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DIVERSITY AND SPATIAL VARIATION OF SHRIMP ASSEMBLAGES IN A MANGROVE ESTUARY OF MALAYSIA

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MERBOK ESTUARY
WATER QUALITY
SHRIMP DIVERSITY
MANGROVE
BARRIER AND STAKE NETS

ABSTRACT. – Among invertebrates living in estuarine ecosystems, shrimps are highly sought after as protein sources by humans and other organisms. Shrimps have a short life cycle and spend critical life stages in estuarine systems. Thus, changes in estuarine environmental parameters could influence shrimp distribution and abundance. This research aimed to determine ecological parameters that influence shrimp diversity in Merbok estuary, a mangrove hotspot area located in the northwest of Peninsular Malaysia. Six water quality parameters (temperature, salinity, conductivity, pH, turbidity, and dissolved oxygen) were recorded at three zones (upper, middle, and lower) along the estuary from September 2012 to March 2013. Shrimps were sampled using barrier and stake nets. Three water parameters showed significant differences among the sampling zones ($p < 0.05$) including salinity, conductivity, and pH. A total of nine species of shrimps from three families (Penaeidae, Palaemonidae, and Alpheidae) were identified, with *Penaeus merguiensis* being the dominant species in each zone. The species composition showed no significant differences among zones. The middle zone had the highest diversity index, attributed to its stable environmental condition, resulting from the mixture of polyhaline and mesohaline sea nutrient sources. Shrimp abundance was negatively correlated with temperature, conductivity, and pH, suggesting these as determinant factors for the assemblage.

INTRODUCTION

Many aquatic species are diadromous, splitting their lifecycles between freshwater and marine habitats. They begin their lives in one environment and soon thereafter migrate to another, where they spend most of their lives feeding until reaching reproductive maturity. The individual then returns to its birth habitat, completing the life cycle (Bauer 2013, Sampaio & Martinelli-Lemos 2014). Therefore, marine and freshwater ecosystems serve as crucial habitats for numerous species of fishes, bivalves, gastropod snails, and shrimps for their continued existence (Adnan *et al*. 2002, Bauer 2013). These migrations are also ecologically essential as they stimulate the export and import of productivity between freshwater and marine environments (Bauer 2013).

The estuarine area is a variable environment due to its position between the watersheds and the sea. It is subjected to abrupt changes in physical condition factors due to tidal patterns and the mixing of marine and freshwater (McLusky & Elliot 2004, Ramos *et al*. 2008). These changes pose numerous challenges to the survival of post-larvae and juvenile stages, which are already at risk of predation and cannibalism. However, these inshore habitats are an essential part of the life-supporting system through provision of nurseries and feeding grounds, including for offshore populations (Jansson *et al*. 1988, Rajendran & Kathiresan 2004). In this context, estuaries that link marine and non-marine habitats acts as an important channel for these animals to migrate into and out of the area. In particular, Diop *et al*. (2007) highlighted that the estuary is crucial for the optimal growth of the shrimp for its nursery function.

Malaysia is located in the Indo-Malay-Philippines Archipelago (IMPA), a region recognized as harbouring highly diverse marine biological resources (Carpenter & Springer 2005) and a rich breeding ground for these faunal assemblages (Myers *et al*. 2000). The Merbok estuary is one of the most important mangrove ecosystems in Malaysia, connecting the Sungai (river) Merbok with the Jerai National Geopark area. Located in the northern Peninsular Malaysia, it is a globally recognized mangrove hotspot. Like other similar habitats, it functions as a channel of migration for aquatic organisms. The estuary receives marine inflow from the Strait of Malacca and freshwater from surrounding streams and land runoff. Its eight tributaries irrigate the surrounding area of 816 km^2, contributing to the diversity of the ecosystem flora and fauna (Nor *et al.* 2019, Ali *et al.* 2021).

The Merbok estuary is recognized as an important nursery ground for fishes and shrimps and habitat for mollusks, critical biological resources which support artisanal fisheries of the local community (Mansor *et al.* 2012). This habitat is surrounded by various industries, including aquaculture, agricultural, and residential areas (Jusoff 2008, Kamrudzamana *et al.* 2012, Fatema *et al.* 2014). While this augurs well for the economy in the short term, there are many challenges in maintaining ecosystem sustainability, which will ultimately influence socio-economic activities. Thus, information on how anthropogenic activities affect the natural resources of this river-estuarine is crucial for developing conservation strategies.

Shrimps are one of the most ecologically and economically significant inshore groups (Venugopal & Gopakumar 2017). As shrimps have a short life cycle and are particularly sensitive to environmental conditions, their assemblages within estuarine ecosystems are often influenced by biotic and abiotic factors (Akin *et al.* 2003, Fauziyah *et al.* 2019). Little is known about the assemblage patterns of shrimps in the Malaysian estuary and the environmental variables involved (Hayase & Haron 2002, Jamizan & Chong 2017). Therefore, the present work aims to investigate the diversity and distribution of shrimp in Merbok estuary and the water quality parameters that influence the shrimp assemblage. These environmental health indicators will be useful for strategizing conservation of this river-estuarine ecosystem to protect and nurture the post-larvae and juveniles before migrating out into the open sea as adults.

