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MACROFAUNAL DIVERSITY ON THE SURFACE SEDIMENT OF MANGROVE HABITAT ADJACENT TO THE SEAGRASS BEDS AT PUNANG-SARI RIVER ESTUARY (MALAYSIAN BORNEO), SOUTH CHINA SEA

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Abstract: Macrofaunal diversity and composition are essential to understanding the ecosystem structures and functions of mangroves in any dynamic estuarine coast. To understand the temporal distribution of macrofaunal community structures and diversity on the surface sediment in the intertidal mangrove forest next to the seagrass beds, this study was conducted at Punang-Sari-River estuary, Lawas, Sarawak (Malaysian Borneo), South China Sea. Sampling was done during post-monsoon, intermediate-September, pre-monsoon, and monsoon from July 2019 to February 2020. The mean macrofauna abundance was higher pre-monsoon, while Gastropoda *Optediceros breviculum* (L. Pfeiffer, 1855) was the most abundant (RA = 0.704). Important Species Index (ISI = 70.36) and percentage of contribution (64.97%) were also higher for this species than any other records from the site. The ANOSIM (Analysis of Similarity), Jaccard index and SIMPER (Similarity Percentage Analysis) analysis suggested that the highest species abundance similarity was observed between pre-monsoon and monsoon, while the highest dissimilarity was observed between intermediate-September and pre-monsoon (74.67%). Seasonal PCA, nMDS, and cluster analysis revealed that pre-monsoon and monsoon were comparable in species and individual abundance. The dominance (0.85) was found significantly higher ($P < 0.0001$) in intermediate-September, while Simpson (0.734), Shannon (1.56) and Evenness indices (0.528) were found higher in monsoon, followed by the higher Margalef richness indices (3.21) in post-monsoon. It was observed that the seasonal ecological parameters were found to be significantly ($P < 0.05$) different, including the temperature, salinity, rainfall, pore water nitrogenous compounds (NO_2, NO_3 and NH_3-N), phosphorus compound (PO_4) and micro minerals. The Canonical Correspondence Analysis (CCA) results suggested that ecological factors influenced several species. Considering the few studies on mangrove macrofauna in Malaysian Borneo, further research on their trophic structures and food web interactions is very important to disclose their overall characteristics and ecosystem functions.

Keywords: Intertidal mangrove, Gastropoda, Bivalvia, macrofauna, benthos.

Introduction

Mangrove is one the important coastal habitat, which significantly impacts the alpha to gamma marine biodiversity, serving foods, shelters, breeding grounds, carbon sequestration, and other economic services (Brander *et al*., 2012; Atkinson *et al*., 2016; Omar *et al*., 2018; Lucas *et al.*, 2020). Malaysia is one of the countries in the world that has mangrove habitats throughout its boundary (Chandra *et al*., 2011; Shah *et al*., 2016; Billah *et al.,* 2017; Abu Hena *et al*., 2020). Mangroves are a very important habitat for bivalve species contributing to the feeding, breeding and nursing ground for different trophic levels of these organisms, which was assessed throughout South-East Asia, while some species of Lucinid bivalve were reported from the Malaysian mangrove habitat of Johor (Glover *et al.*, 2008; Saifullah *et al.,* 2014; Hamli *et al.,* 2015; Kassim *et al.,* 2018; Yahya *et al.,* 2020; Al-Asif *et al.,* 2020, 2021; Duisan *et al.*, 2021). The study on different mangrove-associated oysters suggested that this species can work as a bio-indicator for pollution or any other changes in the particular habitat (Billah *et al.*, 2014; Vaezzadeh *et al*., 2019).

The previous studies from Malaysian mangroves and mudflats reported some of the ecologically important macrobenthos species including the Gastropoda, Bivalvia and Foraminifera from different parts of that country (Broom, 1982; Sasekumar & Chong, 1998; Ellison, 2008; Mohamamad & Jalal, 2018; Kassim *et al.*, 2018; Abd Malek *et al.*, 2021). The first study was reported from the Matang mangrove forest in peninsular Malaysia (Sasekumar & Chong, 1998) and the baseline study from east Malaysia was conducted in the Semantan mangrove forest Sarawak (Ashton *et al.*, 2003). Studies by Mokhtari *et al*. (2016), Salleh-Mukri and Shuhaida (2021), Sharif *et al*. (2019), and Tan and Ng (1994) described the different species of crab abundance from different mangrove habitats, including Sarawak and Sabah. The overall study on seasonal dynamics of surface sediment macrobenthos in mangrove habitats was not conducted in Malaysian mangrove habitats, especially in east Malaysia.

The major ecosystem services provided by mangrove habitat are the home for many benthos (especially on-fauna), feeding and breeding ground for them (Alongi & Christoffersen, 1992; Faust & Gulledge, 1996; Beasley *et al*., 2010). Punang Sari Lawas mangrove habitat is among the mangrove habitat where the seagrass beds and mangroves form unique complex marine ecosystems in this region (Gandaseca *et al*., 2014, 2016; Pazi *et al*., 2016; Al-Asif *et al*., 2020). Studies suggested nine seagrass species are available on the site (Abu Hena *et al*., 2016b). The Punang-Sari Lawas seagrass bed was first reported by some renowned scientists from Malaysia and little comprehensive work on benthos in seagrass-mangrove complex was conducted (Bujang *et al*., 2006; Al-Asif *et al*., 2020; Ismail *et al.,* 2020, 2021; Al-Asif *et al.,* 2023). Previous studies also suggested that mangroves provided shelter to more taxa than non-mangrove-seagrass areas (Al-Asif *et al*., 2020). The research gaps were sought in this area, including the ecology and biodiversity of marine benthos in the seagrass-mangrove complex in Punang-Sari-Lawas seagrass bed, Sarawak Malaysia (Al-Asif *et al*., 2020; Ismail *et al*., 2020, 2021).

In Sarawak, some studies on the macrobenthos community were conducted, but the seasonal distribution, community structures and studies on the ecology of fauna living within mangrove habitats are scarce (Hamli *et al*., 2015; Abu Hena *et al*., 2016a; Al-Asif *et al*., 2020; Al-Asif *et al.,* 2023). A comprehensive checklist of benthic macro bivalves was prepared, while species from mangrove habitat was mentioned, instead their aquatic habitats such as freshwater, marine and brackish water were focused (Al-Asif *et al*., 2021; Hamli & Al-Asif, 2021). The information about the macrofaunal abundance, their ecology, community structures, and seasonality was not comprehensively studied in Malaysia (Ashton *et al.*, 2003) and the information gap led to the investigation of the current study. Therefore, this study aimed to investigate the seasonal benthic on-faunal biodiversity associated with the mangrove habitat next to the seagrass complex and their interaction with ecological parameters. The study focused on the benthic organisms inhabiting the sediment surface, which could potentially contribute to coastal biodiversity conservation in tropical ecosystems.

Materials and Methods

Study Area and Periods

The mangrove habitat in Lawas (4°55’26.6”N, 115°23’30.0”E) is located on the southeastern corner of the South China Sea, within Brunei Bay (Figure 1). Nine seagrass species and other mangrove species co-exist and have been recorded in the study area (Bujang *et al*., 2006; Ahmad-Kamil *et al.,* 2013; Gandaseca *et al*., 2014; Abu Hena *et al*., 2016b).

The major rivers flowing into the study area are Batang Lawas, Sungai Punang, Sungai Sangkurum, Sungai Siang-Siang, and Sungai Bangat. The study was conducted between July 2019 to February 2020, considering the four seasonal patterns, namely post-monsoon (from May to July 2019), intermediate-September (from August to September 2019), pre-monsoon (from October to December 2019) and monsoon (from January to April 2020) adopted, compiled and modified from the study of Ismail *et al*. (2021) (Table 1).

