Demersal Fish and Shrimp Abundance in Relation to Mangrove Hydrogeomorphological Metrics

(Kaitan Kelimpahan Ikan Dasar dan Udang dengan Metriks Hidrogeomorfologi Paya Bakau)

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ABSTRACT

Previous studies have found positive correlations between mangrove forest extent and fisheries yield but none of these univariate relationships provide a reliable estimate of yield from mangrove area. This study tests the hypothesis that the nursery ground value or natural production of fish and shrimps is related to the hydrogeomorphology settings of mangrove forests by using multivariate redundancy analysis (RDA). The hydrogeomorphological metrics of five mangrove forests imaged by satellite were measured using Geographical Information System (GIS). The RDA indicated that the metrics, including mangrove area, multiple waterways and creeks, mangrove-river interface, waterway surface area and sediment organic matter, influenced the diversity and abundance of fish and shrimps. Larger values of these metrics increase the abundance of economically important fish species of the families Lutjanidae, Haemulidae, Serranidae and economically-important penaeid shrimps. Sediment organic matter also significantly correlates with the distribution and abundance of fish that feed off the bottom such as the Leiognathidae, Clupeidae and Mullidae. Mangrove forests with combinations of large mangrove area, river surface area, high stream ordering and longest mangrove-river interface will provide greater role as nursery grounds for fish and shrimps.

Keywords: Fish; GIS; hydrogeomorphology; mangrove; nursery ground value; shrimp; RDA

ABSTRAK

Kajian terdahulu mendapati terdapat korelasi positif antara hutan bakau dan taburan ikan, tetapi bukan semua hubungan univariat tersebut dapat memberikan anggaran yang sebenar hasil tangkapan dari kawasan paya bakau. Kajian ini menguji hipotesis bahawa nilai nurseri atau pengeluaran semula jadi ikan dan udang adalah berkaitan dengan pemboleh ubah hidrogeomorfologi hutan bakau melalui analisis lewahan multivariat (RDA). Metriks hidrogeomorfologi lima hutan bakau dengan pengimejan satelit diukur menggunakan Sistem Maklumat Geografi (GIS). RDA menunjukkan bahawa metrik tersebut termasuk keluasan hutan bakau, beberapa anak sungai dan jeram, interfasa paya bakau-sungai, kawasan permukaan sungai dan bahan organik sedimen, mempengaruhi spesies dan kelimpahan ikan dan udang. Nilai yang besar bagi metriks ini akan meningkatkan spesies ikan yang penting daripada segi ekonomi terutamanya daripada famili Lutjanidae, Haemulidae, Serranidae, dan udang penaeid. Bahan sedimen organik juga jelas mempunyai hubung kait dengan taburan dan kelimpahan ikan yang makan di permukaan dasar seperti Leiognathidae, Clupeidae dan Mullidae. Hutan bakau dengan kombinasi keluasan paya bakau, kawasan permukaan sungai, bilangan anak sungai, dan interfasa bakau-sungai yang tinggi akan memberikan peranan yang lebih besar sebagai kawasan nurseri untuk ikan dan udang.

Kata kunci: GIS; hidrogeomorfologi; hutan bakau; ikan; nilai nurseri; RDA; udang

INTRODUCTION

Mangroves are considered as important nursery places for fish and shrimps including species of ecological, cultural and commercial importance (Abrantes & Sheaves 2009; Beck et al. 2001; Chong 2007; Mumby et al. 2004; Robertson & Duke 1987). Previous studies have demonstrated positive correlations between mangrove extent and shrimp catch and several empirical functions have been derived (Supplement I). However, the quantified relationships between shrimp fisheries and mangrove area are not simple. For example, these equations when applied to the Matang mangrove forest (43,000 ha) in Malaysia would produce annual shrimp catches that varied between only 36.6 tonnes to as high as 27,300 tonnes! It is quite clear that this relationship is location-dependent and also possibly that different mangroves have different nursery ground values. The mangrove area effect is probably confounded by other factors including differences in species composition related to mangrove-dependency; differences in functional mangrove types (riverine, fringed & deltaic) related to their effectiveness as nursery areas; presence of other coastal biotopes (e.g. seagrass meadows) which function as alternative nursery areas; and influence of co-variables, e.g. depth, temperature and salinity (Chong & Ooi 2001).

Three recent papers have attempted to redefine and summarize what constitutes a nursery-role concept based on the development of the stable nursery-role hypothesis (Adams & Ebersole 2002; de la Morinière et al. 2002; Nagelkarken et al. 2000). They proposed such tests that include an evaluation of life history strategies, comparative adult recruits per unit area of nursery habitat, comparison among habitats that juveniles use, movement patterns, and total biomass of individuals recruiting to adult populations. Dahlgren et al. (2006) modified these factors but as pointed out by Sheaves et al. (2014), these ideas basically focused on one aspect of the nursery ground value, i.e. the output of juveniles from nursery grounds to offshore areas. Thus far all the empirical functions are based on this concept but not the mechanisms that drive it. These mechanisms however include a host of interacting factors such as seascape structure and connectivity, ontogeny migrations, ecological interactions, ecophysiological factors and resource dynamics. Nevertheless, these factors are difficult to measure especially for the purpose of initial or rapid assessment and valuation of coastal wetlands as fish habitats. Such rapid assessments may be necessary for prioritization of critical coastal habitats for conservation, e.g. development of ports and harbors for strategic reasons.

