The habitat preference of mangrove crabs in different mangrove forests of Penang, North Peninsular Malaysia

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Abstract. Different crab assemblage compositions may result in distinct pathways in mangrove ecosystem function, attributed to specific preferences and habitat selection criteria by each crab species. This study assessed the preference of crabs to different mangrove forests at Balik Pulau, Penang, Malaysia across temporal scales of four months and spatial scales across three forests. Sites were characterized by Avicennia, Rhizophora and Bruguiera species. Crabs were sampled using hand-catch method, which was then preserved in 70% ethanol and identified to the lowest taxonomic level possible. Environmental variables were determined by in-situ and ex-situ analysis and comprised the collection of canopy cover, root cover, surface temperature, sediment salinity and organic matter data. PERMANOVA analysis showed there was a difference in crab abundance and environmental variables across Month and Forest (p < 0.05). SIMPER analysis revealed that the Grapsidae family dominated mangroves of Balik Pulau, with Perisesarma eumolpe and Perisesarma foresti found to be most abundant in Avicennia and Bruguiera forests respectively. However, in the Rhizophora forest, dominant crab species varied, with Parasesarma sp2. and Perisesarma indiarum found in high abundance in June and August, respectively. In October and December, however Perisesarma foresti was the major contributor to patterns observed in crab assemblage composition in Rhizophora forest. BEST correlation varied among month and forest, with different combinations of salinity, pH, canopy cover and root density explaining patterns in crab assemblages.

1. Introduction
A total of 497 crab species was recorded in mangrove ecosystems with more than 65% of species found mostly concentrated in the Indo-West Pacific region followed by South-East Pacific and Atlantic [1]. South of Peninsular Malaysia, East of Singapore, South-West of Indonesia, South India, and Sri Lanka are recognized as a biodiverse hotspot for mangrove crabs in the West-Pacific region [1]. In Malaysia, records on mangrove crabs were first observed by Sasekumar [2], with a total of 24 species found in Kuala Selangor [3]. In the following decades, work on this taxonomic group included numerous efforts from researchers, such as the seminal work done by Tan and Ng [4] in which 192 different species of mangrove crabs in Singapore and Peninsular Malaysia were identified and published into a checklist. Following that, previous work by authors have included a detailed list of species present in mangroves encompassing the North to South of Peninsular Malaysia [5], Sabah [6] and Sarawak [7]. From the species listed, the Grapsoidae superfamily was identified as a major contributor to large numbers of crab diversity followed by Ocypodidae [1,3,4].

Crabs play crucial roles as ecosystem engineers in mangrove forests and are keystone species in determining mangrove succession [8]. Mangrove crabs ameliorate nutrient cycles [9,10], increase the
production of coastal vegetation [10,11], facilitate increment of below-ground oxygen [12], enhance the growth of the microbial community [13], increase micro-benthos abundance [13] and alter the surrounding environment through the burrowing process [14,15]. Crab activities have also influenced organic matter [14], disturbed redox potential [16], and alter pH and salinity [12,16] in mangrove sediment. Spatial complexity and environmental heterogeneity could influence the distribution of crabs [1,17], therefore understanding the crab-mangrove environment interaction should be done with focus on how crabs utilize and select habitats in the mangrove forest [17,18].