MATERIALS AND METHODS

Sampling area: The Sungai Merbok estuary is located in the northern part of Peninsular Malaysia (Fig. 1), lying between 100°20’57.33”E, 5°40’53.74”N and 100°30’24.56”E, 5°42’13.46”N. The river originates near the town of Bedong and drains into the Strait of Malacca. Many small tributaries flow into the Merbok estuary, as Sungai Merbok is the major river flowing through the area. The length of Sungai Merbok is about 35 km, with depth ranges from 3-15 m (Ong *et al.* 1991). The estuary width ranges from approximately 20 m at the upper reaches to 2000 m at the mouth (Mansor *et al.* 2012, Ismail & Ibrahim 2015).

The sampling area was divided into three zones (Fig. 1) based on the river topography; upper, middle and lower, following Mansor *et al.* (2012). Two stations were selected at each zone based on stake nets locations for ease of sampling. Bimonthly sampling was conducted from September 2012 to March 2013, focusing on the spatial gradient.

Water quality parameters and sample collection: Six surface water quality parameters were recorded *in-situ* in triplicates at each station. Salinity, temperature, and conductivity were measured using YSI Pro 1030, pH and dissolved oxygen were measured using YSI Pro 1020, while turbidity was recorded using a Secchi disk. Shrimp samples were collected using two types of nets, barrier and stake nets, deployed at each station. A barrier net was deployed at the riverbank during low tides. The length of this net was about 250 meters, while the height was about 3-5 meters, with a mesh size of 2.5 cm. This net was used to catch species that inhabit shallow muddy mangrove areas. On the other hand, the stake net, also known as bag net, has a smaller mesh size (1.5 cm) than the barrier net. The stake net was installed permanently by local fishermen in the middle of water bodies, designed to collect the smaller shrimp species inhabiting

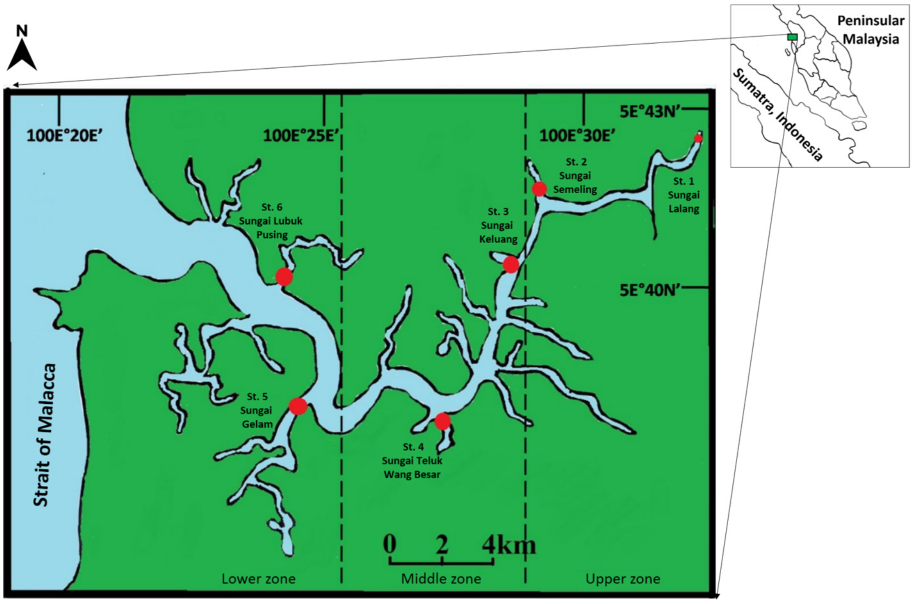

Fig. 1. – Sampling stations at upper, middle, and lower zones of Merbok estuary, Kedah (Inset: Map of Peninsular Malaysia and Sumatra, Indonesia). * Sungai (= river).

deeper waters. In the laboratory, the collected shrimp samples were enumerated and identified to the species level based on the taxonomic keys of Abu-Talib & Mahyam (1986) and the World Register of Marine Species (WoRMS 2013).

Statistical analyses: Data on water parameters and shrimp composition were $\log_{10}(x + 1)$ transformed and subjected to the Shapiro-Wilk test to assess any deviation from a normal distribution (Öztuna *et al*. 2006). Based on normally distributed data (> 0.05), the mean comparisons for water parameters and shrimp composition among the three sampling zones, were analyzed by the parametric one-way ANOVA. Pearson correlation was conducted to determine relationships between water variables and shrimp abundance. All analyses were tested based on a 95% confidence limit at $p = 0.05$. The mean comparison and Pearson correlation analyses were performed using IBM SPSS version 21 (Arbuckle 2012).

All ecological indices for species richness, diversity, evenness, and dominance were based on the rarefaction method. Rarefaction is a statistical procedure to standardize data due to unequal sample numbers among sites (Hughes *et al*. 2001). Thus, a valid comparison of species richness from samples of different sizes can be made after conducting "rarefaction" to standardize the number of individuals among sites (Chiarucci *et al*. 2009). The rarefaction procedure was made by scaling down the number of individuals to the lowest number incorporated in the EcoSim statistical software version 7 (Gotelli & Entsminger 2001).