We therefore propose a simple and functional approach based on hydrogeomorphology defined as the 'interactions and linkages of the hydrologic processes with landforms or earth materials and the interaction of geomorphic processes with surface and subsurface water in temporal and spatial dimensions' (Sidle & Onda 2004). It is hypothesized that the abundance or natural production of fish or shrimps in mangroves (or their nursery ground value) is related to the mangrove hydrogeomorphology. Here, we analyzed the inside of the black box (hydrogeomorphology) but not what that emerged at its end (Sheaves et al. 2014). Nevertheless, the hydrogeomorphological metrics used here represent a subset of the comprehensive factors espoused by Sheaves et al. (2014). We used multivariate analysis of the various hydrological and geomorphological parameters of five mangrove forests in Peninsular Malaysia to determine their influence on fish and shrimp abundance in the mangrove forest (swamp) itself. Hence, the objective of the study was to determine the influence of hydrological and geomorphological parameters of five mangrove forests on the abundance of fish and shrimp in Peninsular Malaysia.

Materials and Methods

Study Area

Five mangrove sites of study were selected based on the type of drainage and their assumed differences in hydrogeomorphological settings. They were Sungai Merbok (5°30'N 100°25'E), Matang (5° 1' N 100° 45' E), Sungai Air Hitam (2°49'N 101°21'E), Sungai Langat (2°48'N 101°24'E) and Sungai Pulai (1°23'N 103°32'E) mangrove forests. All sites are located on the west coast of peninsular Malaysia facing the Straits of Malacca, except Sungai Pulai which is located in the southern end of the peninsular, facing the Straits of Johor (Figure 1). The five mangrove forest sites differed in cover area, ranging from 260 ha to more than 40000 ha and included fringing, riverine, mixed fringe-riverine and deltaic mangroves.

Fish and Shrimp Sampling

Fish and shrimp were sampled by a commercial otter trawl from June 2009 to December 2009. At each mangrove site, three sampling strata or zones were established at the upper reach, middle reach and mouth of the main estuary. Subsamples were taken if the catch was huge. Total number of deployments (5-15 min each) of the trawl net varied from 6-26 times per site depending on the length of the estuarine zone. Collected specimens were enumerated and identified down to the species level and valid names followed Fishbase (fish) and World Register of Marine Species (shrimps).

Hydrogeomorphological Parameters

Concurrent hydrological or water parameters that were measured during field samplings included pH, temperature (°C), dissolved oxygen (mg/L) and salinity (psu). They were measured at all mangrove sites by a multiparameter sonde and meter (YSI 556, USA) at three sampling zones in the estuary. Organic matter content of surface sediment at each zone collected using a soil corer was determined using the combustion method (Buchanan 1984). Three mangrove geomorphology parameters or metrics, mangrove area (ha), river area surface (ha) and mangrove-river interface (km) were measured using GIS based on available Landsat ETM 7 (year 2000) and Spot 5 satellite images (year 2001) with a spatial resolution of 10 m. Although most of the faunal samplings occurred between 7 and 9 years after the satellite images were taken, the available images were considered representative of the mangrove status (i.e. state of mangrove forest and waterways) since there had been no significant changes in the mangrove cover thereafter.

All satellite images were subject to image geometric correction, image enhancement and mosaic using Erdas Imagine Version 8.3.1 software. ArcGIS v9.2 software was used for the digitizing process and data analysis. Although the satellite images used for this purpose were captured during low tide, the boundaries of the mangrove forest with the river were delineated to calculate the mangrove-river interphase, mangrove forest area and river surface area. The mangrove forest and river coverage was calculated using the Spatial Statistic Tools from the ArcToolbox within the ArcGIS software. The polygon feature of the mangrove forest and river was calculated
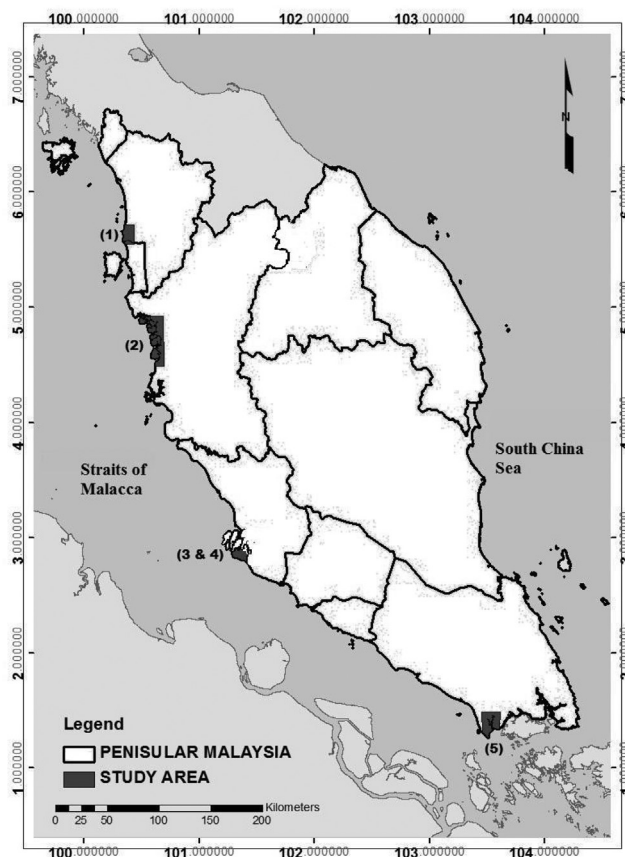
FIGURE 1. Location of study sites in Peninsular Malaysia. Mangrove forest denoted by dark shading. From north to south: (1)Sungai Merbok mangrove, Kedah; (2) Matang mangrove Forest Reserve, Perak; (3) Sungai Air Hitam mangrove and (4) Sungai Langat mangrove, Selangor; (5) Sungai Pulai mangrove, Johor