Collection and Analysis of Ecological Parameters

Pore water samples were collected per EPA rules (Duncan *et al*., 2007). *In-situ* parameters such as the soil pH and land elevation data

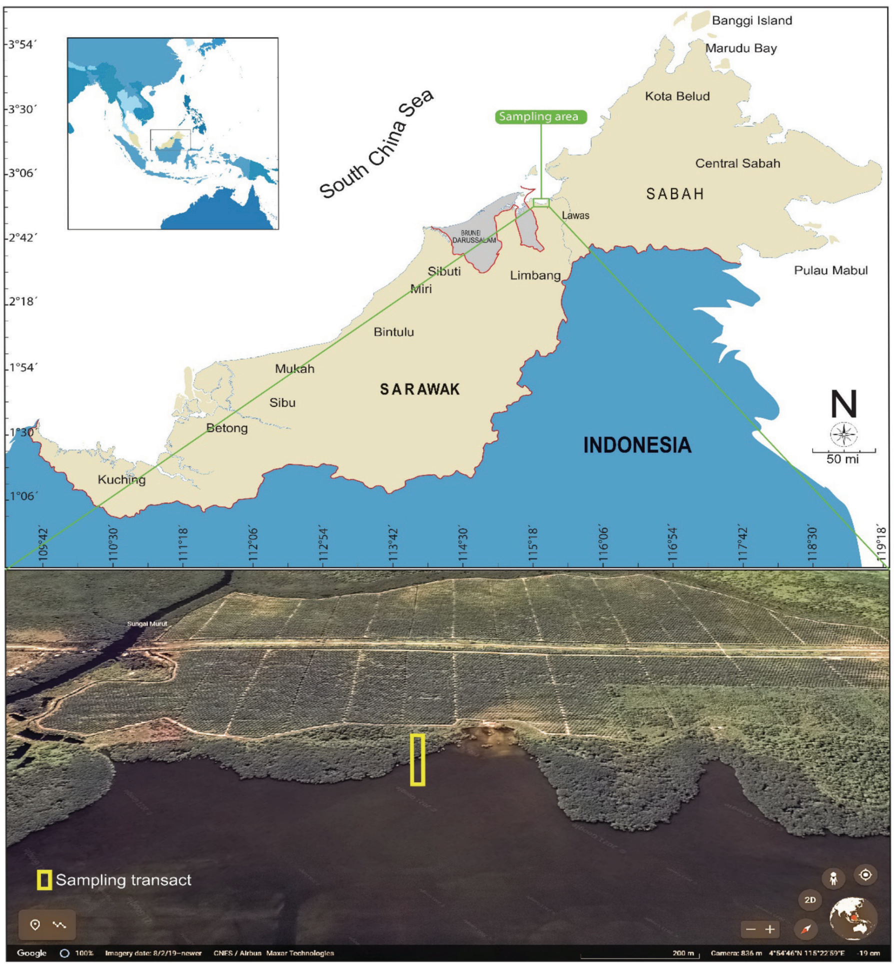

Figure 1: Study area showing the sampling site at the mangrove habitat in Lawas, Sarawak

Table 1: Sampling periods to collect the macrobenthos and ecological samples

Seasons	Code	Seasonal Classifications	Months	Sampling Time
Dry	PoM	Post-monsoon	May to October 2019	July 2019
	INT-S	Intermediate-September		September 2019
Wet	PM	Pre-monsoon	November 2020 to February 2021	December 2019
	MO	Monsoon		February 2020

were collected on-site using a soil pH meter (DM-15) and hose pipe method, respectively. The weather data such as air temperature, wind speed and total rainfall were collected from the Meteorological Department of Malaysia. Each transaction had three replications of pore water samples collected in 250 ml pre-acid washed and labelled bottles. The collected water samples were transported to the Water Quality Laboratory, Universiti Putra Malaysia Bintulu Sarawak for further analysis. The samples were moved from the ice box to a freezer (Protech, chest freezer: model CF500; -19°C) for further analysis. In the laboratory, the pore water pH was measured using a handheld water quality calibration meter (Model: Multiparameters, WQC-24) following Duncan *et al*. (2007). The Phosphate (PO_4-P), ammonium (NH_3-N), and Nitrite (NO_2-N) content of pore water were measured following APHA (2005). Nitrate (NO_3-N) contents of pore water from mangrove habitats were analysed using Kitamura *et al.* (1982). Pore water trace elements such as copper (Cu), zinc (Zn), calcium (Ca), potassium (K) and magnesium (Mg) were analysed through an Atomic Absorption Spectrophotometer (AAS) (Model: S/N 800S4010404) in Analytical Laboratory.

Collection and Analysis of Macrofauna on the Surface Sediment

A 10 m transect was laid perpendicularly from the seaward margin into the mangrove area and three (3) quadrates with 0.123 m^2 (0.35 m × 0.35 m) were settled at starting of transect line, mid of transect line and end of the transect line to collect the on-fauna samples by hand picking from mangrove habitat and converted into meter square (m^2). The collected samples were placed into previously labelled plastic bags and preserved in an ice box until they reached the laboratory for further analysis. The samples were preserved in a negative refrigerator (-19°C) before further analysis, the Gastropoda, Bivalvia, Crabs, Polychaete and other crustaceans were identified and counted using the key of Poutiers (1998), Tan and Clements (2008), Chan (2009), Wong (2009), Cob *et al.* (2012), Hamli *et al*. (2013), and Herbert *et al*. (2018).

Diversity Indices Analysis

The diversity indices, such as the Shanon diversity index (Shannon, 1948), Simpson diversity index (Simpson, 1949), Pielou's evenness index (Pielou, 1966), dominance index (Camargo, 1997) and Margalef's richness index (Margalef, 1974) were calculated using the number of individual present in different seasons in mangrove habitat using PAST 4.03 (Hammer *et al*., 2001).

The relative abundance, frequency, Important Species Index (ISI) and percentage were calculated using these formulas (Ismail *et al*., 2021):

- The relative abundance was measured using the formula,

$$\text{Relative abundance} = \frac{\text{Averages number of individuals of any species in a season or mangrove habitat}}{\text{Total number of species in that particular season or mangrove habitat}} \quad (1)$$

- ISI was calculated using the formula,

  ISI = Average relative abundance in a season or mangrove habitat × Frequency in 100 scale (2)

  While the Jaccard index was calculated using abundance, presence and absence matrix of benthos in the site (Jaccard, 1912; Tanimoto, 1958; Al-Asif *et al*., 2020).

- The Jaccard index was calculated using the formula,

$$J(A,B) = \frac{|A \cap B|}{|A| + |B| - |A \cap B|} \quad (3)$$

Statistical Analysis

One-way analysis of variance ANOVA was used to compare the variation of on-faunal abundance in different seasons and land elevation in mangrove habitats using SAS 9.4. The means were compared and the presence of significance was assessed using the Tukey test. The ANOSIM and SIMPER analysis among different seasons and ecological quality parameters from mangrove habitats were also calculated using PAST 4.10 (Hammer *et al*., 2001). The correlation matrix was used to calculate the Multidimensional Scaling (MDS), and the cluster analysis was performed using the Euclidean dissimilarity (Ward's method) matrix using XLSTAT 2019.2.2. (XLSTAT, 2021). The Canonical Correspondence Analysis (CCA) was performed using PAST 4.10 (Hammer *et al*., 2001).

Results

Diversity Indices of Temporal On-faunal Abundance

The dominance index was found to be significantly ($P < 0.0001$) higher in intermediate-September (0.85), followed by post-monsoon (0.62), pre-monsoon (0.53) and monsoon (0.27). The Simpson diversity index was significantly ($P < 0.0001$) higher in monsoon (0.73), followed by pre-monsoon (0.47), post-monsoon (0.38) and intermediate-September (0.15). On the other hand, the Shannon diversity index was significantly ($P < 0.0001$) higher in monsoon (1.56), followed by post-monsoon (1.08), pre-monsoon (0.998), and intermediate-September (0.40). The evenness index was found to be significantly ($P < 0.0001$) higher in monsoon (0.53), followed by pre-monsoon (0.39), intermediate-September (0.25), and post-monsoon (0.18). Lastly, the Margalef richness index was found significantly ($P < 0.0001$) higher in post-monsoon (3.21), followed by monsoon (1.48), pre-monsoon (1.11) and intermediate-September (1.09) (Table 2).

The number of taxa was found to be higher in post-monsoon (16 species), followed by monsoon (9 species), pre-monsoon (7 species) and intermediate-September (6 species); while the number of the individuals was found higher in pre-monsoon season (223 individuals) (Table 3).

Table 2: The seasonal diversity indices of on-fauna available in the Lawas mangrove habitat, Sarawak

	Post-monsoon	**Intermediate-September**	**Pre-monsoon**	**Monsoon**	***P*-value**
Dominance	0.6202 ± 0.07^{b}	0.8465 ± 0.04^{a}	0.5344 ± 0.04^{c}	0.2662 ± 0.02^{d}	< 0.0001
Simpson	0.3798 ± 0.07^{c}	0.1535 ± 0.05^{d}	0.4656 ± 0.04^{b}	0.7338 ± 0.02^{a}	< 0.0001
Shannon	1.076 ± 0.19^{b}	0.4015 ± 0.09^{d}	0.9989 ± 0.08^{c}	1.559 ± 0.06^{a}	< 0.0001
Evenness	0.1833 ± 0.01^{d}	0.249 ± 0.07^{c}	0.3879 ± 0.03^{b}	0.5281 ± 0.03^{a}	< 0.0001
Margalef	3.21 ± 0.11^{a}	1.088 ± 0.04^{d}	1.11 ± 0.25^{c}	1.484 ± 0.12^{b}	< 0.0001

*Means (value ± standard error) with different letters within the same row indicate significant differences at $P < 0.05$

Table 3: Number of taxa and individuals found in the mangrove habitat in Lawas, Sarawak

	Post-monsoon	Intermediate-September	Pre-monsoon	Monsoon
Taxa	16	6	7	9
Individuals	107	99	223	219

Seasonal On-faunal Abundance

The on-faunal abundance in mangrove habitat was found to be significantly (P < 0.0001) higher in pre-monsoon season (604.34 ind. m^{-2}), followed by monsoon (593.50 ind. m^{-2}), post-monsoon (289.97 ind. m^{-2}), and intermediate-September (268.29 ind. m^{-2}) (Figure 2).