RESULTS

Spatial variations in water quality parameters of Merbok estuary

All water parameters, namely water temperature, conductivity, transparency, salinity, water pH, and dissolved oxygen, showed spatial variations in mean values among the three zones (Fig. 2). Temperature, conductivity, salinity, and pH were lowest in the upper zone and highest in the lower zone. The mean water temperature zones ranged from 29.33° C ± 0.27° C (upper) to 29.61° C ± 0.08° C (lower). The upper zone recorded the lowest mean conductivity (221.13 µS/cm ± 4.61 µS/cm), while the lower zone recorded the highest (297.87 µS/cm ± 2.69 µS/cm). The salinity in the sampling zones ranged from 16.49 ppt ± 4.14 ppt (upper) to 22.70 ppt ± 1.61 ppt (lower). The water pH ranged from 6.88 ± 0.06 (upper)

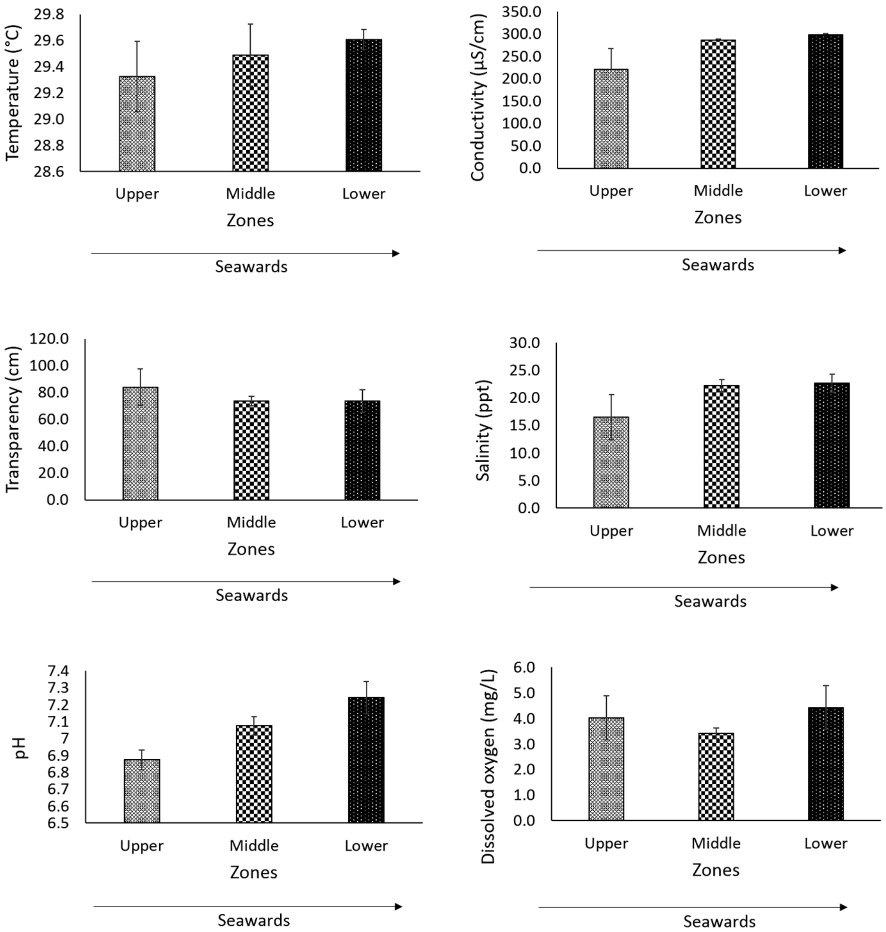

Fig. 2. – Spatial water quality parameters (mean ± sd) in the Merbok estuary (temperature, conductivity, transparency, salinity, pH, and dissolved oxygen).

Table I. – Occurrence of shrimp species at three sampling zones of Merbok estuary.

Family	Species	Common name	Sampling zones		
			Upper	Middle	Lower
Alpheidae	*Alpheus euphrosyne*	Nymph snapping shrimp	16	2	2
Palaemonidae	*Palaemon styliferus*	Roshma prawn	12	12	9
	Macrobrachium equidens	Rough river shrimp	520	582	170
	Macrobrachium nipponense	Oriental river prawn	1	6	0
Penaeidae	*Penaeus merguiensis*	Banana shrimp	1112	761	852
	Penaeus monodon	Tiger shrimp	148	105	105
	Metapenaeus dobsoni	Kadal/Flower tail shrimp	350	437	60
	Metapenaeus ensis	Greasy back shrimp	119	65	134
	Metapenaeus lysianassa	Bird shrimp	158	328	252
		Total number of individuals	2436	2298	1584
		Total number of species	9	9	8
		Total number of families	3	3	3