using the Calculate Areas Function in the Spatial Statistic Tools. The line feature for the river-mangrove interface was calculated using the Calculate Geometry function.

The river network of each mangrove system was obtained from the relevant Malaysian topographical maps; Sungai Merbok (No. 3266), Matang (3363), Sungai Langat and Sungai Air Hitam (3656) and Sungai Pulai (4451). The river network complexity was indexed using the Shreve (stream) ordering method (Shreve 1966). The method assigns a number to each river stretch based on the hierarchy of its tributaries or branches, thus giving an indication of its relative size within the drainage system. The higher the number the more complex is the branching network. All outer branches were assigned an order of 1 and river order increased when two segments intersected below them. Increase in river order was additive, i.e. two first-order links created a second-order link, while the intersection of a second- and third-order link created a fifth-order link and so on until the mouth of the river was reached.

STATISTICAL ANALYSIS

The standard procedure based on the 'swept area method' for estimating demersal fish/shrimps was adopted (Per

Sparre & Venema 1992). Species abundance (biomass) was estimated in term of number (weight) of individuals per hectare (no./ha or kg/ha). The swept area varied between 0.3 and 2.9 ha.

Redundancy Analysis (RDA), a multivariate method was used to elucidate the relationships between species abundance and their environment measured at the same time. RDA is a constrained linear ordination method (canonical ordination) such that the ordination axis must be linear combination of the environmental variables (Ter Braak & Smilauer 2002). For each study site and zone, relative abundance of demersal fish (family level) and shrimp (species level) estimated from trawl catches (no./ha) were related to six concurrently-measured hydrological (pH, temperature, dissolved oxygen, salinity and soil organic matter) and four geomorphological (mangrove area, mangrove-water interface length, water surface area and Shreve stream order) variables using RDA in the CANOCO 4.5 software. In CANOCO 4.5, selection of the linear response model using the direct gradient analysis approach provides the RDA algorithm, with focus on the inter-species correlations. The total number of families or species used in the RDA was 27 families for demersal fish and 16 species for shrimp. Families were used for demersal fish due to the large number of cumulated fish species during the study (122

species). Prior to analysis, $\log_{10}(x + 1)$ transformation was used to normalize the abundance data and the chord distance (Orlóci 1967), which is the Euclidean distance computed after scaling the site vectors to length 1, was selected (standardization by sample norm). Chord distances were used in the RDA instead of Euclidean distances which were inappropriate for raw species abundance data with many zero values (Legendre & Gallagher 2001). In CANOCO, a global Monte-Carlo permutation test was specified to determine the statistical significance of the relation between the species and the environmental variables. Automatic forward selection of environmental variables was carried out and the selected variables in the model were tested for significance at 5% level using Monte-Carlo permutation test (499 random permutations).

RESULTS

MANGROVE HYDROGEOMORPHOLOGY

The mean readings of temperature (°C), dissolved oxygen (mg/L) and pH were found to be quite consistent from the upper estuary towards the river mouth within site (Table 1). However, salinity was relatively higher at river mouths compared to middle reach and upper estuary. Organic matter (%) was the highest in Sungai Pulai (14.38 ± 3.60) while the lowest was recorded at Sungai Air Hitam (4.07 ± 3.05).

The satellite images showed that the Matang mangrove had the highest values in all geomorphological features including mangrove area, waterway area, length of mangrove-river interface and Shreve river order. The lowest was the small Sungai Air Hitam mangrove forest (Table 2). The Matang mangrove has a very complex morphology resulting from the myriads of interconnected waterways as indicated by its high stream order.

FISH

The first two RDA axes explained 21.7% of the total variability in the species data and 59.8% of the species-environment relation. The test of significance of the first RDA axis by Monte-Carlo permutations was highly significant (F=5.856, p=0.002), while the test of all canonical axes was also highly significant (F=2.918, p=0.002). These indicate that the relationship between species (family) and the environmental variables was significant. The first two species-environment correlations were high, 0.862 and 0.903, confirming that the environmental variables accounted for the main variation in the species composition. The important explanatory or environmental variables for fish abundance were mangrove area, waterway surface area, the mangrove-waterway interface distance and Shreve order. However, the first four variables were strongly correlated and the 'forward selection' of environmental variables in the RDA showed that waterway surface area, interface, organic matter and dissolved oxygen accounted for 78% (p<0.05) of the total variance (0.36) explained by all variables.