The utilization of mangrove space by crabs, either on the mangrove forest floor or within physical structures in mangrove ecosystems may be influenced by changes in physiochemical variables such as temperature, light intensity, pH, salinity, dissolved oxygen, and turbidity in the mangrove environment [19]. This may influence the crabs physiologically [20], thus impacting the ecological role of crabs in mangroves [18]. This is attributed to the environment on the mangrove forest floor which differed, and is characterized by each mangrove species [21,22]. Crab preference to a specific space in mangroves have been documented to occur at different tidal zones [18], mudflats zones [23], natural and reforested zones [5,24], under canopy gaps in which crabs were clustered more under the shade of the tree canopy compared with unshaded, open areas [25], and between man-made upper intertidal zone and a natural middle landward zone [26]. In terms of mangrove species preference, crab abundance has been found to correlate with forest maturity as more crabs were found inhabiting older and more established mangrove [5]. Crab species richness also changed with the density and species richness of mangrove trees, being more species rich in more diverse mangroves [1]. This suggests higher tree species availability will create a more complex mangrove structure for marine organisms to use as shelter [27]. Differences in habitat characteristics showed the variability in spatial arrangements of the root system, leaf litter and canopy cover resulting in habitat complexity which functions as the natural shelter for macrofauna. Food availability is also a factor that affects the crab distribution, leading to inter or intra-specific responses for food and space [26]. This will create spatial zonation for crabs [3]. This suggests the distribution of mangrove crabs is directly influenced by spatial arrangements of physical habitat structures in the mangrove ecosystem [5,24]. Across the temporal scale, the environment may change and could affect the crab assemblage and composition [17,18]. For example, the seasonal change affects the distribution and abundance of crabs in their habitat [17]. Changes in water acidity, alkalinity [17], food availability [26] organic matter and temperature [24] could result in different abundance and composition of crabs in the habitat.

Despite the ecological influence of spatial and temporal components on crabs, the influence of mangrove complexity in some regions in Malaysia on crab assemblages is not often addressed in detail. The disappearance of mangroves in the Indo-West Pacific region is at a rapid stage [28], raising concerns and urgency to study the dynamic crab-mangrove relationship. Loss of mangroves not only negatively affects mangrove tree species, but also the inhabitants that are vulnerable to disturbances caused by coastal development [27] and climate crisis [29]. The harsh possibility of mangrove ecological function ceasing to exist in the next 100 years [30], sheds a light on how important it is to understand the spatial distribution of crabs, a potential faunal component in the regeneration of mangrove ecosystems. Despite carrying keystone roles in mangroves [8] there is still a lack of knowledge on some ecological aspects of mangrove crab assemblages in relation to different mangrove tree species. Analysing the complex relationships between mangrove crabs with habitat complexity and environmental heterogeneity in mangroves is the key to increase understanding on predicting future negative impacts on mangrove biodiversity. In this study, crab abundance and species richness were assessed across different mangrove forests dominated by different mangrove tree species. We hypothesized that crab assemblage and composition in Malaysian mangroves will be different according to different forest structure and environmental heterogeneity.
2. Materials and methods

2.1. Study area
This study was conducted at three different forests located at Balik Pulau in the south-west of Penang, Northern Peninsular Malaysia (Figure 1). From 1960 to 2000, 50% of the mangrove forest in Penang were lost [31]. Sites selected were designated as a forest reserve [32]. The Sungai Burung mangrove site is a replanted mangrove characterized with a mixture of *Avicennia marina* (DBH= 3.94 ± 0.67 cm with average tree height recorded at 4.78 ± 0.48 m) and dominated by *Rhizophora apiculata* (DBH= 4.22 ± 0.22 cm with average tree height recorded at 4.99 ± 0.15 m). The Pulau Betong site comprised of mangrove species dominated by *Bruguiera cylindrica*, mixed with *Achantus* sp., and *Acrostichum aureum*. Average diameter breast height for *Bruguiera cylindrica* at Pulau Betong is 13.56 ± 11.3 cm with average tree height recorded at 8.58 ± 3.79 m. In Kuala Sungai Pinang, *Avicennia marina* was the dominant species, with an average diameter breast height of 8.80 ± 0.56 cm and average tree height of 6.52 ± 0.27 m. Sampling session was conducted every two months from June to December during spring tides.

