



Stand structure and biomass estimation in the Klang Islands Mangrove Forest, Peninsular Malaysia

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Abstract

A study was carried out at three sites in the Klang Islands Mangrove Forest Reserve, in Selangor, Malaysia, to obtain baseline information on how land use could affect forest community metrics. The objective was to obtain baseline ecological data that would allow assessment of different land-use types (industrial, village, and pristine mangrove forests) on species composition, stand density, diversity, similarity, importance value index, and biomass. Undisturbed pristine mangrove forest was sampled at Pulau Klang, while disturbed mangrove forests were sampled at Teluk Gong and Pulau Ketam. A total of 14 species from five families were counted across the three sites, with the highest tree density found at Pulau Ketam (2034 trees ha⁻¹), followed by Pulau Klang and Teluk Gong (1627 and 753 trees ha⁻¹, respectively). The dominant species on Pulau Klang and Pulau Ketam was *Rhizophora apiculata* (importance value index, IVI = 181.4). Shannon–Weaver diversity was highest at Pulau Ketam ($H' = 1.81$) and the tree species on that island were also the most evenly distributed (Pielou evenness index, $J' = 0.87$). The highest above-ground and below-ground biomass values for a single species were recorded at Pulau Klang for *R. apiculata* (80.51 and 41.63 t ha⁻¹, respectively), while the second highest values were at Teluk Gong for *Rhizophora mucronata* (71.33 and 27.07 t ha⁻¹, respectively). As a whole, however, the remaining large trees in a disturbed site in Teluk Gong contributed to the highest total biomass (220.64 t ha⁻¹) followed by Pulau Klang and Pulau Ketam (192.22 and 161.93 t ha⁻¹, respectively). Proper assessment and management of these valuable mangrove forests are crucial to ensure mangrove ecosystem health.

Keywords Diversity index · Importance value index · Species composition · Pulau Ketam · Pulau Klang · Telok Gong

Introduction

Mangroves are defined as assemblages of halophytic shrubs and trees growing in the brackish to saline tidal waters of coastal areas (Nagelkerken et al. 2008). The location of mangroves has made them an important zone for flora and fauna, and is characterized by highly variable environmental factors such as temperature, salinity, rainfall, tidal currents, sedimentation, and nutrients (Ashton and Macintosh 2002; Ellison 1999; Wakushima et al. 1994). The peculiar architecture of mangrove trees is unique and functions to help them survive in an unusual environment. For example, some

species like *Rhizophora* and *Bruguiera* spp have massive and spreading root systems, enabling them to stand upright in soft mud.

Species composition, diversity, and biomass of mangroves are important study subjects in coastal research and development (Norhayati et al. 2009; Shah et al. 2016). These parameters can address many mangrove rehabilitation problems and aid in understanding the dynamics of vegetation recovery (Zhu et al. 2015). Mangrove forests can be used sustainably and their management improved, by estimating biomass accumulation rates (Alemayehu et al. 2014). Biomass estimates facilitate the determination of the status of mangrove forests and assessment of the ‘potential revenue’ of commercial timber products, and are a principal component in estimating carbon sequestration (Kirui et al. 2006).

The context of species diversity is an expression of some relation between number of species or species richness and their abundance (Spellerberg 1991). The Shannon–Weaver diversity index, importance value index, and similarity index

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are widely used to elucidate features of an ecological community. The Shannon–Weaver index is commonly used to characterize species diversity in a community (Shannon and Weaver 1949). In addition, the evenness index quantifies how equally distributed are the numbers of each species present (Molinari 1989), to see how representative, the species in a community is. In forest inventory, the importance value index can be used to determine the overall ranking of species in a community from most to least important (Byron et al. 1977). This would indicate whether the species is well represented either by numbers or size.

Above-ground biomass (AGB) estimates of mangroves provide valuable means for comparing ecosystems and evaluating their productivity, nutrient cycle, and energy flow (Kusmana et al. 1992). The allometric method is a non-destructive method (as opposed to the harvest method) developed by many researchers over several decades to estimate above-ground and below-ground biomass (BGB) in mangroves (Komiya et al. 2008). Allometric equations are based on the high correlation between girth and trunk weight. Although allometric relationships are often site- and/or species-dependent, practical common allometric equations have been proposed (e.g., Komiya et al. 2005; Chave et al. 2005). On the other hand, a few studies have estimated below-ground biomass, because it is a complicated process that requires root excavation (Zhila et al. 2014; Hosain 2014).