Matang mangrove had the largest values of the geomorphological metrics measured, while Sungai Langat had the smallest of all these features (Figure 2). Organic matter of sediment was the highest in Sungai Pulai mangrove but not correlated to the geomorphological features. Organic matter was the lowest in the Sungai Langat and Air Hitam mangroves which were the smallest and most disturbed mangroves. Air Hitam mangrove had the highest DO, TDS and pH. Salinity increased in the opposite direction as the four geomorphological metrics and temperature, that is, salinity decreased with longer estuary and larger well-drained mangroves (i.e. high stream ordering). The fringing, more open mangroves of Sungai Langat and Air Hitam with higher salinity water, appeared more attractive to the Engraulidae, Trichiuridae, Stromatidae and Tetraodontidae. High positive correlation existed between organic matter and the Leiognatidae, Clupeidae and Mullidae which were found in mangrove closely associated with coastal mudflats. The Haemulidae, Lutjanidae and Serranidae particularly in the Matang mangrove showed positive correlation with four geomorphological factors, namely mangrove area, waterway surface area, mangrove-river interface and Shreve river order. Although considered to be common mangrove species, fishes from the Dasyatidae, Gymnuridae, Sciaenidae, Ambassidae, Polynemidae and Teraponidae appeared more associated to higher DO and pH but lower organic matter, rather than with any of the mangrove geomorphological metrics. The Scatophagidae, Cynoglossidae and Mugilidae might be more tolerant to warmer water (Table 3).

SHRIMPS

The cumulative percentage variance of the species data as explained by the first two RDA axes was 28.7%, while for the species-environment relation was 58.5%. The test of significance of the first RDA axis by Monte-Carlo permutations was highly significant (F=7.494, p= 0.002) and similarly for all canonical axes (F=4.245, p=0.002). The first two species-environment correlations were very high, 0.870 and 0.850 and thus the environmental variables accounted for the main variation in the species composition.

The environmental variables that were significant (p<0.05) in the forward selection RDA model included organic matter and three geomorphological variables (mangrove-river interface, Shreve order area and waterway area) and two water parameters (oxygen and salinity) which together accounted for 92% of the total variance explained (0.50). *Fenneropenaeus indicus* showed little influence by the geomorphological metrics but were more related to, or preferring higher dissolved oxygen, salinity and pH (Figure 4). In contrast, *Metapenaeus brevicornis*, *Macrobrachium rosenberghii* and *Metapenaeus lysianassa* preferred lower temperature and sediment organic matter. Majority of the prawns analyzed shows positive correlations with the mangrove geomorphological metrics. High Shreve

TABLE 1. Mean and standard deviation of water parameters measured in five mangrove sites in Peninsular Malaysia by zone (upper estuary, middle reach and river mouth. Temp = Temperature (°C), Sal = salinity (ppt), DO=dissolved oxygen (mg/L), pH and organic matter (%)

Site	Zone	Temp °C	Sal (ppt)	DO (mg/L)	pH	Organic matter (%)
Sungai Merbok,	Upper estuary	29.49±0.84	23.82±4.16	3.76±1.52	7.31±0.46	7.03±4.59
Kedah	Middle reach	29.73±0.86	27.20±2.11	3.83±1.22	7.52±0.34	9.64±6.00
	River mouth	29.64±0.97	28.39±2.19	4.10±1.41	7.55±0.31	10.30±4.46
Matang estuary,	Upper estuary	29.87±0.95	16.43±6.68	3.71±0.68	6.92±0.27	8.44±2.84
Perak	Middle reach	29.75±0.72	17.47±5.04	3.22±0.88	6.96±0.20	10.07±1.58
	River mouth	30.09±0.99	20.70±5.05	4.37±1.78	7.20±0.31	12.18±2.66
Sungai Air Hitam,	Upper estuary	28.61±0.94	28.23±6.02	5.06±0.60	7.49±0.47	2.48±1.58
Selangor	Middle reach	28.87±0.86	27.86±6.53	5.52±0.34	7.45±0.49	4.05±3.05
	River mouth	29.02±0.93	28.55±6.82	5.71±0.33	7.54±0.52	5.69±3.12
Sungai Langat,	Upper estuary	29.37±0.22	26.44±3.66	4.69±1.81	7.72±1.11	9.89±1.48
Selangor	Middle reach	29.36±0.20	26.71±3.09	4.66±1.58	7.71±0.98	8.15±0.74
	River mouth	29.39±0.17	27.92±3.04	4.86±1.61	7.85±0.93	7.31±0.46
Sungai Pulai,	Upper estuary	28.55±1.06	26.11±5.37	3.49±1.38	7.14±0.48	15.13±3.93
Johor	Middle reach	28.77±0.54	28.50±3.97	3.82±1.15	7.34±0.68	15.41±3.98
	River mouth	29.18±0.30	29.40±3.06	4.24±090	7.55±0.50	12.29±2.76

TABLE 2. Summary information of the hydrogeomorphological features of five mangrove forest sites
in Peninsular Malaysia (2000/2001)