On-faunal Species Abundance in the Mangrove Habitat of Lawas

The seasonal species abundance of on-fauna in the mangrove habitat in Lawas suggested that Gastropoda *Optediceros breviculum* (L. Pfeiffer, 1855) from the family Assimineidae comprised the highest relative abundance (RA = 0.704). The seasonal frequency of this species was found to be higher in mangrove habitats, while the important species index (ISI = 70.36) and individual percentage (64.97%) of this species were found higher amongst the recorded from Lawas mangrove habitat in different seasons. The species *Vitta virginea* was the second dominant (RA = 0.101; ISI = 5.05) species, followed by *Clithon oualaniense* (RA = 0.065; ISI = 4.87) *Vitta zebra* (RA = 0.018; ISI = 0.91) *Assiminea ovata* (RA = 0.020; ISI = 2.01), *Assiminea grayana* (RA = 0.018; ISI = 1.77) and *Vittina coromandeliana* (RA = 0.016; ISI = 0.79); while the rest of the Important Species Index (ISI) were found less than 0.5 (Table 4).

ANOSIM of Temporal On-faunal Abundance

Seasonal ANOSIM analysis of available on-fauna in mangrove habitat using the Bray-Curtis matrix (permutation = 9999; mean rank within = 34.25; R = -0.028; P = 0.549) suggested that pre-monsoon and monsoon season had the highest similarity with 0.694; meanwhile, pre-monsoon and post-monsoon season had the lowest similarity level with 0.401 (Table 5).

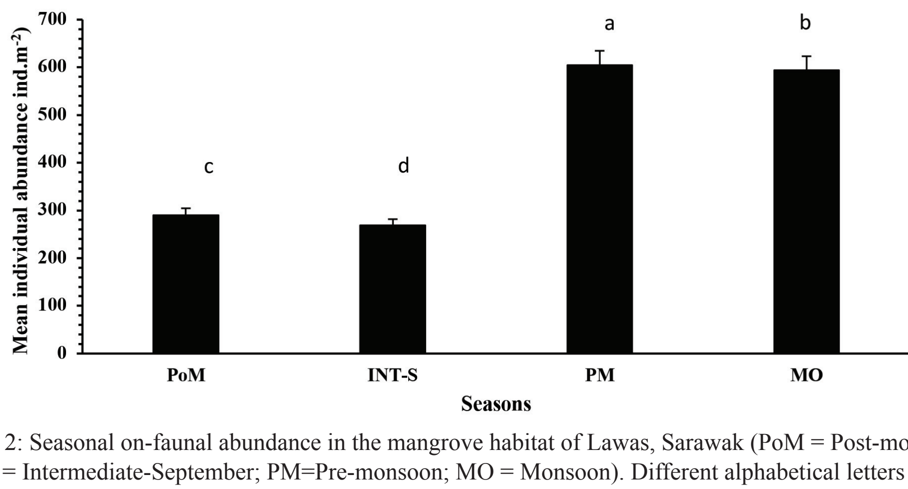

Figure 2: Seasonal on-faunal abundance in the mangrove habitat of Lawas, Sarawak (PoM = Post-monsoon, INT-S = Intermediate-September; PM=Pre-monsoon; MO = Monsoon). Different alphabetical letters within columns indicate significant differences P < 0.05

Table 4: On-faunal species Relative Abundance (RA), Frequency (F), Important Species Index (ISI) and percentage contribution in Lawas mangrove habitat, Sarawak

Family	**Species**	**Code**	PoM*	INT-S*	PM*	MO*	**AVG RA**	**F**	**ISI**	**%**
Assimineidae	*Optediceros breviculum* (L. Pfeiffer, 1855)	OB	84	91	159	87	0.704	100	70.36	64.97
	Assiminea grayana J. Fleming, 1828	AG	3	2	4	1	0.018	100	1.77	1.54
	Assiminea ovata (Krauss, 1848)	AO	2	3	5	2	0.020	100	2.01	1.85
Pisaniidae	*Solenosteira cancellaria* (Conrad, 1846)	SC	1	0	0	0	0.002	25	0.06	0.15
Cerithiidae	*Rhinoclavis kochi* (Philippi, 1848)	RK	1	0	0	2	0.005	50	0.23	0.46
Mangeliidae	*Eucithara marginelloides* (Reeve, 1846)	EM	1	0	0	0	0.002	25	0.06	0.15
Nassariidae	*Nassarius livescens* (Philippi, 1849)	NL	1	0	0	0	0.002	25	0.06	0.15
	Nassarius pullus (Linnaeus, 1758)	NP	3	1	0	0	0.010	50	0.48	0.62
	Nassarius globosus (Quoy & Gaimard, 1833)	NG	1	0	0	0	0.002	25	0.06	0.15
	Nassarius castus (Gould, 1850)	NC	1	1	0	0	0.005	50	0.24	0.31
	Nassarius reeveanus (Dunker, 1847)	NR	1	0	0	0	0.002	25	0.06	0.15
Neritidae	*Clithon oualaniense* (Lesson, 1831)	CO	0	1	18	37	0.065	75	4.87	8.64
	Clithon faba (G. B. Sowerby I, 1836)	CF	0	0	0	8	0.009	25	0.23	1.23
	Vitta virginea (Linnaeus, 1758)	VV	0	0	30	59	0.101	50	5.05	13.73
	Vittina coromandeliana (G. B. Sowerby I, 1836)	VC	0	0	5	9	0.016	50	0.79	2.16
	Vitta zebra (Bruguière, 1792)	VZ	0	0	2	14	0.018	50	0.91	2.47
Potamididae	*Pirenella cingulata* (Gmelin, 1791)	PC	1	0	0	0	0.002	25	0.06	0.15
	Pirenella conica (Blainville, 1829)	Pco	2	0	0	0	0.005	25	0.12	0.31
	Cerithidea obtusa (Lamarck, 1822)	COb	1	0	0	0	0.002	25	0.06	0.15
Thiaridae	*Thiara* sp.	TS	3	0	0	0	0.007	25	0.18	0.46
Portunidae	*Scylla* sp.	SS	1	0	0	0	0.002	25	0.06	0.15

*Number of individuals recorded inside three quadrants (0.123 m^2)

Table 5: Seasonal ANOSIM analysis of on-faunal abundance in Lawas mangrove habitat, Sarawak

	Post-monsoon	**Intermediate-September**	**Pre-monsoon**	**Monsoon**
Post-monsoon		0.5026	0.4009	0.5988
Intermediate-September	0.5026		0.404	0.6869
Pre-monsoon	0.4009	0.404		0.6944
Monsoon	0.5988	0.6869	0.6944	

Similarity Percentage Analysis (SIMPER) of Temporal On-faunal Abundance

The seasonal SIMPER analysis of on-faunal abundance in mangrove habitat found the highest average dissimilarity in intermediate-September and pre-monsoon (74.67%), while the lowest average dissimilarity was observed in post-monsoon and monsoon (64.59%). Seasonal SIMPER analysis also suggested that *Optediceros breviculum* (L. Pfeiffer, 1855), *Vitta virginea* (Linnaeus, 1758) and *Clithon oualaniense* (Lesson, 1831) most contributed to the species abundance among different seasons (Table 6).

Table 6: Seasonal SIMPER analysis of on-faunal abundance in the mangrove habitat of Lawas, Sarawak

SIMPER				
Season	**Average Dissimilarity (%)**	**Major Discriminating Species**	**Contribution (%)**	**Cumul.**
PoM vs INT-S	66.03	*Optediceros breviculum* (L. Pfeiffer, 1855)	70.03	70.03
		Nassarius pullus (Linnaeus, 1758)	4.529	74.55
		Thiara sp.	3.971	78.53
		Assiminea grayana J. Fleming, 1828	3.095	81.62
		Assiminea ovata (Krauss, 1848)	2.825	84.45
		Pirenella conica (Blainville, 1829)	2.495	86.94
		Nassarius castus (Gould, 1850)	1.577	88.52
PoM vs PM	69.55	*Optediceros breviculum* (L. Pfeiffer, 1855)	56.46	56.46
		Vitta virginea (Linnaeus, 1758)	16.77	73.23
		Clithon oualaniense (Lesson, 1831)	10.03	83.26
		Vittina coromandeliana (G. B. Sowerby I, 1836)	2.795	86.05
		Assiminea ovata (Krauss, 1848)	2.148	88.2
		Nassarius pullus (Linnaeus, 1758)	1.642	89.84
		Thiara sp.	1.58	91.42
PoM vs MO	64.59	*Optediceros breviculum* (L. Pfeiffer, 1855)	44.78	44.78
		Vitta virginea (Linnaeus, 1758)	18.75	63.53
		Clithon oualaniense (Lesson, 1831)	11.76	75.29
		Vitta zebra (Bruguière, 1792)	4.449	79.74
		Vittina coromandeliana (G. B. Sowerby I, 1836)	2.86	82.6
		Clithon faba (G. B. Sowerby I, 1836)	2.542	85.14
		Nassarius pullus (Linnaeus, 1758)	2.177	87.32