![Figure 1. Map of three sampling locations (Kuala Sungai Pinang, Kuala Sungai Burung and Pulau Betong) located at the south-west region of Pulau Pinang. Map of Malaysia derived from online free sources [49].](image)

2.2 Sampling design
Data were collected based on a sampling design comprising several different factors (a) Forest (n=3), (b) Month (n=4), (c) Plot (n=3) and Quadrat (n=3) (Figure 2). Three fixed 10 m x 10 m plots were setup in selected sites, with four points to mark a quadrat set up to the nearest mangrove tree. Different sizes of quadrats were used, and three replicates of quadrat were randomly set in the plot to determine crab abundance and environmental parameters. The 2 m x 2 m sized quadrats were used to catch crabs. Then, root density was calculated in three quadrats sized 0.3 m x 0.3 m. Canopy cover and temperature were recorded inside 2 m x 2 m sized quadrats taken in triplicate readings. For sediment salinity, pH, and organic matter, ex-situ analysis was done. The sediment samples were taken from the 0.3 m x 0.3 m quadrat.
Figure 2. Sampling design for sample collection at Balik Pulau mangroves. This design represents the replication of plot setup in each forest replicated at Kuala Sungai Pinang, Sungai Burung and Pulau Betong. This design comprised several factors, (a) Forest (n=3), (b) Month (n=4), (c) Plot (n=2), (d) Quadrat (n=3).

2.3 Crab abundance and identification
Two individuals were assigned to set up a quadrat. Three random 4 m² quadrats were randomly selected, with the square plot perimeter set up using a thin plastic rope to minimize disturbance to crabs that may be affected by thicker lined materials. In the presence of movement during setup of the quadrats, crabs were observed taking shelter inside burrows, between roots and on textured sediment surfaces, instead of running away. Due to this disturbance, one minute of recovery time was allowed for crabs to resume their normal behaviour during pre-set up of the plot. Then, crabs that were observed in the 4 m² quadrats after recovery time were hand captured. Two individuals were assigned to catch crabs in 10 minutes in each of the 4 m² quadrat. Captured crabs were then stored in sealed plastic bags and taken to the laboratory for identification. In the laboratory, crabs were cleaned over a 500 µm sieve and stored in 70% ethanol until further identification. The number of captured crabs were then identified and recorded for each quadrat.

2.4 Environmental variables
Environmental parameters collected were organic matter, surface temperature, sediment pH and salinity. Characterization of habitat complexity was done by assessing and collecting data on canopy cover and root density. Surface temperature was taken using an infrared thermometer. Canopy cover was recorded using Canopeo, an application developed by Oklahoma State University in which an image of the canopy was captured above the head of the observer, and later processed and converted into percentage cover. Roots were counted in each 0.3m x 0.3m quadrats and comprised of pneumatophores, stilt and knee roots depending on each mangrove species.

Sediment pH, salinity, and organic matter measurement were conducted ex-situ. Ten-centimetre length of sediment cores were collected and stored at -8°C until further analysis. Sediment samples were analysed to determine organic matter, pH, and salinity. Sediment pH and salinity were measured using the method by Jones [33] and Sonmez [34]. A dilution factor of 1:2.5 was used to dilute the sediment, comprising a mixture of 10g of sediment and 25 ml of distilled water. The slurry was stirred for 4 minutes and left to settle for 30 minutes before pH and salinity readings were taken using the pH ecoTester and digital refractometer respectively.

Organic matter, analysis and procedures were conducted based on Loss on Ignition (LOI) method in The Blue Carbon Initiative by Howard [35]. Sediment was left to dry in the oven overnight at 105 °C to remove the excess water. After that, sediment samples were left for 3 hours in the desiccator for the cooling process. Then, 10g of sub-sample of dried sediment (DW105) was taken and placed in a muffle furnace at 520 °C for 4 hours (DW520) [36]. Next, samples were kept in a desiccator for 3 hours to cool
the burnt samples. Weight of the sample was determined after burning to determine the organic matter. Calculation on organic matter was done based on Heiri [36] as follow:

\[
LOI_{520}(OM\%) = \left( \frac{DW_{105} - DW_{520}}{DW_{520}} \right) \times 100.
\]

2.5 Data analysis

Crab assemblages were analysed using multivariate procedures comprising permutational analysis of variance (PERMANOVA), non-multidimensional scaling (nMDS) and similarity percentage procedure (SIMPER) in PRIMER v6. Crab assemblages were analysed based on the sampling design in Figure 2. The crab abundance data was square root transformed. Then, data were converted into a similarity matrix based on the Bray-Curtis dissimilarity coefficient for crab data. First, PERMANOVA was conducted to examine the effects of temporal and spatial scales on crab abundance and environmental data. nMDS was used to visualize the pattern of crab assemblage. SIMPER was used to determine which species contributed the most to patterns of the crab assemblage composition across spatiotemporal scales.