	Sungai Merbok, Kedah	Matang estuary, Perak	Sungai Langat, Selangor	Sungai Air Hitam, Selangor	Sungai Pulai, Johor
Main river morphology	Complex, Sinous	Complex, Anabranching	Simple, Straight	Simple, Meandering	Complex, Straight
Mangrove classification	Riverine	Deltaic	Riverine and fringing	Fringing	Riverine
Number of mangrove waterways and creeks	Moderately High	Very High	Low	Low	High
Mangrove area cover (ha)	4,120	42,784	422	260	8,081
Waterway surface area (ha)	1,600	8, 900	100	36	1,700
Mangrove-river interface (km)	131	613	20	20	223
Shreve River Order	72	997	9	11	346
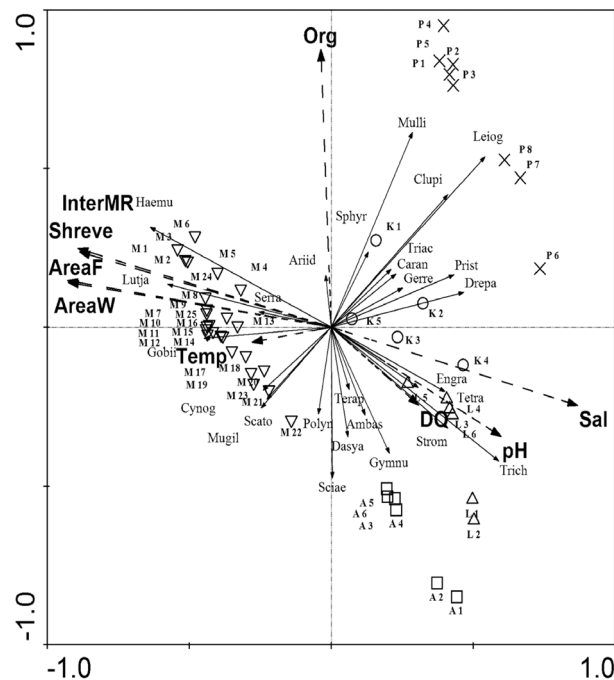
Abbreviations for hydrogeomorphical variables: Sal=salinity (ppt), pH=pH, DO=dissolved oxygen (mg/l), Temp=temperature (°C), AreaW= surface area of mangrove waterways (ha), AreaF=mangrove forest area (ha), interMR=mangrove-river interface (km), Shreve=Shreve stream order, Org= sediment organic matter (%). Abbreviations for fish families: Ambas=Ambassidae, Ariid=Ariidae, Carang=Carangidae, Clupi=Clupidae, Cynog=Cynoglossidae, Dasya=Dasyatidae, Drepa=Drepaneidae, Engrau=Engraulidae, Gerre=Gerreidae, Gobii=Gobiidae, Gymnu=Gymnuridae, Haemu=Haemulidae, Leiog=Leiognathidae, Lutja=Lutjanidae, Mugil=Mugilidae, Mulli=Mullidae, Polyne=Polynemidae, Pristig=Pristigasteridae, Scato=Scatophagidae, Sciae=Sciaenidae, Serra=Serranidae, Sphyr=Sphyrnidae, Stroma=Stromatidae, Terap=Teraponidae, Tetra=Tetraodontidae, Triac=Triacanthodidae, Trich=Trichiuridae

FIGURE 2. Ordination triplot obtained from redundancy analysis (RDA) of hydrogeomorphological data and abundance of demersal fish (family) in five mangrove forest sites. Dotted arrows refer to hydrogeomorphological variables, solid arrows refer to fish families. Site is denoted by symbol and letter (numeral indicates sample): Sungai Merbok mangrove (○, K), Matang mangrove (▽, M Sungai Air Hitam mangrove (□, A), Sungai Langat mangrove (△, L), and Sungai Pulai mangrove (×, P)

river order (indicating the presence of numerous creeks and water channels), large mangrove area and waterways and long mangrove-river interface appeared to enhance the abundance of prawns. For example, the abundance of *F. merguiensis, M. affinis, M. ensis, Pa. sculptilis, Parapeneopsis* sp. and *F. semisulcatus*, were more related to these geomorphological metrics, as compared to *Batepenaeopsis venusta, Metapenaeus lysianassa, Parapeaeopsis hardwickii* and *Macrobrachium rosenbergii* which were more associated with higher pH, dissolved oxygen and salinity as in the Sungai Pulai, Sungai Air Hitam and Sungai Langat mangroves.

TABLE 3. Mean fish/shrimp abundance estimated by trawl (no./ha) samplings in five mangrove forests in Peninsular Malaysia