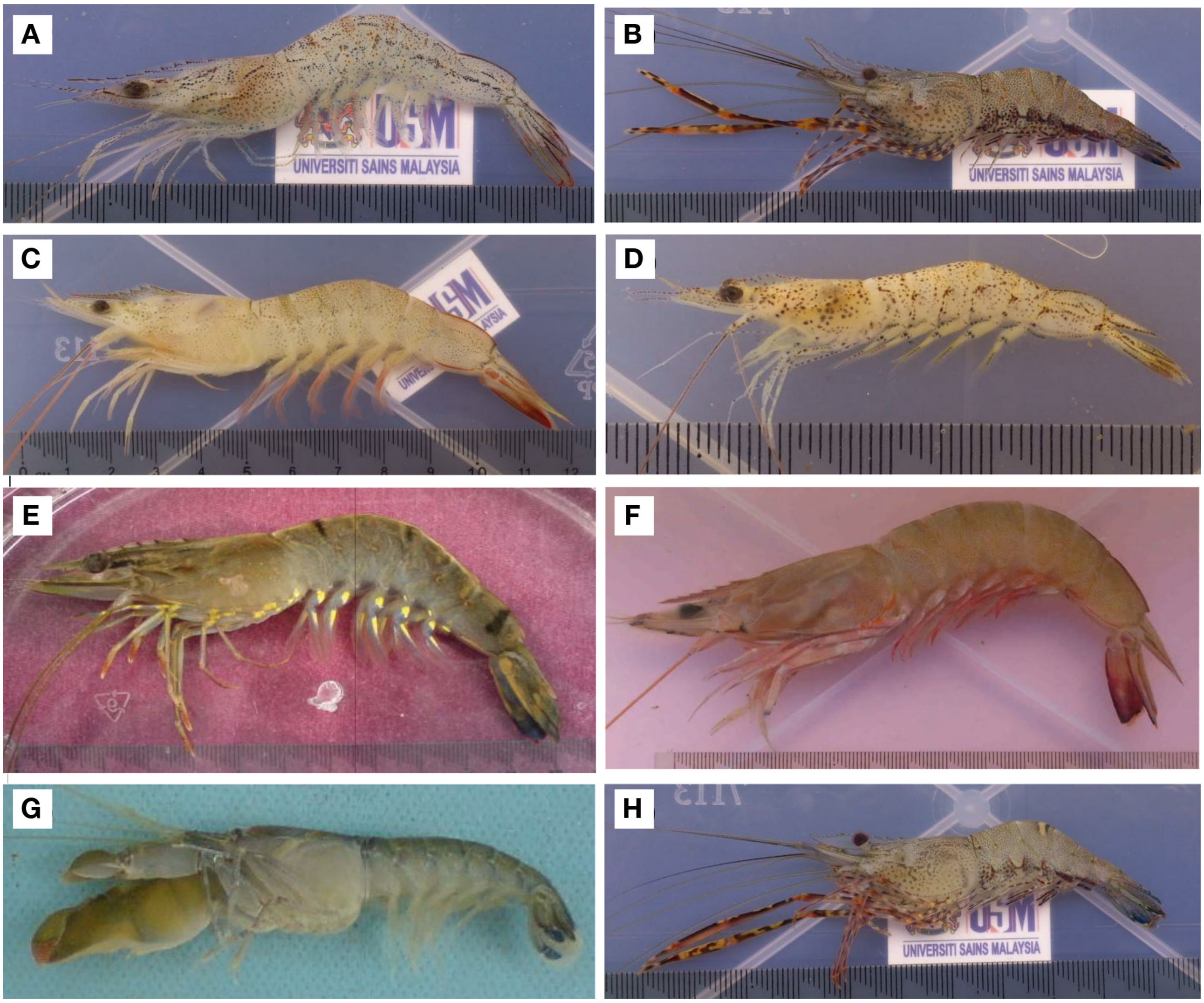

Fig. 3. – Shrimp species of Merbok estuary. **A**: *Penaeus merguiensis* de Man, 1888; **B**: *Macrobrachium equidens* Dana, 1852; **C**: *Metapenaeus dobsoni* Miers, 1878; **D**: *Metapenaeus lysianassa* De Man, 1888; **E**: *Penaeus monodon* Fabricius, 1798; **F**: *Metapenaeus ensis* De Haan, 1844; **G**: *Alpheus euphrosyne* De Man, 1897; **H**: *Macrobrachium nipponense* De Haan, 1849.

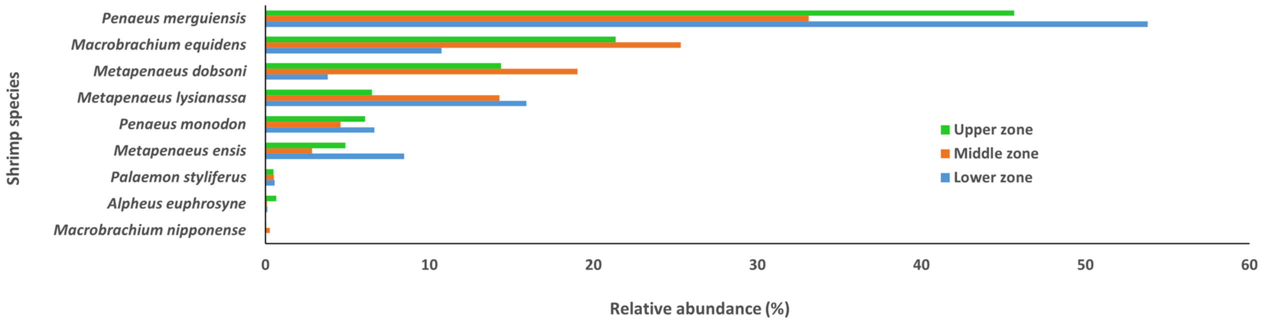

Fig. 4. – Percent relative abundance of shrimp species at the upper, middle, and lower zones of Merbok estuary.