Environmental data were analysed using PERMANOVA. The Log (x+1) transformation was applied to the environmental data and then converted into a similarity matrix based on the Euclidean distance matrix. nMDS was used to visualize the difference in environmental setting in each forest. To determine which environmental variables affected crab composition and distribution, Bio-Env routine test (BEST) procedure based on Spearman’s correlation rank was used to identify which environmental variables could best explain patterns in crab assemblage composition.

3. Results

3.1 Crab abundance and assemblage composition

The Grapsoidea and Ocypodoidea superfamily can be found at Sungai Burung, Pulau Betong and Kuala Sungai Pinang mangrove sites. Nine species of crabs were identified, however the presence of each species varied across forest. Two crab families dominated the mangrove sites in this study, represented by the Sesarmidae and Camptandriidae (Table 1). Both families can be found in all three different forests with Sesarmidae dominating all the mangrove forest except for Clistocoeloma sp., and Episesarma sp., which was absent in Pulau Betong and Kuala Sungai Pinang mangrove sites, respectively.

### Table 1. Crab distribution in mangrove sites of Sungai Burung, Pulau Betong and Kuala Sungai Pinang at Balik Pulau, Pulau Pinang.

| Superfamily    | Family          | Species            | Sungai Burung | Pulau Betong | Kuala Sungai Pinang |
|----------------|-----------------|--------------------|---------------|--------------|---------------------|
| Grapsoidea     | Sesarmidae      | Parasesarma sp.    | +             | +            | +                   |
|                |                  | Parasesarma sp. 2  | +             | +            | +                   |
|                |                  | Perisesarma indiarum | +             | +            | +                   |
|                |                  | Perisesarma foresti | +             | +            | +                   |
|                |                  | Perisesarma eumolpe | +             | +            | +                   |
|                |                  | Episesarma sp.     | +             | +            | -                   |
|                |                  | Episesarma versicolor | +             | +            | +                   |
|                |                  | Clistocoeloma sp.  | +             | -            | +                   |
| Ocypodoidea    | Camptandriidae  | Paracleistotoma depressum | +             | +            | +                   |

PERMANOVA showed crab assemblage composition varied across forest and month (Table 2; p <0.05). No significant interaction of forest x month was observed (Table 2).
Table 2. Permutational analysis of variance (PERMANOVA) of crab assemblage composition across temporal and spatial scale. Data collected comprised of samples from Month: 4 x Forest: 3 x Plot: 2 x Quadrat: 3. Significant effects at p < 0.05 indicated in bold type.

| Source      | df  | SS      | MS       | Pseudo-F | p   | p(MC) |
|-------------|-----|---------|----------|----------|-----|-------|
| Month       | 3   | 7666.5  | 2555.5   | 2.43     | 0.008 | 0.014 |
| Forest      | 2   | 57480   | 28740    | 27.25    | 0.001 | 0.001 |
| Month x Forest | 6   | 8681.1  | 1446.9   | 1.37     | 0.151 | 0.151 |
| Residual    | 60  | 63286   | 1054.8   |          |       |       |
| Total       | 71  | 1.37 x 10^5 |         |          |       |       |

The clear separation of crab assemblages among forest and months were observed in the nMDS (Figure 3) in each month, with crab assemblage composition in Kuala Sg. Pinang clearly separated from crab assemblage in Sg. Burung and Pulau Betong. Crab assemblage in Sg. Burung and Pulau Betong is not separated as such in each month.