According to Hamilton and Casey (2016), Indonesia, Brazil, Malaysia, and Papua New Guinea recorded the largest mangrove holdings in the world. Nevertheless, they also revealed that Southeast Asian countries showed high amounts of mangrove loss. The extent of mangrove forests in Malaysia was estimated at 494,600 ha in 2000 and reduced to 469,100 ha in 2014 (Hamilton and Casey 2016). In Peninsular Malaysia, the largest areas under mangroves are in the states of Perak followed by Johor and Selangor. Selangor is the most developed and populated state, housing the nation's largest and busiest port and airport. The state has seen rapid development of infrastructure and facilities, and land conversion to housing, industries, agriculture, and businesses has substantially reduced mangrove forest cover over the years (Hamdan et al. 2012). In the Klang Islands, which hold 75% of the state's mangrove forests, the latest report recorded that only 16,600 ha remain (Hamdan et al. 2012) out of the 19,000 ha estimated in 2008 (Jusoff and Taha 2008). However, the current status of mangrove coverage in the Klang Islands is unknown.

The mangrove forests of the Klang Islands are particularly vulnerable to degradation and habitat loss. In addition to harvesting of mangrove timber, and pollution from shipping traffic (Ashton and Macintosh 2002), the proximity of the mangrove forests to Port Klang has resulted in encroachment by residential and commercial development. The present

study was carried out in Pulau Klang (pristine mangrove forest), Teluk Gong (mangrove forest with industrial, port, and marina activities), and Pulau Ketam (mangrove forest with human settlements). The objective was to assess how two different land-use activities (industrial and human settlement) affect four forest community metrics (species composition, importance value index, diversity, and biomass) of the Klang mangrove forests. The ultimate goal of this study is to get a better understanding of how the mangroves respond to human disturbance, for the current and future management of mangroves, including restoration efforts.

Materials and methods

Site description

The Klang Islands Mangrove Forest is spread across three main islands (Pulau Klang, Pulau Ketam, and Pulau Carey) surrounding Port Klang, and the Selat Kering, Pulau Gedong, Che Mat Zain, Jugra, and Teluk Gong mangrove forest reserves (Fig. 1) (Norhayati et al. 2009). The study was conducted at the Teluk Gong, Pulau Klang, and Pulau Ketam mangrove forest (Fig. 1).

Teluk Gong ($3^{\circ}2'54.56''\text{N}$, $101^{\circ}22'43.79''\text{E}$) on the mainland is now an industrial and human settlement area. Much of the mangrove forest initially gazetted for reserve (2400 ha) had been denuded by 1999, except for 800 ha of fringing mangrove forest (Haliza 2004). The mangrove reserve is located near to roads, factories, and residences. In 2001, a further 80.9 ha of Teluk Gong mangrove forest reserve was degazetted for development (Haliza and Rohasliney 2010), creating more disturbance to the coastal mangrove. A forest inventory was conducted in the early 2016. Sampling took place at compartments 56, 57, and 58, which were among the few sites being gazetted by the Selangor Forestry Department. The Pulau Klang ($3^{\circ}1'41.05''\text{N}$, $101^{\circ}19'35.93''\text{E}$) mangrove forest reserve is an undisturbed forest reserve (5371 ha) gazetted by the Selangor Forestry Department in 1904 (Haliza 2004) and located 11 km from Port Klang. Compartments studied at this site were compartments 14, 16, 18, and 19. The third mangrove study site was at Pulau Ketam ($3^{\circ}1'32.41''\text{N}$ $101^{\circ}15'49.75''\text{E}$), about 22 km from Port Klang. Pulau Ketam has a small settlement—aquaculture, fishing, and fisheries industries are the main economic activities here. The island has a land area of about 3000 ha, and is covered with mud flats and mangrove forest.