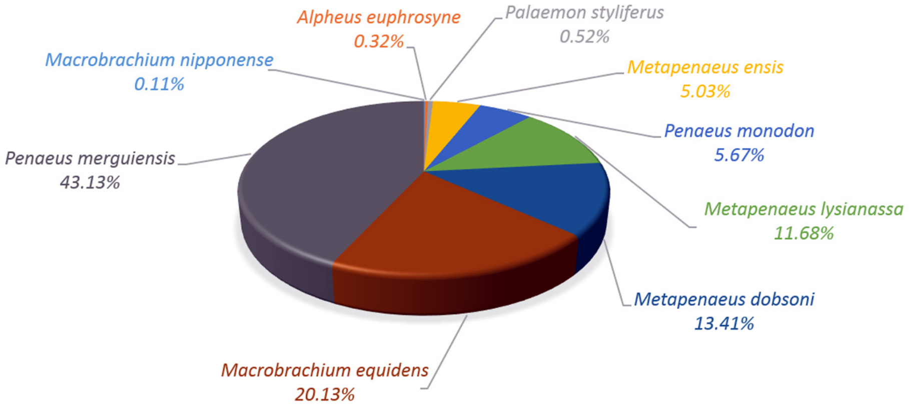

Fig. 5. – Percent relative abundance of shrimp species in the Merbok estuary

to 7.24 ± 0.09 in the lower zone. Mean transparency concentrations varied from 73.73 cm ± 3.48 cm (middle) to 84.01 cm ± 13.54 cm (upper). Dissolved oxygen was the lowest in the middle zone (3.42 mg/L ± 0.20 mg/L), while the lower zone had the highest mean value (4.43 mg/L ± 0.85 mg/L). However, only three parameters, namely conductivity, salinity, and pH, were significantly different ($p < 0.05$) among sampling zones, where the upper zone recorded the lowest values compared to that of the middle and lower zones.

Shrimp diversity in Merbok estuary

A total of three families comprising nine species were recorded in this study. Penaeidae was the most dominant family with five species, followed by Palaemonidae with three species, while another family, Alpheidae, was only represented by a single species (Table I). Nine species were recorded at both upper and middle zones, while eight were recorded at the lower zone. Species richness at the former zones surpassed that at the latter by only one species, *Macrobrachium nipponense*. The highest abundance of shrimp was recorded at the upper zone with 2436 individuals, followed by the middle zone and lower zone with 2298 and 1584 individuals, respectively. Several species are illustrated in Fig. 3. *Penaeus merguiensis* dominated all sampling zones (Fig. 4). Shrimp composition was not significantly different between zones ($p > 0.05$).

The dominant family, Penaeidae contributed 78.92 % of the total abundance at all three zones, followed by Palaemonidae (20.77 %) and Alpheidae (0.32 %). The dominant species, *Penaeus merguiensis* de Man, 1888 [in de Man, 1887-1888] made up 43.13 % of the relative abundance, followed by *Macrobrachium equidens* Dana, 1852 (20.13 %), *Metapenaeus dobsoni* Miers, 1878 (13.41 %), *Metapenaeus lysianassa* de Man, 1888 [in de Man, 1887-1888] (11.68 %), *Penaeus monodon* Fabricius, 1798 (5.67 %), *Metapenaeus ensis* De Haan, 1844 [*in* De Haan, 1833-1850] (5.03 %), *Palaemon styliferus* H. Milne Edwards, 1840 [*in* H. Milne Edwards, 1834-1840] (0.52 %), and *Alpheus euphrosyne* de Man, 1897 [*in* de Man, 1895-1898] (0.32 %), while *Macrobrachium nipponense* De Haan, 1849 [*in* De Haan, 1833-1950] (0.11 %) was the least dominant (rare) species in the Merbok estuary (Fig. 5).

Ecological indices of shrimp abundance in Merbok estuary

The average rarefaction indices based on the lowest value (1584) among the three zones (Table I) is presented in Fig. 6. The species richness was slightly higher in the middle zone (8.91) compared to that at the upper (8.65) and lower (8.00) zones (Fig. 6). Similarly, high diversity (Shannon) and evenness (Hulbert's Pie) were observed in the middle zone, followed by the upper and lower zones.