Based on SIMPER analysis (Table 3), crab species which contributed to the pattern observed in crab assemblage composition differed across forest. In Kuala Sg. Pinang (Table 3a), only two species of crabs were found to be present in the study site. *P. eumolpe* is the main contributor with cumulative contribution of above 80%. *P. eumolpe* is considered as the discriminating species that contributed to the different crab assemblage composition across forest. In Pulau Betong and Sungai Burung, the crab community was represented by various discriminating species (Table 3b-c). Seven species contributed to patterns in crab assemblage composition in Pulau Betong (Table 3b). *P. foresti* is the typical species found in the study site at Pulau Betong with consistently high Similarity/SD ratio, indicating that *P. foresti* was a good discriminating species. In Sungai Burung, contributing crab species varied across month (Table 3c). In June, *Parasesarma* sp.2 recorded the highest contribution to the composition with 70.97%. The average similarity in August is 38.29 with more than 50% contributed by *P. indiarum*. *P.
foresti contributed a cumulative 66.09% and 71.80% in Sg. Burung for October and December, respectively.

**Table 3.** Bray-Curtis similarity percentage analysis (SIMPER) on the crab species assemblage by forest and month. Data present in the ratio of similarity and standard deviation, contribution, and cumulative contribution.

|                | June Av. Sim: 34.98 | August Av. Sim: 31.04 | October Av. Sim: 54.05 | December Av. Sim: 38.86 |
|----------------|---------------------|-----------------------|------------------------|-------------------------|
|                | P. foresti          | P. foresti            | P. foresti             | P. foresti              |
|                | Sim/ Contr. Cum.    | Sim/ Contr. Cum.      | Sim/ Contr. Cum.       | Sim/ Contr. Cum.        |
|                | SD (%) (%)          | SD (%) (%)            | SD (%) (%)             | SD (%) (%)              |
| a) Kuala Sg. Pinang | 1.11 59.49 59.49   | 0.77 56.28 56.28      | 5.79 66.79 66.79       | 1.06 38.68 38.68        |
|                | Clistocoeloma sp.   |                       |                        |                         |
|                | Sim/ Contr. Cum.    |                       |                        |                         |
|                | SD (%) (%)          |                       |                        |                         |
|                | 0.48 7.14 93.46     |                       |                        |                         |
| b) Pulau Betong | Episesarma versicolor |                       |                        |                         |
|                | Sim/ Contr. Cum.    |                       |                        |                         |
|                | SD (%) (%)          |                       |                        |                         |
|                | 0.70 29.71 89.20    |                       |                        |                         |
|                | Parasesarma sp.     |                       |                        |                         |
|                | Sim/ Contr. Cum.    |                       |                        |                         |
|                | SD (%) (%)          |                       |                        |                         |
|                | 0.47 14.06 70.33    |                       |                        |                         |
|                | P. indiarum         |                       |                        |                         |
|                | Sim/ Contr. Cum.    |                       |                        |                         |
|                | SD (%) (%)          |                       |                        |                         |
|                | 0.78 15.28 82.07    |                       |                        |                         |
|                | Parasesarma sp2.    |                       |                        |                         |
|                | Sim/ Contr. Cum.    |                       |                        |                         |
|                | SD (%) (%)          |                       |                        |                         |
|                | 0.47 12.57 82.90    |                       |                        |                         |
|                | P. indiarum         |                       |                        |                         |
|                | Sim/ Contr. Cum.    |                       |                        |                         |
|                | SD (%) (%)          |                       |                        |                         |
|                | 0.48 11.33 94.23    |                       |                        |                         |
3.2 Environmental variables