INT-S vs PM	74.67	*Optediceros breviculum* (L. Pfeiffer, 1855)	62.3	62.3
		Vitta virginea (Linnaeus, 1758)	17.8	80.09
		Clithon oualaniense (Lesson, 1831)	10.5	90.59
		Vittina coromandeliana (G. B. Sowerby I, 1836)	2.966	93.56
		Assiminea ovata (Krauss, 1848)	2.391	95.95
		Assiminea grayana J. Fleming, 1828	1.619	97.57
		Vitta zebra (Bruguière, 1792)	1.146	98.71
INT-S vs MO	73.77	*Optediceros breviculum* (L. Pfeiffer, 1855)	57.18	57.18
		Vitta virginea (Linnaeus, 1758)	17.19	74.37
		Clithon oualaniense (Lesson, 1831)	10.95	85.32
		Vitta zebra (Bruguière, 1792)	4.079	89.4
		Vittina coromandeliana (G. B. Sowerby I, 1836)	2.622	92.03
		Clithon faba (G. B. Sowerby I, 1836)	2.331	94.36
		Assiminea ovata (Krauss, 1848)	1.695	96.05
PM vs MO	64.94	*Optediceros breviculum* (L. Pfeiffer, 1855)	48.82	48.82
		Vitta virginea (Linnaeus, 1758)	23.21	72.04
		Clithon oualaniense (Lesson, 1831)	14.32	86.36
		Vitta zebra (Bruguière, 1792)	4.109	90.47
		Vittina coromandeliana (G. B. Sowerby I, 1836)	3.656	94.12
		Clithon faba (G. B. Sowerby I, 1836)	2.049	96.17
		Assiminea ovata (Krauss, 1848)	1.967	98.14

(PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

Jaccard Index of Temporal On-faunal Abundance

The Jaccard Similarity Index (JSI) of on-faunal species abundance among seasons in mangrove habitat was found to be higher in pre-monsoon and monsoon seasons (JSI = 0.77), followed by intermediate-September and pre-monsoon (JSI = 0.44), intermediate-September and monsoon (JSI = 0.36), post-monsoon and intermediate-September (JSI = 0.29), post-monsoon and monsoon (JSI = 0.19), and the lowest Jaccard similarity index was found in post-monsoon and pre-monsoon (JSI = 0.15) (Figure 3).

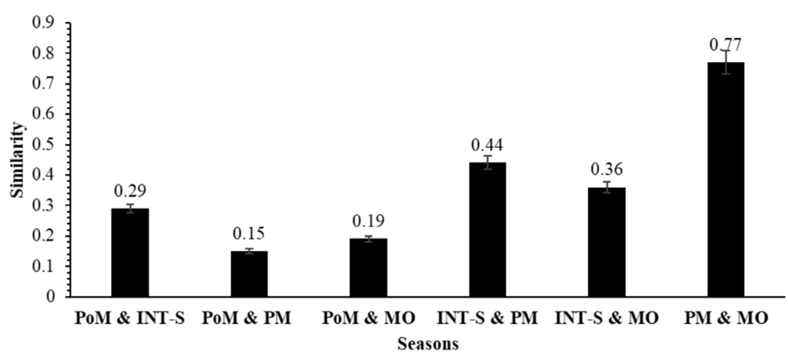

Figure 3: Comparison of on-faunal Jaccard similarity index among seasons in mangrove habitat (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

Principal Component Analysis (PCA) of On-faunal Abundance in Mangrove Habitat

The principal component analysis (PCA) of on-faunal abundance in mangrove habitats revealed that the first PC contributes 65.327 % of the variance, while the second (34.673%) PCs contribute most of the total cumulative variance. The two PCs contribute 100% of the total variation in the dataset and the eigenvalue refers to PC1 (2.613) and PC2 (1.387) (Table 7). While the seasonal on-faunal PCA analysis suggested that post-monsoon was negatively correlated with both PCs, the intermediate-September was highly positively correlated with the second PC (factor loading = 0.914). Pre-monsoon (factor loading = 0.948) and monsoon (factor loading = 0.983) strongly correlated with the first PC and correlated with each other.

In the bi-plot and loadings plot, it was observed the monsoon (factor loading = 0.983, 0.182) and pre-monsoon (factor loading = 0.948, -0.318) were found to be highly correlated with each other and formed a cluster while the angular distance between intermediate-September (factor loading = -0.407, 0.914) and the post-monsoon (factor loading = -0.763, -0.647) was found to be higher than that of the other seasonal cluster (Figure 4).

Table 7: Loading of variables on the two principal components of on-faunal abundance in mangrove habitat

	PC1	PC2
Post-monsoon	-0.763	-0.647
Intermediate-September	-0.407	0.914
Pre-monsoon	0.948	-0.318
Monsoon	0.983	0.182
Eigenvalue	2.613	1.387
Variability (%)	65.327	34.673
Cumulative (%)	65.327	100.000

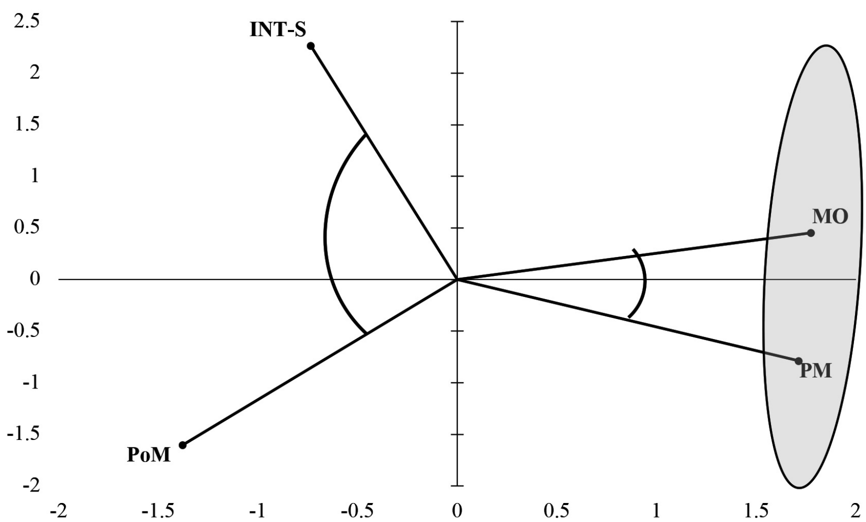

Figure 4: PCA of on-faunal abundance in the mangrove habitat of Lawas (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

MDS Analysis of Temporal On-faunal Abundance

With a Kruskal's stress (1) value of 0.094, the Multidimensional Scaling (MDS) analysis of different seasons based on the on-faunal abundance in Lawas mangrove revealed that pre-monsoon (dimension = 0.731, 0.085) and monsoon (dimension = 0.694, -0.160) found strongly correlated with each other and formed one group. While post-monsoon (dimension = -0.807, 0.683) and intermediate-September (dimension = -0.618, -0.609) were found dissimilar in terms of on-faunal abundance in mangrove habitats (Figure 5). The Shepard diagram states that the MDS result of on-faunal abundance in the Lawas mangrove habitat was reliable (Figure 6).

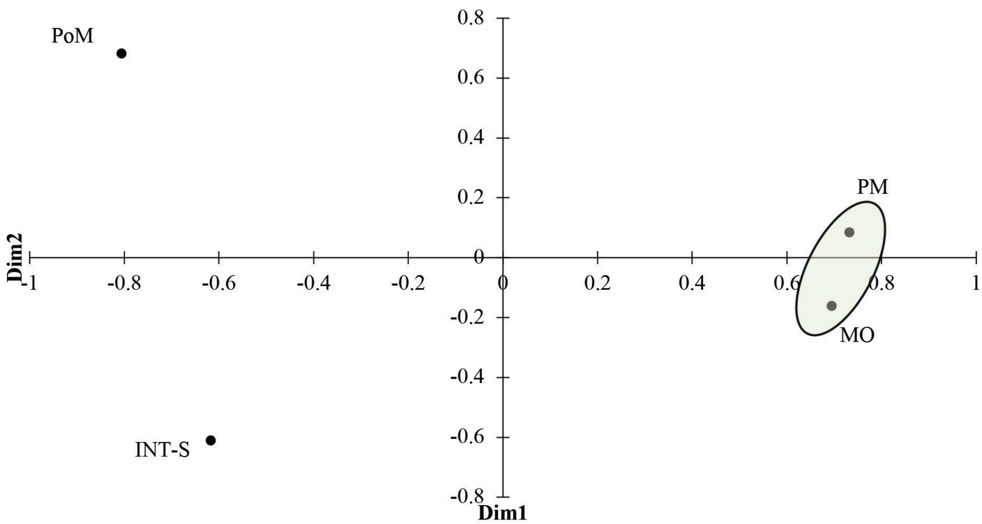

Figure 5: Seasonal Multidimensional Scaling (MDS) of on-faunal abundance in Lawas mangrove habitat, Sarawak (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