Temperature, rainfall, and humidity data were obtained from The Malaysian Meteorological Department (2016). The daily temperature ranged from 22 to 33 °C with the warmest and coolest months being April and September, respectively.



Fig. 1 Map of Klang Islands Mangrove Reserve Forest

High humidity of 75–85% was also recorded. Cumulative annual precipitation averaged 2500 mm. The wettest and driest months were April and June, respectively.

Plot establishment

The sampling methodology was based on Kauffman and Donato (2012). At every site, 15 round plots (radius 7 m) were established 25 m apart, giving a total sampling area of 0.231 ha per site. Within each plot, trees with diameter at breast height (DBH) ≥ 5 cm were tagged and their DBH measured with a diameter tape. For *Rhizophora* species, DBH was measured

30 cm above the highest prop root (Komiya et al. 2005; Kauffman and Donato 2012).

Species composition, importance value index, and diversity indices

Trees were identified to species. The importance value index (IVI) for each tree species was calculated (after Cintron and Novelli 1984) as follows:

IVI = Relative frequency + Relative density + Relative dominance.

The following species diversity indices were also calculated as follows:

Shannon–Weaver index (Shannon and Weaver 1949), $H' = \sum P_i \ln P_i$,

where P_i is the proportion of individuals belonging to the i th species and \ln is the natural logarithm.

Pielou evenness index (Pielou 1966), $J' = H' / \ln(S)$,

where H' is Shannon Weaver diversity and S is the total number of species in a sample, across all samples in data set. The result ranges from 0.0 to 1.0 with 1.0 reflecting total evenness.

Sorenson's similarity index (Sorenson 1948), $S_s = \frac{2J}{A+B}$,

where J is total number of species common in both samples, A is total number of species in sample A, and B is total number of species in sample B. This formula is used to indicate how similar is the vegetation species in one site/plot to that in the other plot. The range of values of S_s is from 0 (completely dissimilar) to 1 (complete similarity).

Biomass calculation

The allometric method was used in this study to estimate tree biomass. This is a non-destructive method that has been developed by several authors and is being used widely to estimate biomass in mangrove forests. Allometric equations based on main stem measurements were used to estimate whole or partial tree weight (Komiya et al. 2008). For each species of mangrove tree encountered, species-specific allometric equation was used. When no specific allometric equation is available, a common allometric equation was

used (Table 1). In addition to trunk diameter, approximate wood density values were assigned to tree species identified in the plots, based on known wood density values of tree species (Table 1).

Above-ground and below-ground biomass values derived from DBH and wood density were then converted to biomass per ha by dividing total biomass of a species with the total sample area (0.231 ha) of each site:

$$\text{Biomass per ha (t ha}^{-1}\text{)} = \frac{\text{Total biomass}}{0.231 \text{ ha}}$$

Results

Species composition, diameter, importance value index, and diversity indices

Table 2 shows that a total of 14 species from five families were recorded in this study, with Rhizophoraceae being the most dominant family at all sites. The family Rhizophoraceae accounted for 87.5% of the species found in Pulau Klang, 60% in Pulau Ketam, and 50% in Teluk Gong. *Rhizophora apiculata* was the most frequent species encountered, especially in Pulau Kelang and Pulau Ketam, totaling up to 346 individuals or comprising 34% of the mangrove community in this area. The total number of trees recorded in all study plots is also shown in Table 2, which depicts Pulau Ketam as the most abundant. Consequently, tree density was highest at Pulau Ketam

Table 1 Allometric equations for calculating biomass of mangrove trees using measured diameter at breast height (DBH) and wood density (ρ) of trees