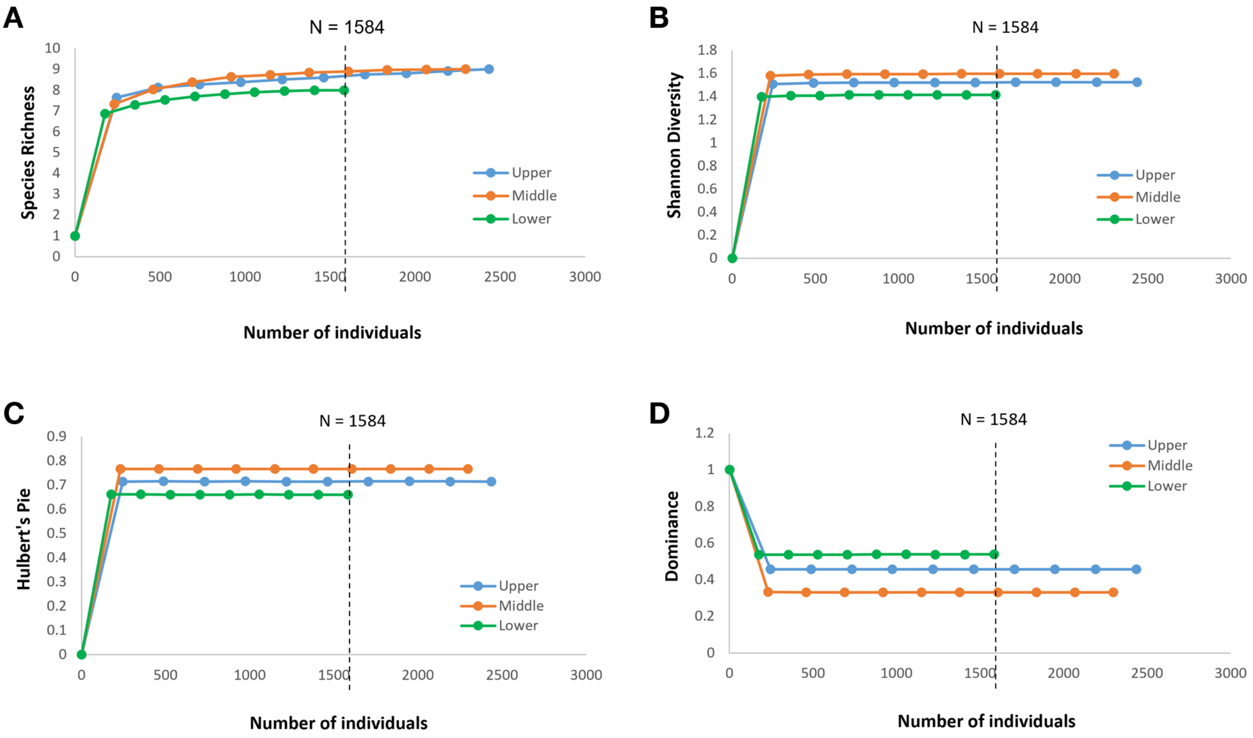

Fig. 6. – Rarefaction curve of ecological indices of shrimp assemblages at upper, middle, and lower zones of Merbok estuary conducted at N = 1584 for (**A**) Species richness, (**B**) Shannon Diversity, (**C**) Hulbert's Pie, (**D**) Dominance.

On the other hand, the species dominance was slightly higher at the lower zone, D = 0.54 than at the upper, D = 0.46, and middle, D = 0.33. However, there were no significant differences ($p > 0.05$) in richness, diversity, evenness, and dominance indices of shrimp assemblages among the upper, middle, and lower zones of the Merbok estuary.

Relationships between water quality parameters and shrimp abundance

The correlation between water quality parameters and shrimp abundance in the Merbok estuary is shown in Table II. The distribution of *A. euphrosyne*, *P. styliferus*, *M. equidens*, and *P. monodon* is negatively correlated ($p < 0.05$) with the temperature. In addition, *A. euphrosyne* and *P. monodon* are negatively correlated ($p < 0.05$) with pH and conductivity. Although the correlation are insignificant ($p > 0.05$), abundance of *A. euphrosyne*, *P. merguiensis* and *P. monodon* could be found at lower salinity environment, while the distribution of *P. styliferus* and *M. equidens* are negatively correlated with pH. Moreover, *M. dobsoni* and *P. merguiensis* are negatively correlated with temperature and conductivity, respectively. There was no correlation between dissolved oxygen and transparency with the shrimp distribution.

Table II. – Pearson correlation between water quality parameters and shrimp abundance in the Merbok estuary, Temperature (TEMP, °C), Conductivity (COND, µS/cm), Transparency (TRAN, cm), Salinity (SAL), pH (pH) and Dissolved Oxygen (DO, mg/L). * Significant correlation ($p < 0.05$)

Species name	TEMP	COND	TRAN	SAL	pH
Alpheus euphrosyne	–0.837*	–0.835*		–0.769	–0.828*
Palaemon styliferus	–0.884*				–0.755
Macrobrachium equidens	–0.867*				–0.737
Macrobrachium nipponense					
Metapenaeus dobsoni	–0.761				
Metapenaeus ensis					
Metapenaeus lysianassa					
Penaeus merguiensis		–0.788		–0.742	
Penaeus monodon	–0.837*	–0.835*		–0.769	–0.828*

DISCUSSION

Shrimp diversity in Merbok estuary

Our study is the first comprehensive report of shrimp diversity and distribution in a mangrove hotspot, the Merbok estuary located in northern Peninsular Malaysia. Although shrimps, especially *Peneaus* spp. and *Metapeneaus* spp. (Penaeidae), are the most popular species for fisheries and aquaculture globally (Songsangjinda *et al.* 2005, Manan & Ikhwanuddin 2021), there is a paucity of scientific knowledge on the shrimps' diversity in estuarine and coastal areas, which is critical for shrimp resource management (Hajisamae & Yeesin 2014). In Malaysia, shrimp diversity and distribution studies have been reported from the mangrove areas of the Matang River, Perak (Liu *et al.* 2015), Kuala Selangor, Selangor (Lee *et al.* 2013), Klang Strait, Selangor (Sasekumar *et al.* 1992) and in several ecosystems along the Johor Strait, off Singapore Island (Upanoi 2015). Notably, scientific data on shrimp diversity and abundance in the Merbok estuary are scarce; a 1996-1998 study by Hayase & Haron (2002) and another in 2009 (Jamizan & Chong 2017), where six and five species were recorded, respectively compared to nine in the current study. Taken together, this gives a total of 13 species recorded in the Merbok estuary (Jamaluddin *et al.* 2019). Therefore, this study is a significant contribution to shrimp diversity and distribution information, which could facilitate effective monitoring and management of shrimp fisheries in this critical biodiversity area.

An unbiased comparison of species diversity and distribution among the sampling areas of different Malaysian estuaries is not possible considering the non-uniformity of the sampling parameters. However, we noticed several trends which may indicate causal relationships of the diversity variation. In comparison to the nine species in the current study, eight was recorded at Kuala Selangor (Lee *et al.* 2013) and a higher diversity of 18 penaeid species in the northern and northeastern coasts of Singapore, along the Johor Strait (Upanoi 2015). The differences in species diversity recorded could be attributed to several factors; spatial coverage of sampling sites, duration of data collection, sampling gear (efficiency and set up), and sampling period (breeding, tides, etc.). For example, Upanoi (2015) sampled from various habitats, including mangrove creek, river mouth, seagrass bed, and subtidal seabed, compared to the current single ecosystem. From the total 18, only five species were recorded in the single mangrove creek. On the other hand, the eight species documented in Lee *et al.* (2013) were collected from two different mangrove sites in Selangor through monthly sampling over a six month period, while the current study was conducted at six stations bimonthly, for seven months. Thus, increasing the habitat coverage appears a better strategy than frequency of survey due to habitat-specific species preferences.