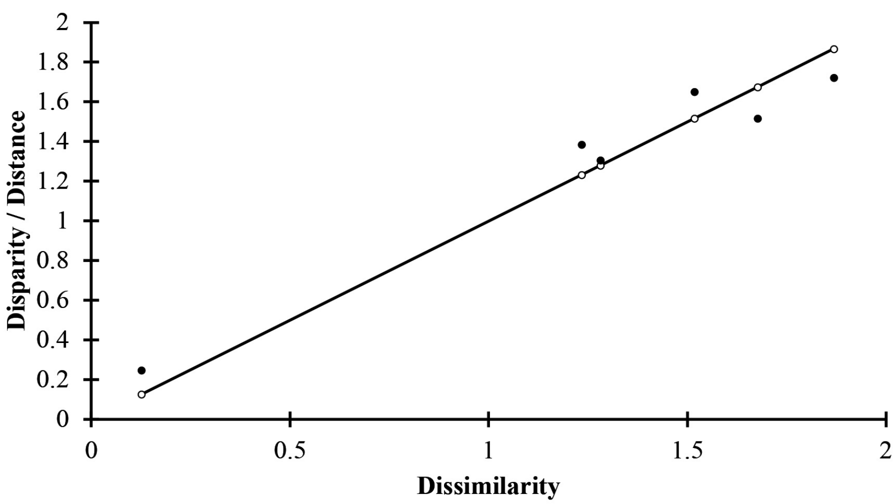

Figure 6: Seasonal on-faunal Shepard diagram of Multidimensional Scaling (MDS) analysis of mangrove habitat in Lawas, Sarawak

Cluster Analysis of Temporal on-faunal Abundance

The cluster dendrogram (Euclidean distance matrix; Ward's method) of on-faunal abundance in the mangrove habitat of Lawas revealed three distinctive clusters were formed. Here, pre-monsoon and monsoon formed one cluster with a dissimilarity level of 1% (average distance to centroid = 21.37), whereas intermediate-September and post-monsoon formed two different clusters with different dissimilarities (Figure 7).

Ecological Parameters

Seasonal ecological parameters indicate that air temperature, wind speed and soil pH were found to be significantly ($P < 0.0001$) higher in the monsoon, while rainfall of the site was found to be significantly ($P < 0.0001$) higher in pre-monsoon. On the other hand, pore water parameters such as salinity, PO_4, Cu, Zn, K and Mg were found to be significantly ($P < 0.0001$) higher in monsoon. The pore water pH and NH_3-N were significantly higher ($P < 0.0001$) in intermediate September. The presence of NO_2 and NO_3 were found to be significantly ($P < 0.05$) higher in post-monsoon, while no significant difference was observed in the land elevation measurement of the sampling transacts (Table 8).

CCA of Temporal On-faunal Abundance

The first Canonical axis of the variance of on-faunal, seasonal and ecological parameters accounted for 84.34% of the variance (eigenvalue = 0.30), while the second axis comprised 15.66% of the variance (eigenvalue = 0.06); that of the two axes contributed 100% variance (permutation = 999; trace $P = 0.05$). The abundance of on-fauna in intermediate-September, post-monsoon and the pre-monsoon were mostly influenced by ecological parameters such as NO_3, water pH, and NH_3-N; while the soil pH, salinity, and minerals such as Ca, K, Mg and Zn influenced monsoon. The important and most abundant species, such as *Optediceros breviculum* (OB) and *Assiminea ovata* (AO) (coded according to Table 4), were found to be influenced by the concentration of NH_3-N and water pH (Figure 8).

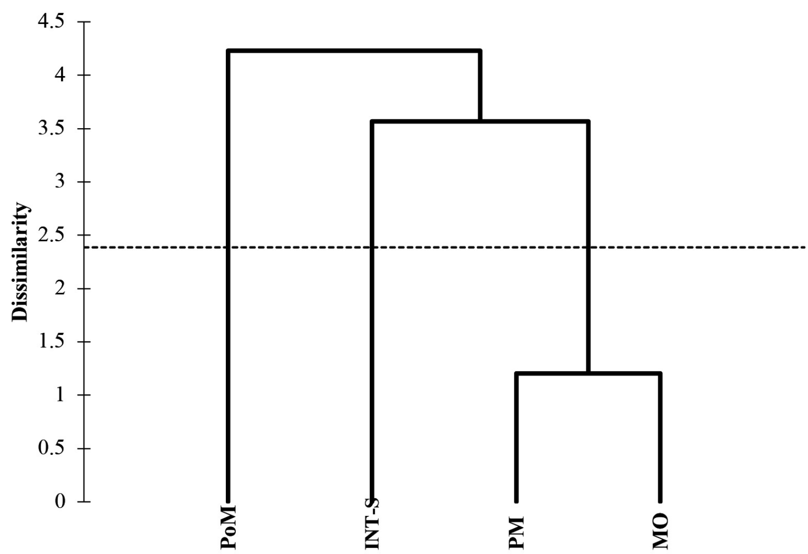

Figure 7: Seasonal cluster dendrogram of on-faunal abundance in the mangrove habitat of Lawas, Sarawak (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

Table 8: Analysis of Variance (ANOVA) table of seasonal ecological parameters from the mangrove habitat of Punang-Sari-Lawas, Sarawak

Parameters	**Post-monsoon**	**Intermediate-September**	**Pre-monsoon**	**Monsoon**	***P*-value**
Air Temperature (ºC)	27.59 ± 0.00c	27.69 ± 0.00b	26.88 ± 0.00d	27.77 ± 0.00a	< 0.0001
Wind speed (m/s)	1.26 ± 0.00d	1.30 ± 0.00c	1.34 ± 0.00b	1.83 ± 0.00a	< 0.0001
Total rainfall (mm)	241.2 ± 0.00b	87.70 ± 0.00c	364.60 ± 0.00a	31.20 ± 0.00d	< 0.0001
Soil pH	6.07 ± 0.20c	6.07 ± 0.05c	6.30 ± 0.09b	6.90 ± 0.09a	< 0.0001
Land elevation (cm)	5.0 ± 3.97a	5.0 ± 3.97a	5.0 ± 3.97a	5.0 ± 3.97a	1.00
Pore water parameters					
Salinity (PSU)	18.74 ± 2.70b	19.12 ± 0.74b	21.80 ± 6.26b	28.08 ± 0.64a	< 0.0001
Water pH	7.53 ± 0.059ab	7.60 ± 0.01a	7.52 ± 0.09b	6.96 ± 0.05c	< 0.0001
NH_3-N (mg/l)	0.71 ± 0.11b	1.44 ± 0.17a	0.73 ± 0.48b	0.10 ± 0.01c	< 0.0001
PO_4 (mg/l)	0.57 ± 0.07b	0.84 ± 0.02a	0.81 ± 0.10a	0.88 ± 0.16a	< 0.0001
NO_2 (mg/l)	0.04 ± 0.03a	0.01 ± 0.002b	0.01 ± 0.001b	0.01 ± 0.001b	0.0011
NO_3 (mg/l)	0.10 ± 0.03a	0.09 ± 0.003b	0.08 ± 0.001b	0.08 ± 0.003b	0.0056
Cu (mg/l)	0.05 ± 0.01a	0.05 ± 0.004a	0.04 ± 0.01b	0.05 ± 0.01a	< 0.0001
Zn (mg/l)	0.04 ± 0.00b	0.04 ± 0.004b	0.05 ± 0.01b	0.08 ± 0.05a	0.0016
Ca (mg/l)	2.17 ± 0.17c	2.60 ± 0.17b	2.29 ± 0.32c	3.71 ± 0.07a	< 0.0001
K (mg/l)	2.17 ± 0.14c	2.79 ± 0.08b	2.29 ± 0.38c	3.78 ± 0.10a	< 0.0001
Mg (mg/l)	0.54 ± 0.04c	0.70 ± 0.02b	0.56 ± 0.06c	0.85 ± 0.01a	< 0.0001

**Means (value ± standard error) with different letters within the same row indicate significant differences at $P < 0.05$

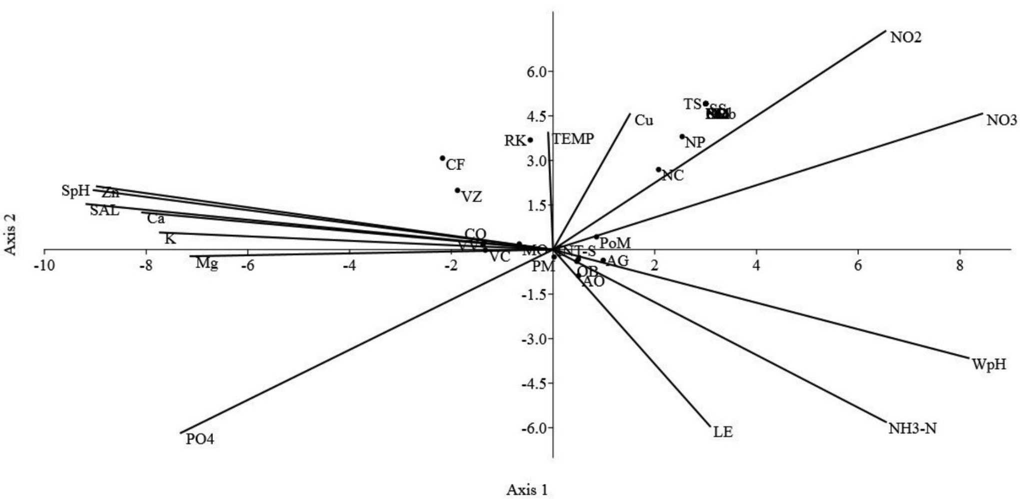

Figure 8: CCA ordination showed the relationship among different seasons, ecological parameters and on-faunal abundance in the mangrove habitat of Lawas, Sarawak