| Species | AGB | BGB | ρ (wood density, g cm ⁻³) |
|---|---------------------------------------|--|--|
| <i>Avicennia alba</i> Blume | 0.251 ρ DBH ^{2.46} [1] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.506 [1] |
| <i>Bruguiera sexangula</i> ^a (Lour.) Poir | 0.251 ρ DBH ^{2.46} [1] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.749 [1] |
| <i>Bruguiera cylindrica</i> (L.) Blume | 0.251 ρ DBH ^{2.46} [1] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.749 [1] |
| <i>Excoecaria agallocha</i> L | 0.251 ρ DBH ^{2.46} [1] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.334 [5] |
| <i>Sonneratia alba</i> Sm | 0.251 ρ DBH ^{2.46} [1] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.475 [1] |
| <i>Rhizophora apiculata</i> Blume | 0.1709 ρ DBH ^{2.46} [1] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.770 [1] |
| <i>Rhizophora mucronata</i> Lam | 0.1709 ρ DBH ^{2.46} [1] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.867 [5] |
| <i>Bruguiera parviflora</i> ^a Wight & Arn. Ex Griffith | 0.168DBH ^{2.42} [2] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.749 [1] |
| <i>Bruguiera gymnorrhiza</i> (L.) Lam | 0.186DBH ^{2.31} [2] | 0.199 $\rho^{0.899}$ DBH ^{2.22} [1] | 0.699 [1] |
| <i>Xylocarpus granatum</i> J.König | 0.0823DBH ^{2.59} [2] | 0.145DBH ^{2.55} [4] | |
| <i>Xylocarpus moluccensis</i> (Lam.) M.Roem | 0.0823DBH ^{2.59} [2] | 0.145DBH ^{2.55} [4] | |
| <i>Ceriops tagal</i> (Perr) CB.Rob | 0.189DBH ^{2.34} [2] | 0.159DBH ^{1.95} [3] | |
| <i>Avicennia marina</i> (Forsk.) Vierh | 0.308DBH ^{2.11} [3] | 1.28DBH ^{1.17} [3] | |

References (in square parentheses): 1=Komiya et al. (2005), 2=Clough and Scott (1989), 3=Comley and McGuinness (2005), 4=Poongparn et al. (2002), and 5=Simpson (1996)

^aAllometric equation for *B. cylindrica* was used

Table 2 Mean diameter at breast height (\pm SD), abundance (n) in round parentheses, total abundance (N), and tree density (ha^{-1}) of mangrove species recorded at the three sites

| Species (family) | Pulau Klang | Teluk Gong | Pulau Ketam |
|-----------------------------------|---------------------|---------------------|---------------------|
| <i>Rhizophora mucronata</i> (R) | 10.3 \pm 2.7 (72) | 21.8 \pm 9.9 (30) | 9.4 \pm 4.2 (101) |
| <i>Rhizophora apiculata</i> (R) | 9.9 \pm 4.5 (234) | 25.5 \pm 18.6 (7) | 9.1 \pm 4.0 (105) |
| <i>Bruguiera gymnorrhiza</i> (R) | 9.7 \pm 7.5 (27) | 22.8 \pm 14.0 (8) | 8.5 \pm 4.3 (62) |
| <i>Bruguiera parviflora</i> (R) | 6.1 \pm 1.2 (8) | 5.5 \pm 0.0 (1) | 8.0 \pm 2.5 (13) |
| <i>Bruguiera sexangula</i> (R) | 19.7 \pm 11.2 (7) | – | – |
| <i>Bruguiera cylindrica</i> (R) | 8.0 \pm 0.0 (1) | – | 7.7 \pm 3.6 (127) |
| <i>Ceriops tagal</i> (R) | 9.0 \pm 2.9 (26) | 12.4 \pm 6.2 (7) | 6.4 \pm 1.2 (21) |
| <i>Avicennia marina</i> (A) | – | 11.0 \pm 3.1 (89) | 11.6 \pm 7.5 (30) |
| <i>Avicennia alba</i> (A) | – | 13.6 \pm 4.4 (27) | – (1) |
| <i>Xylocarpus granatum</i> (M) | 5.0 \pm 0.0 (1) | 18.1 \pm 7.3 (3) | – |
| <i>Xylocarpus moluccensis</i> (M) | – | – | 10.8 \pm 7.3 (6) |
| <i>Sonneratia caseolaris</i> (L) | – | 15.9 \pm 0.0 (1) | – |
| <i>Sonneratia alba</i> (L) | – | – | 10.9 \pm 4.3 (4) |
| <i>Excoecaria agallocha</i> (E) | – | 14.2 \pm 0.0 (1) | – |
| Total abundance (N) | 376 | 174 | 470 |
| Tree density (ha^{-1}) | 1627 | 753 | 2034 |