Taxa	Sg. Merbok, Kedah	Matang estuary, Perak	Sg. Air Hitam, Selangor	Sg. Langat, Selangor	Sg. Pulai, Johor
Fish families					
Ambassidae	10.22	2.21	-	14.77	-
Ariidae	2321.18	765.58	456.7	124.36	256.22
Batrachoididae	-	20.78	-	0.55	1.42
Carangidae	44.92	-	-	1.26	0.58
Cichlidae	-	0.83	-	-	-
Clupidae	9.50	-	-	1.26	7.53
Cynoglossidae	-	16.02	0.85	6.34	-
Dasyatidae	9.97	41.95	22.51	23.45	2.95
Drepanidae	0.27	0.35	3.66	14.06	7.34
Eleotridae	-	9.38	5.91	1.26	0.26
Engraulidae	107.14	72.79	497.00	308.09	954.65
Ephippidae	-	-	-	-	5.21
Gerreidae	0.73	-	-	1.26	0.64
Gobiidae	-	25.70	0.40	5.25	-
Gymnuridae	-	-	0.46	8.86	-
Heamulidae	9.09	66.61	-	-	5.97
Hemiscylliidae	-	-	-	-	3.27
Kurtidae	-	-	-	-	5.49
Leiognathidae	806.51	11.21	4.81	-	73.42
Lutjanidae	1.62	472.13	-	-	0.22
Mugilidae	5.68	10.90	1.83	8.48	-
Mullidae	-	-	-	-	18.78
Muraenesocidae	0.39	-	-	-	-
Ostraciidae	-	-	-	-	0.47
Paralichthyidae	-	-	-	-	1.44
Platycephalidae	-	0.76	-	-	0.21
Plotosidae	0.50	21.84	-	4.58	0.18
Polynemidae	2.88	8.54	5.90	3.23	0.13
Pristigasteridae	6.01	1.11	26.28	-	277.92
Scatophagidae	45.81	66.19	14.29	4.07	-
Sciaenidae	653.16	413.68	258.97	856.95	127.75
Scombridae	0.32	-	0.52	-	1.60
Serranidae	-	7.00	-	-	-
Sphyrnidae	0.27	0.36	-	1.91	1.37
Stromatidae	3.96	-	4.58	2.25	0.55
Synodontidae	-	-	-	-	1.28
Teraponidae	-	-	-	11.57	0.99
Tetraodontidae	9.05	9.23	9.07	104.28	8.91
Triacanthodidae	19.18	1.23	-	7.88	2.41
Trichiuridae	10.72	-	16.09	4.15	16.47
Total Density	4048.63±3866.17	2181.94±1056.71	1329.83±678.84	1520.12±888.39	1785.63+1067.57
Total Biomass	129.23±115.64	75.21±29.78	70.08±44.27	63.88±49.10	29.2±2.36
Prawn Species					
Alpheus sp. A	-	0.12	-	-	-
Exopaleomon styliferus	-	0.26	0.91	-	0.37
Macrobachium equidens	-	0.37	-	-	-
Macrobachium rosenbergii	-	0.00	-	2.53	-
Batepenaeopsis venusta	-	0.00	5.35	-	0.91
Fenneropenaeus indicus	50.41	2.94	3.99	10.92	3.29
Fenneropenaeus merguiensis	-	40.84	-	4.59	-
Fenneropenaeus penicillatus	-	5.02	2.28	-	-
Metapenaeus affinis	-	62.44	151.18	29.02	-
Metapenaeus brevicornis	-	84.19	0.79	127.56	3.29
Metapenaeus ensis	0.63	18.02	64.02	-	1.83
Metapenaeus lysianassa	0.63	0.35	3.38	-	0.37
Parapenaeopsis hardwickii	-	-	29.66	-	0.37
Parapenaeopsis sculptilis	3.26	91.52	-	-	2.2
Parapeneopsis sp. B	-	1.95	-	-	-
Penaeus monodon manillensis	1.28	6.73	-	-	-
Total density	56.21±27.67	314.76±68.21	261.57±124.18	174.62±46.19	12.63±21.86
Total biomass	0.73±0.09	1.18±3.39	1.22±0.39	0.86±0.27	0.1±0.17

All fish families used in RDA except Batrachoididae, Cichlidae, Eleotridae, Ephippidae, Hemiscyliidae, Kurtidae, Muraenesocidae, Ostraciidae, Paralichthyidae, Platycephalidae, Plotosidae, Scombridae, and Synodontidae,
All prawns and shrimps species used in RDA
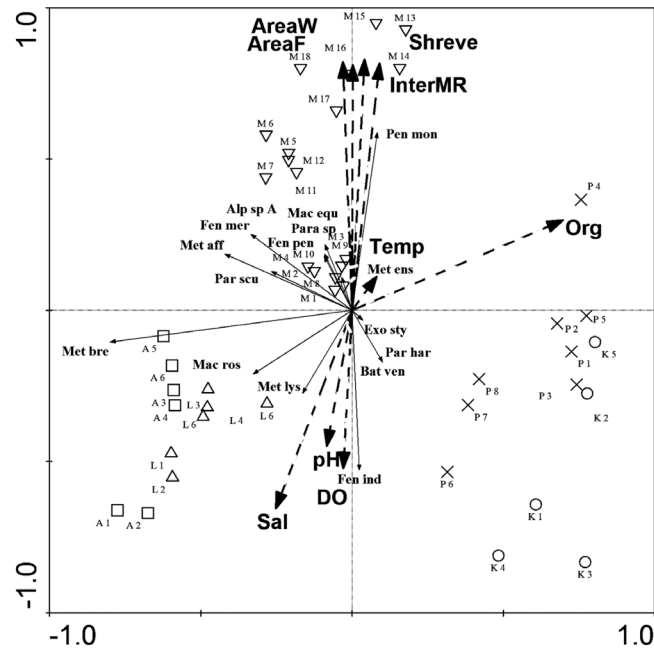
Abbreviations for hydrogeomorphogical variables: Sal=salinity (ppt), pH=pH, DO=dissolved oxygen (mg/L), Temp=temperature (°C), AreaW= surface area of mangrove waterways (ha), AreaF=mangrove forest area (ha), interMR=mangrove-river interface (km), Shreve=Shreve stream order, Org= sediment organic matter (%). Abbreviations for shrimp species: Alp sp= *Alpheus sp A*, Bat ven=*Batepenaeopsis venusta*, Exo sty=*Exopaleomon styliferus*, Fen ind=*Fenneropenaeus indicus*, Fen mer=*Fenneropenaeus merguiensis*, Fen pen=*Fenneropenaeus penicillatus*, Mac equ= *Macrobachium equidens*, Mac ros=*Macrobachium rosenbergii*, Met aff=*Metapenaeus affinis*, Met bre=*Metapenaeus brevicornis*, Met ens=*Metapenaeus ensis*, Met lys=*Metapenaeus lysianassa*, Par har=*Parapenaeopsis hardwickii*, Par scu=*Parapenaeopsis sculptilis*, Par sp= *Parapenaeopsis sp A*, Pen mon=*Penaeus monodon manillensis*