The average pH recorded from all three mangrove sites were almost the same, ranging from 7 to 8 (Error! Reference source not found.a). Mean temperature recorded was similar in each site with consistently lowest readings across month at average of 26.63 ± 0.32 °C recorded at Pulau Betong. Average temperature at Sungai Burung and Kuala Sg. Pinang were 28.68 ± 0.36 °C and 28.65 ± 0.40 °C respectively (Error! Reference source not found.d). For salinity (Error! Reference source not found.b), the lowest reading recorded at Kuala Sg. Pinang was an average 3.08 ± 0.53 across month. Salinity in Pulau Betong was the highest at an average 6.83 ± 0.78 across month, with salinity recorded at 9.67 ± 1.54 and 9.83 ± 0.91 ppt in June and October, respectively. Next, the canopy cover (Error! Reference source not found.c) at Kuala Sungai Pinang is the lowest with mean range of 28% to 38% while Pulau Betong was characterized by the highest canopy cover from the range of 35% to 45%. Root density in Kuala Sungai Pinang was the highest with more than 200 pneumatophore roots recorded per meter square (Error! Reference source not found.c). Organic matter content in the sediment did not vary across forest, ranging from 9% to 14% (Error! Reference source not found.f).

Environmental variables differed across forest, months, and forest x month (Table 4; p < 0.05).
Figure 4. Mean (+ SEM) readings of environmental variables for each month and forest comprising of sediment pH, sediment salinity, canopy cover and temperature. Data collected across Months: 4 x Forest: 3 x Plot: 2 x Quadrat: 3.
Table 4. Permutational analysis of variance (PERMANOVA) of environmental variables across temporal and spatial scale. Data collected comprised of samples from Month: 4 x Forest: 3 x Plot: 2 x Quadrat: 3. Significant effects at p < 0.05 indicated in bold type.

| Source          | df | SS   | MS    | Pseudo-F | p     | p(MC)  |
|-----------------|----|------|-------|----------|-------|--------|
| Month           | 3  | 61.70| 20.57 | 3.18     | 0.001 | 0.002  |
| Forest          | 2  | 93.62| 46.81 | 7.24     | 0.001 | 0.001  |
| Month x Forest  | 6  | 95.76| 15.96 | 2.47     | 0.001 | 0.001  |
| Residual        | 60 | 387.92| 6.47  |          |       |        |
| Total           | 71 | 639  |       |          |       |        |

The variability across spatiotemporal scales was observed in the nMDS of environmental variables (Figure 5). Across all sampling months, Kuala Sg. Pinang was observed to be separated from Sg. Burung and Pulau Betong (Figure 3a-d).

Figure 5. Non-multidimensional (nMDS) ordination of environmental variables in study sites at Sungai Burung, Pulau Betong and Kuala Sungai Pinang, across month a) June, b) August, c) October, d) December and forest by non-multidimensional scale (nMDS). Samples taken from the mangrove of Balik Pulau, Pulau Pinang. (Month: 4 x Forest: 3 x Plot: 2 x Quadrat: 3).

Overall, patterns in crab assemblage composition were affected by different environmental variables (Table 5). Significant correlations were found across month but not at forest level. The relationship that were significant between environmental variables and crab assemblage composition across months were recorded in June, August, and December. The strongest correlation was found between crab abundance with pH and root density in June with $p = 0.535$, (
Table 5, p< 0.05). In August, the environmental variables that best explained the crab assemblage composition was salinity with $\rho = 0.462$, p< 0.05. Canopy cover and root density explained crab assemblage patterns in December with $\rho = 0.428$, p< 0.05.

Table 5. Bio-Env routine (BEST) of environmental parameters that best explained crab assemblage composition using the Spearman ranked correlation, a) Month, and b) Forest. Environmental variables comprised of 1) pH, 2) Salinity, 3) Canopy cover, 4) Temperature, 5) Roots density and 6) Organic matter. Significant correlation at p<0.05 indicated in bold type.