R Rhizophoraceae, A Avicenniaceae, M Meliaceae, L Lythraceae, E Euphorbiaceae

Table 3 Importance value index (IVI) for mangrove species recorded at the three sites and site diversity indices

| Species | IVI | | |
|----------------------------------|-------------|------------|-------------|
| | Pulau Klang | Teluk Gong | Pulau Ketam |
| <i>Rhizophora mucronata</i> | 46.5 | 59.8 | 59.8 |
| <i>Rhizophora apiculata</i> | 181.4 | 17.4 | 64.0 |
| <i>Bruguiera gymnorrhiza</i> | 20.6 | 15.8 | 40.3 |
| <i>Bruguiera parviflora</i> | 12.4 | 2.9 | 15.2 |
| <i>Bruguiera sexangula</i> | 8.3 | – | – |
| <i>Bruguiera cylindrica</i> | 2.3 | – | 61.9 |
| <i>Ceriops tagal</i> | 26.2 | 15.8 | 12.7 |
| <i>Avicennia marina</i> | – | 134.1 | 31.6 |
| <i>Avicennia alba</i> | – | 39.8 | 1.7 |
| <i>Xylocarpus granatum</i> | 2.3 | 8.7 | – |
| <i>Xylocarpus moluccensis</i> | – | – | 9.6 |
| <i>Sonneratia caseolaris</i> | – | 2.9 | – |
| <i>Sonneratia alba</i> | – | – | 3.3 |
| <i>Excoecaria agallocha</i> | – | 2.9 | – |
| Shannon–Weiner index, H' | 1.17 | 1.49 | 1.81 |
| Pielou evenness index, J' | 0.57 | 0.72 | 0.87 |
| Sorenson's similarity index, S | | | |
| Pulau Klang | – | 0.67 | 0.55 |
| Teluk Gong | – | – | 0.70 |

(2034 trees ha^{-1}) followed by Pulau Klang (1627) and Teluk Gong (753) respectively. Although Teluk Gong recorded the lowest tree density, the trees at Teluk Gong were the largest in term of DBH (Table 2). Species like *Rhizophora apiculata*, *Bruguiera gymnorrhiza*, and *Rhizophora mucronata* had mean DBH values exceeding 20 cm

(with the maximum of 51 cm) which were not recorded at the other two sites. The mean DBH of tree species on Pulau Ketam ranged between 6.4 and 11.6 cm (maximum being 36.6 cm), while, on Pulau Klang, except *Bruguiera sexangula* (DBH 19.73 \pm 11.22 cm), the mean DBH ranged from 5.0 to 10.3 cm (maximum being 44 cm).

The dominant species on Pulau Klang and Pulau Ketam was *R. apiculata*, as indicated by its high IVI value and reflecting individual counts, while, at Teluk Gong, *Avicennia marina* was the dominant species (Table 3). Examination of the Shannon–Weaver index showed that diversity was highest at Pulau Ketam ($H' = 1.81$, Table 3). The Pielou evenness index also showed that mangrove species in Pulau Ketam were highly evenly distributed ($J' = 0.87$). Pulau Klang with smaller number of species recorded low diversity and evenness. Since the mangrove species found in these areas are somewhat similar (with at least nine common species in two sites), the Sorenson similarity index amongst these three sites was also high. Teluk Gong and Pulau Ketam, which are both disturbed sites, were 70% similar in terms of species composition (Table 3).

Figure 2 charts the DBH range of mangrove species at the study sites. It was apparent that the population structure was represented by younger individuals. Young trees (DBH < 15 cm) comprised 94.4 and 92.3% of the trees recorded from Pulau Ketam and Pulau Klang, respectively, while, at Telok Gong, trees of this size made up 69.0% of tree census. Unlike in Pulau Klang and Pulau Ketam, the population distribution in Telok Gong showed a continuous age structure where all DBH sizes were represented.