FIGURE 3. Ordination triplot obtained from redundancy analysis (RDA) of hydrogeomorphological data and abundance of shrimp species. Dotted arrows refer to hydrogeomorphological variables, solid arrows refer to shrimp species. Site is denoted by symbol and letter (numeral indicates sample): Sungai Merbok mangrove (○, K), Matang mangrove (∇, M), Sungai Air Hitam mangrove (□, A), Sungai Langat mangrove (Δ, L) and Sungai Pulai mangrove (×, P)

DISCUSSION

Geomorphological settings of the mangrove have a strong influence on the distribution and abundance of the fish families of Lutjanidae, Haemulidae and Serranidae and penaeid shrimps, all of which have high economic value in fisheries production. Large mangrove forests that are drained by numerous creeks and waterways with large area of water surface, and long mangrove-river interface are likely to provide the most suitable nursery habitats for these fishes and shrimps. A similar observation was also reported for the Lutjanidae and Haemulidae in the Caribbean where the catches (biomass) of these two families were significantly higher (>400%) in larger compared to smaller mangrove area (Mumby et al. 2004). Faunce and Serafy (2007) reported that the gray snapper, *Lutjanus griseus* and haemulid, *H. sciurus*, after entering the mangrove habitat, migrate farther upstream (up to 12 km) along the mangrove shoreline with ontogenetic development. In southwest Florida, the offshore abundance of the goliath grouper, *Epinephelus itajara*, is attributed to the abundance of mangrove and not seagrass habitats that serve as its nursery area for a period of 5-6 years (Koenig et al. 2007). Tanaka et al. (2011) reported that large mangrove forests such as in Matang are essential nursery

areas for the mangrove snapper (*Lutjanus johnii*) whose young juveniles (<5 cm TL) initially enter and reside in the lower regions of the mangrove swamp but eventually move far into the upper estuarine waters (up to 18 km) as they develop. In the nursery area, they feed on a variety of mysid, sergestid and penaeid shrimps. Nagelkerken et al. (2000) described the mangroves as an important biotope for juveniles of two species of Lutjanidae (*L. apodus* and *L. griseus*) in Bonaire, Netherlands Antilles. They reported that the catches of these two species in the mangroves were significantly higher compared to the seagrass bed.

The abundance of penaeid shrimps and the pistol prawn *Alpheus* sp. is also related to the tested mangrove geomorphological metrics. Hypothetically, the longer mangrove-river interface and numerous channels and creeks should provide more refugial space for juvenile shrimps. For instance, a sinusoidal river with numerous creeks that drain the mangrove forest will provide more opportunity for shrimps and other vagile organisms to enter into the mangrove forest from the river or shoreline, as well as providing shallow refuge ground to retreat to during high and low tide, respectively. Faunal distribution studies in Matang mangrove have provided evidence of an 'edge effect' distribution in that estuarine shrimps

and macrobenthos were mainly confined to the banks of the mangrove waterways during ebb tide (Low et al. 1999; Muhammad Ali et al. 1999). Nevertheless, a large mangrove area with few creeks/waterways may not necessary has the same effect.

The results from a study in northern Australia showed that juvenile banana prawns (*Fenneropenaeus merguiensis*) of wide range of sizes moved considerable distances into the mangrove forest via the numerous tidal creeks at high tide (Vance et al. 1996). Many small fish also moved well into the forests, but the larger fish (predators) were found only at the outer fringe of the mangrove (Ronnback et al. 1999; Vance et al. 1996). Lee (2004) reported that the extent of the intertidal area (as measured by tidal amplitude) has a bigger effect on shrimp catch than mangrove area per se. These findings are corroborated by the present study (geomorphological metrics) but indicate that species habit or dependency on mangrove areas should also be considered. In the present study, several species of *Metapenaeus* and *Parapenaeopsis* were not abundant inside the mangroves as do *Fenneropenaeus* and *Penaeus*, but on the coastal mudflats where they were dependent on other hydrological factors including sediment organic matter. These species of mangrove independent species may enter adjacent mangrove areas during high tide, as in the Sungai Langat and Air Hitam fringing mangroves. Mangroves with low values of their geomorphological metrics also support a lower diversity of fish and prawns as compared to mangroves with higher values. Only 65 species of fish and invertebrates were sampled in Sungai Air Hitam and 66 species in Sungai Langat mangroves, whereas samplings in the Matang and Sungai Pulai mangroves recorded 84 and 81 different species, respectively.