Discussion

The dominance index of on-faunal abundance in mangrove habitat was higher in intermediate-September with a large number of Optediceros breviculum, while the Simpson, Shannon and evenness index was higher in monsoon. The diversity indices are the key indicator for analysing biodiversity in a particular habitat, while the higher Simpson, Shannon and evenness index suggested the biodiversity in monsoon was very high. The richness index of post-monsoon was higher due to the higher number of different species than the individuals of benthos. Similar diversity indices of benthic faunal abundance were calculated and presented in different mangrove habitats in Thailand (Srisunont *et al*., 2016), Pondicherry mangroves, India (Kumar & Khan, 2013), the mangrove forest in estuary setup (Rahman *et al*., 2021), a subtropical estuary in Bangladesh (Matin *et al*., 2018) and Futian Mangrove National Nature Reserve, Guangdong, China (Li *et al*., 2017).

The on-faunal abundance in mangrove habitats in different seasons ranged from 268.29 ind. m^{-2} and 604.34 ind. m^{-2}, while the highest abundance was observed in the pre-monsoon season. A recent study from the mangrove-seagrass complex on the Red Sea coast, of Saudi Arabia revealed that the mean abundance might range from 124 ± 8 ind. m−2 to 405 ± 51 ind. m^{-2} (Abrogueña *et al*., 2021). Another study from an Indonesian mangrove forest suggested that the mean abundance of macrobenthos ranged from 2038 ind. m^{-2} and 6752 ind. m^{-2} (Muskananfola *et al*., 2020); however, they considered both the infauna and on-fauna species abundance from mangrove habitat, while the present study only considered the on-faunal assemblage in mangrove habitat.

The seasonal species abundance of on-fauna in the mangrove habitat in Lawas suggested that the gastropod *O. breviculum* from the family Assimineidae comprised the highest relative abundance, frequency, important species index and percentage of the individual. The gastropod *O. breviculum* is found very common in the mangrove habitat of the Southeast Asian region. The evolutionary size of this fauna, their adaptability in intertidal coastal areas, availability of food, lack of presence of any predatory animal, and less inter and intra-specific competition might be the reason for the higher abundance of this species in the current site (Sow-Yan & Lup, 2020; Wu *et al*., 2020). A previous study from Singapore confirmed that *O. breviculum* was present in the mangrove habitat of the Southeast Asian region (Sow-Yan & Lup, 2020). In the Indonesian mangrove forest, the presence of *O. breviculum* was frequently found to contribute to most of the benthic epifaunal assemblage in the mangrove habitat (Wu *et al*., 2020). The study from the same mangrove-seagrass complex suggested that the presence of the *O. breviculum* was detected in the mangrove habitat, but that study did not present the percentage and abundance of the shell (Al-Asif *et al*., 2020). The study by Ismail *et al.* (2021) suggested the important species index (ISI), the relative abundance of species in different seasons and the percentage of their contribution might be the important indicator for the availability and abundance of certain species.

The ANOSIM analysis suggested that pre-monsoon and monsoon had the highest similarity in terms of on-faunal abundance in mangrove habitat in Lawas, while in the SIMPER analysis, the lowest dissimilarity was observed in post-monsoon and monsoon, but the second lowest dissimilarity was detected in the pre-monsoon and monsoon. Almost similar species composition and the number of individuals were observed in the pre-monsoon and monsoon; however, this might be the reason for the highest similarity and dissimilarity in ANOSIM and SIMPER results (Figure 2 and Table 4). Similar ANOSIM result was presented and approved by some research from macrobenthos in Iranian mangrove forest (Vahidi *et al*., 2021), Indian coast (Vijapure *et al*., 2019), Malaysian mangrove forest from Penang (Stiepani *et al*., 2021) and the west coast of India, Arabian Sea (Joydas & Damodaran, 2009). A similar SIMPER analysis suggested that the macrofaunal abundance in different seasons and site-specific locations might vary, while the SIMPER analysis helped to identify the major clusters of seasons and locations (Santos & Aviz, 2019; Hajializadeh *et al.*, 2020; Pan *et al.*, 2021; Zhang *et al.*, 2021).

The Jaccard Similarity Index (JSI) of on-faunal species abundance among seasons in mangrove habitats was higher in pre-monsoon and monsoon, supporting the previous results of ANOSIM and SIMPER. On the other hand, similar JSI was achieved from different studies elsewhere, including mangrove, seagrass and mangrove-seagrass complex habitats (Schloss & Handelsman, 2006; Fulthorpe *et al.*, 2008; Foshtomi *et al*., 2018; Mendoza *et al*., 2019; Al-Asif *et al*., 2020).

From PCA, nMDS and cluster analysis results, the on-faunal species abundance in mangrove habitat in pre-monsoon and monsoon was found to be strongly correlated with each other, this result supports the previous all analyses and similar analyses were done elsewhere to know the correlation within macrobenthos species abundance and the seasonal influence (Ashton *et al.*, 2003; Kumar & Khan, 2013; Dissanayake & Chandrasekara, 2014; Muskananfola *et al*., 2020; Hajializadeh *et al*., 2020; Almaniar *et al.*, 2021; Pan *et al*., 2021).

The land elevation was constant during the study period, while the land elevation might be important for the benthic assemblage in the different mangrove zones; however, we only considered the intertidal zones where heavy fluctuations of ecological parameters took place and the benthos community was optimal (Feller *et al.*, 2017; Chaudhuri *et al.*, 2019; Bernardino *et al*., 2020). The abundance of on-fauna in different seasons was mostly influenced by ecological parameters such as NO_3, water pH, and NH_3-N, while the soil pH, salinity, and minerals such as Ca, K, Mg and Zn influenced monsoon. The important and most abundant species such as *O. breviculum*, and *Assiminea ovate* were influenced by the concentration of NH_3-N and water pH. Previous studies suggested that the macrofaunal abundance in different habitats might be influenced by ecological parameters such as NH_3-N and water pH (Srisunont *et al*., 2016; Zhao *et al*., 2017; Almaniar *et al*., 2021).

The availability, accumulation, and translocation of heavy metals in some mangrove plants were altered by salinity and pH variations, with the effects being more pronounced when the plants were grown for longer periods (Wakushima *et al*., 1994; Cabañas-Mendoza *et al.*, 2020). Some studies referred to the average soil pH in mangrove habitats might be towards the acidic level rather the alkaline (Wakushima *et al*., 1994; Ukpong, 1995; Joshi & Ghose, 2003; Pazi *et al*., 2016; de Andrade *et al*., 2018). When exposed to acute salinity stress, mangrove seedlings have increased leaf mortality rates, which are often followed by declines in leaf production rates and biomass production rates, ultimately resulting in the death of the plants (Chen & Ye, 2014; Shiau *et al*., 2017; Kodikara *et al*., 2018). On the other hand, salinity acts as a vital factor for benthic assemblage in different coastal habitats, including the mangrove ecosystem (Dissanayake & Chandrasekara, 2014; Liu *et al*., 2014; Wang *et al*., 2021). The huge coverage of the mangrove forest might be helpful to buffer the acidification of water in the regional coastal area, which also influences the global change of ocean acidification (Sippo *et al*., 2016). Generally, the water pH is a vital influencer of water chemistry for bio-assemblage in mangrove habitats, especially for benthic macrobenthos (Hajializadeh *et al*., 2020).

The NH_3 concentration is considered significantly important due to its biogeochemical cycle to convert nitrate and nitrite into the ecosystem, one of the major nutrients for mangrove plants (Holmboe & Kristensen, 2002; Balk *et al*., 2015). In addition, some bacteria uptake ammonium compound for their essential nutrients, along with this is the limiting factor for many macrobenthos inhabiting the mangrove ecosystem (Srisunont *et al*., 2016; Kanhai & Juman, 2018; Putri *et al*., 2021; Rao *et al*., 2021). Phosphorus is one of the essential nutrients for mangrove plants due to the leaf water potential, stomatal conductance and photosynthetic carbon-assimilation rates deficiency might occur (Nielsen & Andersen, 2003; Lovelock *et al*., 2006; Samidurai *et al.*, 2012; Barcellos *et al*., 2019). The concentration of phosphate significantly affects the diversity, density and abundance of macrobenthic faunal assemblage in mangrove ecosystems, while some previous studies suggested that excessive phosphate concentration might be harmful to some benthos, especially polycheates, bivalves and gastropods (Ellis *et al*., 2004; Samidurai *et al*., 2012; Qiu *et al*., 2015). As nitrogenous compounds are essential to plant growth and physiology, the concentration of NO_2 and NO_3 in the pore water of the mangrove habitat provides essential nutrients to the mangrove plants (Balk *et al*., 2015; Qiu *et al*., 2015). The macrobenthic fauna absorbed their essential nutrient from the water (Kristensen *et al*., 1988). The trace mineral concentrations significantly differ among seasons, but certain concentrations of these elements are essential for both mangrove plants and associated macrobenthos in the ecosystem (Reef *et al.,* 2010; Alongi, 2017, 2021; Thanh-Nho *et al.*, 2019; Yanti *et al.,* 2021).