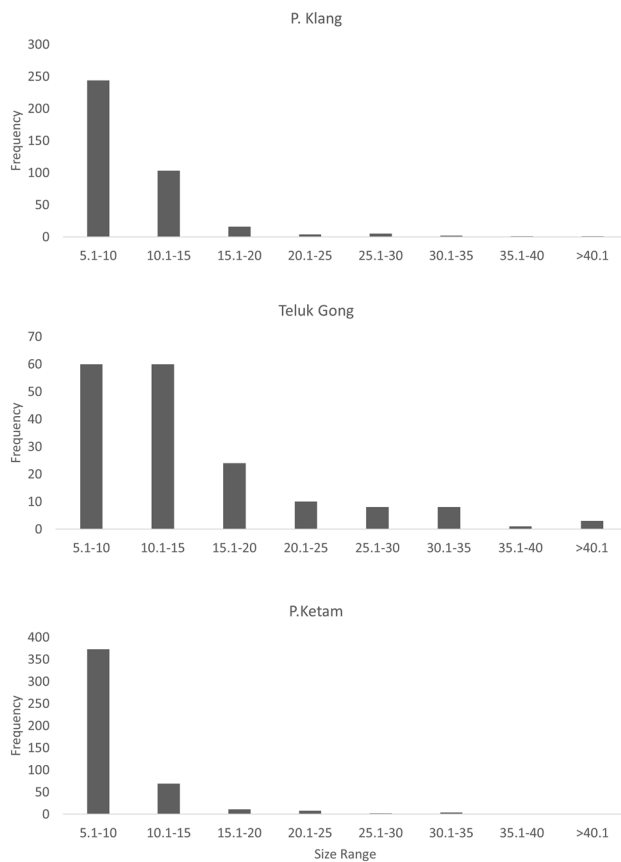


Fig. 2 Range of plant size at study sites

Table 4 Estimated above-ground (AGB) below-ground (BGB) and biomass ($t\ ha^{-1}$) for the mangrove species at the study sites

| Species | Pulau Klang | | Teluk Gong | | Pulau Ketam | |
|--------------------------------|-------------|-------|------------|-------|-------------|-------|
| | AGB | BGB | AGB | BGB | AGB | BGB |
| <i>Rhizophora mucronata</i> | 21.16 | 10.49 | 71.33 | 27.07 | 29.96 | 14.15 |
| <i>Rhizophora apiculata</i> | 80.51 | 41.63 | 33.61 | 12.70 | 28.62 | 15.14 |
| <i>Bruguiera gymnorrhiza</i> | 8.46 | 4.93 | 13.26 | 7.47 | 10.07 | 6.17 |
| <i>Bruguiera parviflora</i> | 0.48 | 0.26 | 0.05 | 0.03 | 1.62 | 0.83 |
| <i>Bruguiera sexangula</i> | 13.50 | 4.90 | – | – | – | – |
| <i>Bruguiera cylindrica</i> | 0.14 | 0.07 | – | – | 23.10 | 10.31 |
| <i>Ceriops tagal</i> | 4.23 | 1.42 | 2.79 | 0.78 | 1.38 | 0.55 |
| <i>Avicennia marina</i> | – | – | 20.59 | 8.26 | 10.55 | 3.03 |
| <i>Avicennia alba</i> | – | – | 10.81 | 4.71 | 0.18 | 0.07 |
| <i>Xylocarpus granatum</i> | 0.02 | 0.04 | 2.36 | 3.68 | – | – |
| <i>Xylocarpus moluccensis</i> | – | – | – | – | 1.92 | 3.00 |
| <i>Sonneratia caseolaris</i> | – | – | 0.54 | 0.24 | – | – |
| <i>Sonneratia alba</i> | – | – | – | – | 0.89 | 0.41 |
| <i>Excoecaria agallocha</i> | – | – | 0.25 | 0.12 | – | – |
| Total | 128.50 | 63.72 | 155.58 | 65.06 | 108.27 | 53.66 |
| Total biomass ($t\ ha^{-1}$) | 192.22 | | 220.64 | | 161.93 | |