| Sources          | Variables | Ranked correlation $\rho$ | p   |
|------------------|-----------|---------------------------|-----|
| a) Month         |           |                           |     |
| June             | 1 and 5   | 0.535                     | 0.001|
| August           | 2         | 0.462                     | 0.002|
| October          | 1 and 4   | 0.344                     | 0.055|
| December         | 3 and 5   | 0.428                     | 0.007|
| b) Forest        |           |                           |     |
| Sungai Burung    | 5         | 0.024                     | 0.957|
| Pulau Betong     | 1,2 and 4 | 0.269                     | 0.072|
| Kuala Sungai Pinang | 1 and 2 | 0.031                     | 0.982|

4. Discussion

4.1. Crab assemblage and composition

Superfamilies Grapsoidae and Ocypodoidea dominated mangrove sites in this study, represented in the majority by the Sesarmid family. Sesarmidae is among the most diverse family that can be found in the Indo-pacific region [3]. The dominating presence of sesarmid crabs in mangrove sites from this study was similar to the findings of crab species in Selangor [2], Singapore and Peninsular Malaysia [4], in Melaka Straits-Andaman seacoast of Thailand and Malaysia [5], and in Sematan, Sarawak [7]. The number of species found in the study site is low compared to species found by Sasekumar [2] and Tan & Ng [4]. The number of crab species recorded was in the range of crab species found in the mangrove of Merbok, Kedah [5] and Marudu Bay, Sabah [6], where 10 and six species of crabs were found, respectively. In this study, Sesarmid crabs were dominant in terms of species richness and abundance, while in Marudu Bay, Ocypodidae is the most dominant family [6]. This indicated the influence of larger spatial scales and biogeographical factors in influencing crab distribution. There may also be a possibility of under-sampling crabs in this study, and not all species were caught on the mangrove forest floor, as some may actively avoid capture and hid in burrows [37,38] throughout the sampling period.

Crab assemblages varied at multiple spatial and temporal scales. SIMPER analysis showed that various crab species contributed to patterns in crab assemblage composition, suggesting a preference for specific types of mangroves [1,24]. There were different contributing species that explained patterns observed in crab assemblage composition, even though the study sites were in the same region of Pulau Pinang. Generally, most of the species that represented mangrove crab assemblages were from the family Grapsidae. This is similar to the findings from previous studies in which Grapsidae plays a vital role in influencing the mangrove ecosystem in this part of Peninsular Malaysia [4,39]. Only one species each contributed consistently to crab community structure which were P. eumolpe in the Avicennia marina dominated Kuala Sg. Pinang, and P. foresti in the Bruguiera cylindrica dominated Pulau Betong. The crab assemblage composition in the Rhizophora apiculata dominated Sg. Burung site differed
among each month. Differences in crab species dominance in each forest suggest some mangrove structure may facilitate the dominance behaviour and increase the survival chances of crabs [17,40,41]. In this study, the complexity created by the mangrove structure may have created different microhabitats which could shape the community structure of crabs [3,5,24,26]. Ashton [5] found that mangrove species richness in certain habitats contributed to the high mangrove crab species richness, similar to the findings by Sharifian [1]. The variable environment and complexity created by different mangrove species can be utilized as an important baseline in determining the diversity of mangrove crabs [1].

4.2. Environmental variability
The environmental condition under specific species of mangrove was different in each of the study sites. The pH reading recorded in this study is similar to several mangroves in the west coast state and different from the East coast mangrove of Peninsular Malaysia. pH readings were similar to those in Johor Park at an average of pH 8 [22] and Sepang-Lukut, Selangor at an average of pH 6 to 7 [23]. However, it differs from readings in Delta Kelantan [22] and mangrove of Awat-awat, Sarawak [21] which was more acidic. The salinity recorded in this study averaged from 1 to 9 ppt, lower compared to other studies [7,23]. The sediment salinity in this study differed from other sites, comprising 25 ppt at Sepang-Lukut mangrove [23], 20 ppt at Merbok, Kedah, average 11 to 20 ppt at Matang, Perak and 27 to 35 ppt in Kuala Selangor [7]. From the three study sites, Kuala Sg. Pinang was characterized by the lowest salinity; most likely affected by the location situated nearest to freshwater flow. The freshwater discharge from the nearest river located close by may have influenced the salinity reading [11].