Conclusions

The on-faunal macrobenthos in the mangrove habitat of the Lawas area had significant differences among various seasons. With the ecological parameters, the on-faunal abundance also varies significantly, and in this study, we established and revealed the relationship among benthic on-faunal abundance in mangrove habitats, their seasonality and the ecological parameters. The higher species diversity, relative abundance, and richness during the monsoon imply that the monsoonal climate was the most important for introducing macrobenthos in this coastal ecosystem compared to other seasons. The findings of this study would help manage the mangrove habitat in that particular region and on a large scale nationwide. However, this extensive work on benthic fauna in Malaysian mangrove habitats will open the door to many researchers to investigate the macrobenthos community as a bio-indicator in Sarawak, Malaysia, which is the least studied.

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References

Abd Malek, M. N., Frontalini, F., Yahya, K., Talib, A., & Zakaria, L. (2021). Taxonomical diversity of benthic foraminifera in mangrove sediments: Initial insight into total diversity from Malaysia to worldwide mangrove forests records. *Biodiversity and Conservation*, *30*(7), 2033-2056. https://doi.org/10.1007/s10531-021-02179-7

Abrogueña, J. B. R., Joydas, T. V., Pappathy, M., Cali, N. A., Alcaria, J., & Shoeb, M. (2021). Structure and composition of the macrobenthic community associated to shallow mangrove-seagrass habitat along the southern Red Sea coast, Saudi Arabia. *Egyptian Journal of Aquatic Research*, *47*(1), 61-66. https://doi.org/10.1016/j.ejar.2020.10.001

Abu Hena, M. K., Idris, M. H., Khairul, R. M. Y., Bhuiyan, M. K. A., Hoque, N., & Kumar, U. (2016a). Diversity of macro-benthos in the mangrove forest of Kuala Sibuti, Miri, Sarawak. *Conferences Malaysia International Biology Symposium (i-SIMBIOMAS 2016)*, *Putrajaya International Convention Center, Putrajaya, Malaysia*, 1-2.

Abu Hena, M.K., Ismail, J., Idris, M. H., & Bhuiyan, M. K. A. (2016b). Seagrasses from Lawas, Sarawak, Malaysia: Diversity and ecosystem approaches. *Conferences International Fisheries Symposium - IFS 2016*, 1-350.

Abu Hena, M. K., Hoque, M. M., Idris, M. H., Ahmed, O. H., Bhuiyan, M. K. A., Billah, M. M., Hoque, M. N., & Rosli, Z. (2020).

Decay of Rhizophora apiculata (Blume) and Xylocarpus granatum (Koenig) detrital sources in the Sarawak Mangrove, Malaysia. *Journal of Forestry Research*, *31*(2), 613-623. https://doi.org/10.1007/s11676-018-0776-5

Ahmad-Kamil, E. I., Ramli, R., Jaaman, S. A., Bali, J., & Al-Obaidi, J. R. (2013). The effects of water parameters on monthly seagrass percentage cover in Lawas, East Malaysia. *The Scientific World Journal*, *2013*(892746), 1-8. https://doi.org/10.1155/2013/892746

Al-Asif, A., Hamli, H., Abu Hena, M. K., Idris, M. H., Gerusu, G. J., Ismail, J., & Abualreesh, M. H. (2021). Bivalves (Bivalvia) in Malaysian Borneo: status and threats. *Journal of Threatened Taxa*, *13*(11), 19553-19565. https://doi.org/10.11609/jott.7287.13.11.19553-19565

Al-Asif, A., Hamli, H., Abu Hena, M. K., Idris, M. H., Gerusu, G. J., Ismail, J. B., & Karim, N. U. (2020). Benthic macrofaunal assemblage in seagrass-mangrove complex and adjacent ecosystems of Punang-Sari Estuary, Lawas, Sarawak, Malaysia. *Biodiversitas*, *21*(10), 4606-4615. https://doi.org/10.13057/biodiv/d211019

Al-Asif, A., Hamli, H., Hanafi, M., James, G., Ng, J. F., & Abu Hena, M. K. (2023). Macro-infaunal diversity and assemblage in the mangrove habitat of Lawas, Sarawak, Malaysia. *Regional Studies in Marine Science*, *60*, 102889. https://doi.org/10.1016/j.rsma.2023.102889Almaniar, S., Rozirwan, & Herpandi. (2021). Abundance and diversity of macrobenthos at Tanjung Api-Api waters, South Sumatra, Indonesia. *AACL Bioflux*, *14*(3), 1486-1497.

Alongi, D. M., & Christoffersen, P. (1992). Benthic infauna and organism-sediment relations in a shallow, tropical coastal area: Influence of outwelled mangrove detritus and physical disturbance. *Marine Ecology Progress Series*, *81*(3), 229-245. https://doi.org/10.3354/meps081229

Alongi, Daniel M. (2017). Micronutrients and mangroves: Experimental evidence for copper limitation. *Limnology and Oceanography*, *62*(6), 2759-2772. https://doi.org/10.1002/lno.10604

Alongi, Daniel M. (2021). Macro-and micronutrient cycling and crucial linkages to geochemical processes in mangrove ecosystems. *Journal of Marine Science and Engineering*, *9*(5), 456. https://doi.org/10.3390/jmse9050456

APHA. (2005). *Standard methods for the examination of water and wastewater* (21st ed.). American Public Health Association.

Ashton, E. C., Macintosh, D. J., & Hogarth, P. J. (2003). A baseline study of the diversity and community ecology of crab and molluscan macrofauna in the Sematan mangrove forest, Sarawak, Malaysia. *Journal of Tropical Ecology*, *19*(2), 127-142. https://doi.org/10.1017/S0266467403003158

Atkinson, S. C., Jupiter, S. D., Adams, V. M., Ingram, J. C., Narayan, S., Klein, C. J., & Possingham, H. P. (2016). Prioritising mangrove ecosystem services results in spatially variable management priorities. *PLOS One*, *11*(3), 1-21. https://doi.org/10.1371/journal.pone.0151992

Balk, M., Laverman, A. M., Keuskamp, J. A., & Laanbroek, H. J. (2015). Nitrate ammonification in mangrove soils: A hidden source of nitrite? *Frontiers in Microbiology*, *6*(MAR), 1-10. https://doi.org/10.3389/fmicb.2015.00166

Barcellos, D., Queiroz, H. M., Nóbrega, G. N., de Oliveira Filho, R. L., Santaella, S. T., Otero, X. L., & Ferreira, T. O. (2019). Phosphorus enriched effluents increase eutrophication risks for mangrove systems in northeastern Brazil. *Marine Pollution Bulletin*, *142*(January), 58-63. https://doi.org/10.1016/j.marpolbul.2019.03.031

Beasley, C. R., Fernandes, M. E. B., Figueira, E. A. G., Sampaio, D. S., Melo, K. R., & Barros, R. S. (2010). Mangrove infauna and sessile epifauna. In M. M. Caldwell, G. Heldmaier,

R. B. Jackson, O. L. Lange, H. A. Mooney, E.-D. Schulze, & U. Sommer (Eds.), *Mangrove dynamics and management in North Brazil: Ecological studies* (pp. 109-123). Springer-Verlag Berlin Heidelberg 2010. https://doi.org/10.1007/978-3-642-13457-9_7

Bernardino, A. F., Sanders, C. J., Bissoli, L. B., Gomes, L. E. de O., Kauffman, J. B., & Ferreira, T. O. (2020). Land use impacts on benthic bioturbation potential and carbon burial in Brazilian mangrove ecosystems. *Limnology and Oceanography*, *65*(10), 2366-2376. https://doi.org/10.1002/lno.11458

Billah, M., Kamal, A. H. M., Idris, M. H. Bin, Johan Bin, I., & Bhuiyan, K. A. (2014). Cu, Zn, Fe, and Mn in mangrove ecosystems (sediment, water, oyster, and macroalgae) of Sarawak, Malaysia. *Zoology and Ecology*, *24*(4), 380-388. https://doi.org/10.1080/21658005.2014.978527

Billah, M. M., Abu Hena, M. K., Idris, M. H., & Ismail, J. (2017). Mangrove macroalgae as biomonitors of heavy metal contamination in a tropical Estuary, Malaysia. *Water, Air, and Soil Pollution*, *228*(9), 347. https://doi.org/10.1007/s11270-017-3500-8