That mangroves contain high densities of juvenile fish has been attributed to their structural complexity which provides refugial space against predators (Primavera 1997; Robertson & Blaber 1992). A number of laboratory experiments have added support for the refuge value of complex structures from investigations on the behavior of fish and crustacean in vegetated (real or artificial) and non-vegetated areas, with or without predators present. For example, juvenile fishes of a number of species actively sought shelter among artificial structures in a tank in the presence of predators but moved away from these structures when predators were absent (Laegdsgaard & Johnson 2001). Various metrics used to quantify structural complexity of mangrove included canopy width, tree height, mangrove fringe width and prop root density (Faunce & Seraphy 2007; Ley & McIvor 2002). Structural complexity does vary among the different species of mangrove and several experimental manipulations have shown increased fish abundance with habitat complexity (de la Moriniere et al. 2004; Nagelkarken et al. 2010; Verweij et al. 2006). Although mangrove structural complexity was not investigated in the present study, all mangrove areas in the present study contain various mangrove species except Matang, a silvicultured mangrove plantation of largely *Rhizophora apiculata*. Nonetheless,

the Matang mangrove has not suffered any ill impact on its aquatic faunal abundance and diversity.

The present study did not consider enhanced or co-effects of associated biotopes (e.g. Mudflats and seagrass beds) in the mangrove areas. Sungai Pulai mangrove has nearby seagrass beds and mudflats, while the rest are connected to coastal mudflats. Co-occurring habitats may increase fish diversity (Chong & Sasekumar 2002) but their influence on stock density has not been clearly established since few studies have examined the effect of multiple habitats on fish abundance (Mumby et al. 2004; Nagelkarken 2007; Saintillan 2004). As pointed out by Meynecke et al. (2007), mudflats and sandflats often connected to the mangrove ecosystem have greatly been underestimated as feeding areas in broad-scale analyses. These ecosystems are also important habitats for fish species, with their high organic component, microbial activity and large quantity of microphytobenthos. They concluded that the structural connectivity of estuarine habitats determines fish stock size. Dependency of multiple habitats has been reported in many fish species, e.g. the emperor red snapper (Cappo & Kelley 2000), lemon shark (Guttridge et al. 2012), haemulids and other snappers (Nagelkerken 2007). The post larvae of certain species of haemulid and lutjanid in southeast Florida first settle on seagrass beds before entering the mangrove habitat (Faucy & Serafy 2007). Adult densities of several coral reef species are enhanced by the presence of nearby bays harboring mangroves and seagrass beds (Nagelkerken 2007). Lee (2004) suggested that to maintain fisheries production, the combination of various estuarine habitats utilized by the various life-history stages of different species should be considered.

The present study implies that the construction of aquaculture ponds which first removed or filled up the many small mangrove creeks at the periphery can alter mangrove hydrogeomorphology and thus reduce the number of fish species and abundance. Eventually the removal of more mangroves down to the main channel will reduce the mangrove-river interface with similar effects on fish abundance. Other anthropogenic effects which may not alter mangrove geomorphology can instead alter the hydrological state or quality. The Sungai Pulai estuary presumably suffers from such effects including those due to Port Tanjung Pelepas and the Tanjung Bin power plant. The present study has some weaknesses that can be verified in future investigations. Samplings covered three months; more samplings over a year in each mangrove site could show seasonal changes in fish abundance, e.g. due to fish recruitment and emigration. This study did not consider the water quality of the mangrove waters although DOE (2008) scored all sites as slightly polluted with water quality index (WQI) that ranged from 75-78. Other effects, mainly anthropogenic such as human settlement, aquaculture, agriculture and other land uses may be confounding factors. In fact, the incorporation of socio-economic parameters into the hydrogeomorphological model would make it a more realistic and powerful model.

CONCLUSION

This study demonstrates the usefulness of the hydrogeomorphological metrics in the evaluation of mangrove nursery value. Although salinity may influence diversity and abundance of certain species spatially (upstream and downstream sites), the geomorphological settings of the mangrove forests have the most significant effects. Larger values of the geomorphological metrics suggest more niches and habitat space for fish and shrimp. The study indicates that the size of the mangrove area cannot be used as the sole criterion for quantifying fish/ shrimp abundance inside the mangrove. The number of waterways, channels and creeks that dissected the mangrove area and the mangrove-river interface appear important to facilitate the use of mangrove as habitat and refugia. The hydrogeomorphological approach has the benefit of using satellite images and GIS technology to measure the various metrics. This study thus ranked Matang mangrove as the most successful nursery ground for fish and prawns and the Air Hitam mangrove as the least. Given the difficulty of fishery/forest managers to provide quick information of the direct value of mangrove forests to fisheries, the implication of this study is that managers could rank the mangrove forests in their country in terms of their nursery ground value using this rapid approach. Nonetheless, the hydrogeomorphological approach could be refined and improved if other water quality and land-use parameters are incorporated into the multivariate model. Another implication of the study is that manipulations such as rehabilitation of mangrove forests are possible to enhance the hydrogeomorphological requirements in order to increase diversity and abundance of mangrove-dependent fauna.

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