Sediment temperature recorded varied across forests, but the pattern is stable across months. Pulau Betong recorded low sediment temperature compared to other study sites. This could be attributed to high canopy cover percentage in Pulau Betong which altered light intensity, thus lowering the sediment surface temperature [43]. Since B. cylindrica in Pulau Betong is the biggest compared with R. apiculata and A. marina at different study sites, denser canopies is likely to form [44]. The roots structure on the mangrove floor in each study sites were characterized by different types of root and revealed the zonation pattern of the study sites. In the A. marina forest at Kuala Sg. Pinang, root cover was the densest with high numbers of pneumatophore, an indicator that this forest experienced long inundation periods [45]. Sg. Burung and Pulau Betong were located more towards the landward area. In Sungai Burung, the mangrove forest floor was characterized by a mixture of stilt roots from R. apiculata and pneumatophore roots from Avicennia sp. In Pulau Betong, the knee root structure was present and was observed with spatial gaps among the knee root structure. Thus, complexity on the forest floor was clearly different among mangrove sites in this study.

4.3 Crab assemblage and the environment in mangrove habitat
The influence of habitat structure and the environment could also be affected by spatiotemporal scales [17,46]. However, this varies according to the response of the studied organism in question to spatial complexity and environmental heterogeneity in different mangroves. In this study, a significant relationship was observed only across time and not space. This may be due to the weather changes across time that affected the condition in the study site. Sen [17] found seasonal changes was the driving factor in the changes of environmental variables. In June, pH and roots density were found to have the strongest correlation that effects crab assemblage. In this study, crabs that were found in the study sites showed a preference of basic to alkaline pH. This is because if the pH tends to be acidic, this could increase the metabolic rate of crabs, leading to inefficient energy expenditure that will affect their adaptation to other harsh environmental changes [41]. Roots are complex mangrove structures that will give more benefit to marine organisms in the mangrove, as there is increased availability of variable surface areas for shelter and protection [27]. From observation in Pulau Betong, knee roots coupled with green vegetation height less than four feet such as Acanthus sp., Acrostichum aureum, Derris trifoliata and B. cylindrica saplings created a more complex habitat. That may explain why the highest number of species were found on the Pulau Betong mangrove floor.
In August, salinity was the factor that explained crab assemblage composition. According to Frusher [40], salinity played a crucial role in determining the crab zonation. Overall, salinity was recorded at a low range in this study with \textit{P. eumolpe} dominating the lowest salinity area at Kuala Sungai Pinang. In terms of salt content in water, some species that have better osmoregulation adaptation can tolerate high salinity environment and thus dominate their chosen territory [40,47]. Physical structure of canopy cover and roots density influenced the crab assemblage composition in December. During that month, the state of Penang experienced less precipitation, and the surrounding temperature is high, but in the study site, the temperature recorded did not fluctuate compared with data recorded from the previous observation. Canopy cover provides shade to crabs, reducing heat stress [42]. This may increase the activity of crabs on sediment such as foraging and bioturbation near the tree structure [25]. From this study, crab abundance and diversity could be influenced by environmental variables [1,5,17,24,25,40], although this effect varied across time.

5. Conclusion
In conclusion, crab assemblage composition differed across time, and to some extent may have been influenced by different combinations of environmental variables. This can be attributed to mangrove structure that created different habitat complexity and various environmental variables that change across time. In terms of importance, non-commercial species of mangrove crabs from families Grapsidae and Ocypodidae are often overlooked compared with crabs from the Portunidae family [48]. With increasing anthropogenic disturbance, lack of awareness and monitoring of biodiversity in increasingly deforested mangrove areas could increase the undetected decline of mangrove crab species and other marine organisms [1], thus negatively impacting mangrove ecosystem function and health. Therefore, monitoring and maintenance on crab diversity and abundance could provide a more ecologically accurate way to assess changes happening in the mangrove ecosystem in Malaysia and other tropical and subtropical regions of the world.

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