in Sungai Haji Dorani can be attributed to its degraded mangrove forest nature; hence, the study concluded that species diversity in natural mangrove forest (Kuala Selangor) is less than is obtained in degraded mangrove forest (Sungai Haji Dorani). While *B. parviflora* is the dominant species in Sungai Haji Dorani, *A. marina* dominated Kuala Selangor.

The study discovered that above-ground biomass was higher in a natural mangrove forest compared to degraded mangrove, but the opposite for below-ground biomass. The accuracy of the biomass estimation, its proportion value and the variation in biomass found for mangrove forest area of Kuala Selangor and Sungai Haji Dorani may be related to the ecology, species, density, season, tree age and global positioning of mangrove forests.

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