Biomass estimation

The highest above-ground and below-ground biomass values for a single species were recorded at Pulau Klang for *R. apiculata* (80.51 and $41.63\ t\ ha^{-1}$, respectively), while the second highest values were at Teluk Gong for *R. mucronata* (71.33 and $27.07\ t\ ha^{-1}$, respectively; Table 4). *Xylocarpus granatum* recorded the smallest biomass, 0.02 and $0.04\ t\ ha^{-1}$, respectively. As a whole however, Teluk Gong had the highest total (above-ground and below-ground) vegetational biomass ($220.64\ t\ ha^{-1}$), attributed to its larger trees, followed by Pulau Klang ($192.22\ t\ ha^{-1}$) and Pulau Ketam ($161.93\ t\ ha^{-1}$).

Discussion

This study recorded 14 (from 5 families) of the 41 mangrove species that can be found in Malaysia (FAO 2007). Notably, ten species were recorded at both disturbed sites (Teluk Gong and Pulau Ketam) compared to the eight species found in Pulau Klang, and both disturbed forests had higher species similarity. Species diversity recorded in the present study was similar to the ten species (three families) reported nearby for Pulau Indah and Pulau Che Mat Zin (Norhayati et al. 2009) but lower than the 16 species found in a disturbed fringe mangrove forest at Carey Island, where oil palm plantations cover 70% of the island (Saraswathy et al. 2009). A similar finding was recorded by Zhila et al. (2014) where a degrading mangrove forest in Sungai Haji Dorani was a little more speciose than a natural mangrove forest in Kuala Selangor Nature Park. Zhila et al. (2014) opined that

anthropogenic disturbances like plantation establishment may have altered the environment, e.g., soil quality and tidal movement, thus allowing the introduction of additional tree species to the disturbed forests.

The abundance of *R. apiculata* in the present study (especially in the pristine mangroves at Pulau Klang) has also been reported for other mangrove forests, e.g., at Awat–Awat (Chandra et al. 2011) and Sibuti (Shah et al. 2016) in Sarawak, and the Andaman and Nicobar Islands of India (Ragavan et al. 2015). The Rhizophoraceae species demonstrate adaptability to extreme mangrove environments (Tomlinson 2016) and our findings concur with the previous reports that the Rhizophoraceae is the most widespread family. For instance, the Rhizophoraceae was the dominant family at Johor Park in southern Peninsular Malaysia, with *Bruguiera cylindrica* as the most abundant species (Tan et al. 2012). *Bruguiera parviflora* was likewise found to be the major species at the undisturbed mangrove forest in Kuala Selangor Nature Park (Zhila et al. 2014).

The mean DBH (25.5 ± 18.6 cm) for *R. apiculata* at Teluk Gong was higher than previously reported for this species in Sibuti (20.83 ± 13.79 cm; Shah et al. 2016), while mean DBH values for Pulau Ketam and Pulau Klang (9.1 ± 4.0 and 9.9 ± 4.5 cm, respectively) were lower than previously reported for the species in Awat–Awat (14.4 ± 0.4 cm; Chandra et al. 2011). The high percentage of young mangrove trees with DBH less than 15 cm in the present study indicated a healthy population with plenty of young individuals available to replace older individuals—a situation favorable to sustaining the mangrove population. Noteworthy, the largest tree (DBH > 50 cm) was recorded from Telok Gong. The population distribution in Telok Gong also showed a smooth transition in age structure where all DBH sizes were represented. The high IVI value (181.4) for *R. apiculata* at Pulau Klang, in the present study, was also noted for this species at the disturbed Semporna Mangrove Forest in Sabah (173.6; Wah et al. 2011). However, the highest IVI values (134.06) for *A. marina* recorded at the disturbed mangroves of Teluk Gong were much higher than reported for the disturbed mangroves at Sungai Haji Dorani (46.16; Zhila et al. 2014).