Gear selection is another important factor. Previous Merbok surveys involved only otter trawling (Hayase & Haron 2002, Jamizan & Chong 2017). Despite the longer sampling duration (34 months, and seven months, respectively), fewer species were recorded. Our dual fishing gear strategy resulted in more species capture. For example, *Metapenaeus dobsoni* could only be trapped in stake nets, *Penaeus monodon* using barrier nets, while the rest were obtained from both. Utilizing nets of variable mesh sizes (2.5 cm and 1.5 cm vs 3.8 cm in Lee *et al.* 2013) offers another advantage (Mansor *et al.* 2010, Hamid *et al.* 2015). This permitted the small *M. lysianassa*, as well the large *P. merguiensis*, to be caught. Thus, all methods for fish collection involve some degree of size selectivity, either due to the physical characteristics of the gear, behavioral responses to the gear or the spatial distribution of the target population (Christiansen *et al.* 2022).

In addition to Penaeidae, the other two families present were Palaemonidae and Alpheidae. Palaemonidae is the second largest family of suborder Caridae (De Grave *et al.* 2008), represented by *Macrobrachium equidens*, *M. nipponense,* and *Palaemon styliferus*. They have been reported in the mangrove-estuarine ecosystems of the Matang River (Liu *et al.* 2015) and Kuala Selangor (Lee *et al.* 2013). Holthuis (1980) and Salman & Bishop (1990) reported that adult genera *Macrobrachium* and *Palaemon* are usually found in freshwater while immature stages in brackish waters, particularly in tropical and subtropical regions. However, although members of the genus *Macrobrachium* are recognized as 'freshwater' shrimps, several are entirely restricted to estuaries (Short 2004). Thus, our current study is in agreement with the hypotheses and findings of previous researchers on the habitat distribution of the shrimps. The family Alphiedae was represented here by only *Alpheus euphrosyne*. This species is also known as mangrove shrimps as it prefers muddy estuarine areas of mangrove swamps (Banner & Banner 1982). This is hardly surprising as most members of this species-rich family are marine with a few freshwater species. But other carideans may tolerate seasonal freshwater or polyhaline waters, such as those found in river-estuary environments (De Grave *et al.* 2008). Apparently, the muddy estuarine mangrove of Merbok provides favorable habitat for the estuarine *A. euphrosyne*.

Our study highlights the importance of the Merbok estuary-mangrove ecosystem as a critical habitat for food and refuge for the shrimps to grow and develop. This is evident through the study by Fatema *et al.* (2015) which documented high food resources in the Merbok estuary. Similarly, Macia (2004) concluded that the main factor in the selection of post-larvae and juveniles nursery area is the food availability. Juvenile shrimps feeding on decomposed leaves of mangroves, *e.g.*, *Rhizophora mucronata* showed good growth and high food conversion efficiency (Rajendran & Kathiresan 2004). Furthermore, cholesterol diet extracted from *R. apiculata* leaves promote the growth, assimilation, and production of *P. indicus* (Ramesh & Kathiresan 1992). The Merbok estuary also provides shelter through the prop roots, fallen trees, channels, and other obstructions concealing them from larger predators, as noted in other studies (Primavera 1998, Laegdsgaard & Johnson 2001, Rönnbäck *et al.* 2002). Furthermore, the high turbidity of estuarine water reduces predator visual efficiency (Johnson & Sheaves 2007, Hajisamae & Yeesin 2014).

The distribution of shrimp assemblages is governed by the specific preference/dependency of each species (Hajisamae & Yeesin 2014). The adult estuarine-dependent species, *M. equidens* and *M. nipponense* from the family Palaemonidae (Ferreira *et al.* 2010), were found more abundant in the upper and middle zones. Generally, the estuarine species survive in freshwater when adults, but as the larval stage occurs in brackish water, the species' distribution is limited to rivers that flow directly to the sea (Mossolin & Bueno 2002). However, as expected, marine-dependent species (such as Penaeidae) were abundant at the lower zone. In addition to salinity and temperature, species composition in the lower reaches was also related to other factors, such as the seasonal migration of marine-dependent species (Smith & Parrish 2002). This could be in response to phytoplankton biomass and nutrient availability in the spring tide due to out-welling from the mangrove swamp and creek (Tanaka & Choo 2000). On the other hand, the brackish and marine habitat adaptable species, *P. styliferus* were equally distributed across the three zones.

Ecological indices of shrimp abundance in Merbok estuary

The middle zone harbored the highest shrimp species diversity. The mixture of polyhaline and mesohaline sea nutrient sources creates a suitable and stable habitat in the middle zone (connecting zone), contributing to a higher diversity and richness of shrimps. Related to this is its high evenness index (Clarke & Warwick 2001). It also provides a good nursery and shelter ground for penaeid and palaemonid juveniles (Mansor *et al.* 2012). The low richness and diversity indices in the lower zone is attributed to the extreme environmental conditions where some species such as *Macrobrachium* shrimp, could not withstand the high temperature and salinity concentration (Lal *et al.* 2012, Chand *et al.* 2015). *Peneaus merguiensis* dominated, followed by *M. lysianassa*, which contributed to the slightly higher dominance value in this lower zone. Similarly, the upper zone is typically dominated by low salinity tolerant freshwater species such as *M. ensis* juveniles (Pensri & Suchat 1996, Hajisamae & Yeesin 2014).