The H' and J' values were highest at Pulau Ketam (1.81 and 0.87, respectively), while D_{Mg} (1.74) was highest at Teluk Gong. Nevertheless, H' at all three sites was higher than that at the Sibuti (Shah et al. 2015) and Semantan (Ashton and Macintosh 2002) mangrove forests in Sarawak. Pulau Klang, Teluk Gong, and Pulau Ketam mangrove forests were comparatively higher in terms of diversity, richness, and evenness. While the IVI was highest at the virgin mangroves in Pulau Klang, the disturbed mangrove forest at Pulau Ketam had the highest diversity, evenness, and density. In terms of species composition and diversity, the

similarities between the present and the previous research findings could be due to the same biogeographical location of these studies in the tropics. According to Hoque et al. (2015), climate and other edaphic factors such as soil pH, nutrients, organic matter, and tidal inundation do not usually fluctuate much in tropical ecosystems.

The AGB of mangroves enables comparison among sites or ecosystems as well as the evaluation of productivity patterns, nutrient cycles, and energy flow (Kusmana et al. 1992). Nevertheless, we need to be cautious as the AGB is merely an estimate. Although the tree density was lowest at Teluk Gong, the estimated total AGB (155.58 t ha^{-1}) and total BGB (65.06 t ha^{-1}) were greater than that at Pulau Klang and Pulau Ketam. The higher biomass estimates for the tree species at Teluk Gong are due to the larger trees as compared to those at the other two sites, as a result of patches of forest reserve in the midst of industrial area. However, *R. apiculata* in Pulau Klang had the highest estimated AGB and BGB, similar to the Matang Mangrove Forest where *R. apiculata* was also dominant (Putz and Chan 1986). In contrast, tree species from the degraded mangroves at Sungai Haji Dorani had lower AGB, because disturbance (tree clearing and tidal erosion) had resulted in smaller trees (Zhila et al. 2014). The AGB in Johor Park mangrove was reported to range from 133.9 to 206.93 t ha^{-1} , reflecting the presence of smaller trees there (DBH 9.02–11.33 cm; Tan et al. 2012), while Norhayati and Latiff (2001) reported an AGB of 115.56 t ha^{-1} for mangrove forests in Langkawi Island, Malaysia. It is clear that the biomass of mangrove tree species can vary greatly even among undisturbed sites and land-use types, as suggested by Komiyama et al. (2008) who noted that the total above-ground biomass of *Rhizophora* spp. in the Pacific and Australia region ranges from 40.7 to 460 t ha^{-1} . Komiyama et al. (2008) attributed this variability to different local climatic conditions, e.g., temperature and rain, and environmental factors, e.g., soil and nutrient status. However, our present study only covered a small sampled area of mangrove forest fringing the island, and thus, our results may not represent the whole island status.

Conclusion

A varied species distribution and abundance can be seen in this study, indicating dominance of certain species like *Rhizophora* spp, while other species like *Sonneratia* are poorly represented. The soil condition could be the main factor for this, as the latter species may prefer river, creek, or inlet mouths. Anthropogenic activities may have altered the sediment, leading to vegetation changes. Pulau Ketam and Telok Gong have larger and suitable accreting shores for pioneer species like *Avicennia*. The most important species

at each location was different; *R. apiculata* at Pulau Klang, *A. marina* at Teluk Gong, and *B. cylindrica* at Pulau Ketam. *Rhizophora* spp have always been the preferred choice for charcoal production, poles, firewood, and other uses, and had prior been harvested in Pulau Ketam and Telok Gong. In general, Pulau Klang has the most important species (*R. apiculata*) and Pulau Ketam recorded the highest density, diversity, and evenness, while Teluk Gong had the largest trees. These large trees are the remaining older trees left, in the remaining patches forest reserves that is suitable for sampling. Status as forest reserve clearly plays an important role to ensure that the mangrove is remained intact. The settlement in Pulau Ketam may get larger and possibly creating more disturbances to the mangrove ecosystem. Visual observation revealed that trees have been felled to pave way to build electricity supply. Hence, managing and close monitoring the activities here would be the key for wise use, since Pulau Ketam is State land and not a forest reserve. Nevertheless, this study reveals that both above-ground and below-ground biomass was greatest at the disturbed mangrove forest at Teluk Gong. This study shows that none of the mangrove forest metrics studied could be usefully applied to evaluate human disturbance effects among islands; this is attributable to the varied species dominance, tree age, sedimentary dynamics, freshwater inputs, hydrogeochemical conditions, and human impacts.

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