Relationships between water quality parameters and shrimp abundance

Changes in biotic and abiotic environmental variables (such as salinity, water temperature, food availability) and the interaction of these environmental factors creates a stable environmental condition for shrimp assemblages, growth, and survivorship (Akin *et al.* 2003, Pombo *et al.* 2005, Fauziyah *et al.* 2019). The most crucial abiotic factor that affects shrimp distribution and growth is water temperature since it determines habitat selection and induces the molting cycle (Zacharia & Kakati 2004). Even slight variations in water temperature could impact the aquatic ecosystems, thus affecting the life cycles of marine organisms (Azra *et al.* 2020). High temperature causes continuous evaporation, reducing water flow and consequently increases the organic matter. Therefore, high water temperatures can rapidly regenerate the nutrients through microbial action (Lewis 2000, Adam *et al.* 2001). Optimal water temperature is needed for survival and molting (Adnan *et al.* 2002, Chand *et al.* 2015). The water temperature (20° C to 35° C) at Merbok estuary lies within the range of the optimum temperature for growth in the tropics (Vijayan & Diwan 1995), attributing to its diversity.

Water salinity also influences shrimp distribution and growth (Zacharia & Kakati 2004, Samphan *et al.* 2015). Several post-larvae and juvenile species could inhabit high salinity environments, while others dwell in low salinity environments (Vijayan & Diwan 1995). The salinity in the Merbok estuary (15-24 ppt) is within the acceptable range of 15-25 ppt (Bett & Vinatea 2009). Extreme salinities of < 5 ppt and > 35 ppt, could inhibit the molting process, and causing mortality (Fast & Lester 2013). However, most *Penaeus* shrimps can survive a wide range of salinity in their life cycles (Zacharia & Kakati 2004, Rahi *et al.* 2021), evident by the high occurrences of *P. merguiensis* and *P. monodon* at all sampling zones of Merbok estuary. Both species prefer a lower salinity environment during juvenile and then migrate to higher salinity areas as they grow into the adult stage (Nisa & Ahmed 2000, Chaitanawisuti *et al.* 2013). In agreement with other studies, *A. euphrosyne* was recorded as a low salinity tolerant species, limited to the upper zone (De Grave *et al.* 2008).

Water pH is another factor that affects the growth of several shrimp species (Bhuiyan & Nessa 1998) as it is involved in the molting process regulation. Extreme acidic (< 4.5) and alkaline (> 9) conditions are detrimental to growth (Vijayan & Diwan 1995). The ideal range of water pH is between 6.5 and 7.5 (Angell 1998) while pH 5.5 depresses the growth of *P. monodon* (Allan & Maguire 1992). We observed favorable condition of pH 6.83-7.02 in the estuary, another contributing factor for the high abundance of particular species.

Shrimp species diversity is also associated with water conductivity. The Merbok estuary is exposed to various anthropogenic perturbations from nearby oil palm plantations, paddy cultivations, aquacultures, and other human activities, resulting in higher conductivity values at the middle and lower zones due the chemical discharges (Mansor *et al*. 2012). The abundance of *P. merguiensis, P. monodon,* and *A. euphrosyne* was inversely related to the conductivity. This suggests that the three species are more sensitive to such environmental disturbances than other shrimp species in the Merbok estuary.

Although this study revealed that water temperature, conductivity, salinity, and pH impacted the relative abundance of shrimp in the Merbok estuary, it should be recognized that other parameters could also play a role. As reported by Fauziyah *et al*. (2019) in their study at Banyuasin coastal waters, Indonesia, biotic and abiotic factors such as seabed features, food availability, tidal and sea-level patterns, community composition, interactions among species, and the reproductive strategies of its component species could influence benthic communities. These factors interact to influence the species' occurrence and their biology, eventually leading to an adaptive process throughout evolution, that facilitates the species' capacity to cope with environmental changes (Furlan *et al*. 2013). However, our study could not differentiate the individual influence of these factors in the estuary.

As the Merbok estuary offers an excellent environment for all (or most) life stages of numerous estuarine-dependent species, its protection is critical for conserving the marine and estuarine fisheries. This can only be achieved through regulations and awareness by the stakeholders, particularly the local community dependent on artisanal fishing especially of highly economically important species such as *M. ensis* and *P. monodon* (Jamizan & Chong 2017, Pickens *et al*. 2021).

In conclusion, this study highlights the importance of the Merbok estuary in supporting the high shrimp diversity composing of nine species; *i.e*., *P. merguiensis, P. monodon, M. ensis, M. lysianassa, M. dobsoni, M. equidens, M. nipponense, P. styliferus,* and *A. euphrosyne*. The biotic resources in the Merbok estuary, such as shrimp are exposed to environmental fluctuations (water salinity, conductivity, and pH) but are generally within favorable limits. In addition, the tidal cycle and physical activities near the river contribute towards the various species' distribution and abundance. However, thorough monitoring needs to be conducted for the long-term conservation of the fisheries resources associated with the anthropogenic factors along the Merbok estuary. This study also supports that the mangrove along the riverbank of this estuary has provided a favorable habitat for shrimp protection, development and survival.

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