Brander, L. M., Wagtendonk, A. J., Hussain, S. S., McVittie, A., Verburg, P. H., de Groot, R. S., & van der Ploeg, S. (2012). Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. *Ecosystem Services*, *1*(1), 62-69. https://doi.org/10.1016/j.ecoser.2012.06.003

Broom, M. J. (1982). Structure and seasonality in a Malaysian mudflat community. *Estuarine, Coastal and Shelf Science*, *15*(2), 135-150. https://doi.org/10.1016/0272-7714(82)90024-5

Bujang, J. S., Zakaria, M. H., & Arshad, A. (2006). Distribution and significance of seagrass ecosystems in Malaysia. *Aquatic Ecosystem Health and Management*, *9*(2), 203–214. https://doi.org/10.1080/14634980600705576

Cabañas-Mendoza, M. D. R., Santamaría, J. M., Sauri-Duch, E., Escobedo-Graciamedrano, R. M., & Andrade, J. L. (2020). Salinity affects pH and lead availability in two mangrove plant species. *Environmental Research Communications*, *2*(6), 061004. https://doi.org/10.1088/2515-7620/ab9992

Camargo, J. A. (1997). A rebuttal to: "Assessing changes in community structure by dominance indices: A comparative analysis". *Journal of Freshwater Ecology*, *12*(4), 637-641. https://doi.org/10.1080/02705060.1997.9663580

Chan, S.-Y. (2009). The Melongenidae (Mollusca: Gastropoda) of Singapore. *Nature in Singapore*, *2*(February), 63-67.

Chandra, I. A., Seca, G., & Abu Hena, M. K. (2011). Aboveground biomass production of *Rhizophora apiculata* Blume in Sarawak mangrove forest. *American Journal of Agricultural and Biological Science*, *6*(4), 469-474. https://doi.org/10.3844/ajabssp.2011.469.474

Chaudhuri, P., Chaudhuri, S., & Ghosh, R. (2019). The role of mangroves in coastal and estuarine sedimentary accretion in Southeast Asia. *Sedimentation Engineering*, 1-23. https://doi.org/10.5772/intechopen.85591

Chen, Y., & Ye, Y. (2014). Effects of salinity and nutrient addition on mangrove *Excoecaria agalloch*a. *PLOS One*, *9*(4). https://doi.org/10.1371/journal.pone.0093337

Cob, Z., Samat, A., Muda, W., & Mazlan, A. (2012). Preliminary checklist of marine invertebrate fauna within the intertidal of Teluk Penyabong and Teluk Gorek, Mersing, Johor, Malaysia. *Journal of Tropical Marine Ecosystem*, *1*, 1-14.

de Andrade, K. V. S., Holanda, F. S. R., de Oliveira Santos, T., Santana, M. B. S., & de Araújo Filho, R. N. (2018). Mangrove soil in physiographic zones in the Sao Francisco River Estuary. *Floresta e Ambiente*, *25*(2), 2-9. https://doi.org/10.1590/2179-8087.063816

Dissanayake, N., & Chandrasekara, U. (2014). Effects of mangrove zonation and the physicochemical parameters of soil on the distribution of macrobenthic fauna in Kadolkele mangrove forest, a tropical mangrove forest in Sri Lanka. *Advances in Ecology*, *2014*, 1-13. https://doi.org/10.1155/2014/564056

Duisan, L., Salim, G., Soon, T. K., & Ransangan, J. (2021). Sex ratio, gonad and condition indices of mangrove clam, *Polymesoda* (*Geloina*) *erosa* (Bivalvia: Corbiculidae) in Marudu Bay, Sabah, Malaysia: Implication for broodstock selection in artificial breeding program. *Journal of Fisheries and Environment*, *45*(1), 106-119.

Duncan, D., Harvey, F., Walker, M., & Australian Water Quality Center. (2007). *EPA Guidelines: Regulatory monitoring and testing water and wastewater sampling*. Environment Protection Authority.

Ellis, J., Nicholls, P., Craggs, R., Hofstra, D., & Hewitt, J. (2004). Effects of terrigenous sedimentation on mangrove physiology and associated macrobenthic communities. *Marine Ecology Progress Series*, *270*, 71-82. https://doi.org/10.3354/meps270071

Ellison, A. M. (2008). Managing mangroves with benthic biodiversity in mind: Moving beyond roving banditry. *Journal of Sea Research*, *59*(1–2), 2-15. https://doi.org/10.1016/j.seares.2007.05.003

Faust, M. A., & Gulledge, R. A. (1996). Associations of microalgae and meiofauna in floating detritus at a mangrove island, Twin Cays, Belize. *Journal of Experimental Marine Biology and Ecology*, *197*(2), 159-175. https://doi.org/10.1016/0022-0981(95)00159-X

Feller, I. C., Friess, D. A., Krauss, K. W., & Lewis, R. R. (2017). The state of the world's mangroves in the 21st century under climate change. *Hydrobiologia*, *803*(1), 1-12. https://doi.org/10.1007/s10750-017-3331-z

Foshtomi, M. Y., Leliaert, F., Derycke, S., Willems, A., Vincx, M., & Vanaverbeke, J. (2018). The effect of bio-irrigation by the polychaete Lanice conchilega on active denitrifiers: Distribution, diversity, and composition of nosZ gene. *PLOS One*, *13*(2), 1-25. https://doi.org/10.1371/journal.pone.0192391

Fulthorpe, R. R., Roesch, L. F. W., Riva, A., & Triplett, E. W. (2008). Distantly sampled soils carry few species in common. *ISME Journal*, *2*(9), 901-910. https://doi.org/10.1038/ismej.2008.55

Gandaseca, S., Rosli, N., Mustapha, A., Pazi, M., & Arianto, C. I. (2014). Effects of land use on river water quality of Awat-Awat Lawas Mangrove Forest Limbang Sarawak Malaysia. *International Journal of Physical Sciences*, *9*(17), 386-396. https://doi.org/10.5897/IJPS2014.4179

Gandaseca, S., Wahab, N. L. A., Pazi, A. M. M., Rosli, N., & Zaki, P. H. (2016). Comparison of water quality status of disturbed and undisturbed mangrove forest at Awat-Awat Lawas Sarawak. *Open Journal of Forestry*, *6*(1), 14-18. https://doi.org/10.4236/ojf.2016.61002

Glover, E. A., Taylor, J. D., & Williams, S. T. (2008). Mangrove-associated lucinid bivalves of the central Indo-West Pacific: Review of the "*Austriella*" group with a new genus and species (Mollusca: Bivalvia: Lucinidae). *Raffles Bulletin of Zoology Supplement*, *18*(18), 25-40.

Hajializadeh, P., Safaie, M., Naderloo, R., Shojaei, M. G., Gammal, J., Villnäs, A., & Norkko, A. (2020). Species composition and functional traits of macrofauna in different mangrove habitats in the Persian Gulf. *Frontiers in Marine Science*, *7*(September), 1-16. https://doi.org/10.3389/fmars.2020.575480

Hamli, H., Idris, M. H., Abu Hena, M. K., Wong, S. K., & Arshad, A. (2013). Checklist and habitat descriptions of edible gastropods from Sarawak, Malaysia. *Journal of*

Fisheries and Aquatic Science, *8*(2), 412-418.

Hamli, H., Rahim, A. A., Idris, M. H., Abu Hena, M. K., & King, W. S. (2015). Morphometric variation among three local mangrove clam species of Corbiculidae. *Songklanakarin Journal of Science and Technology*, *37*(1), 15–20.

Hamli, H., & Al-Asif, A. (2021). Trends of bivalve (Bivalvia) research in East Malaysia: A systematic review. *Asian-Australasian Journal of Bioscience and Biotechnology*, *6*(2), 50-59. https://doi.org/10.3329/aajbb.v6i2.56140

Hammer, Ø., Harper, D., & Ryan, P. (2001). PAST: Paleontological statistics software package for education and data. *Palaeontologia Electronica*, *4*(1), 1-9.

Herbert, D. G., Jones, G. J., & Atkinson, L. J. (2018). Phylum Mollusca. In L. J. Atkinson & K. J. Sink (Eds.), *Field guide to the offshore marine invertebrates of South Africa* (pp. 249-320). Malachite Marketing and Media.

Holmboe, N., & Kristensen, E. (2002). Ammonium adsorption in sediments of a tropical mangrove forest (Thailand) and a temperate Wadden Sea area (Denmark). *Wetlands Ecology and Management*, *10*(6), 453-460. https://doi.org/10.1023/A:1021301918564

Ismail, J., Abu Hena, M. K., Idris, M. H., Amin, S. M. N., Denil, N. A., Kumar, U., & Karim, N. U. (2020). Species composition and diversity of fishes from the seagrass habitat of Lawas, Sarawak, Malaysia. *Journal of Environmental Biology*, *41*(July), 1382-1389. https://doi.org/http://doi.org/10.22438/jeb/41/5(SI)/MS_32

Ismail, J., Abu Hena, M. K., Idris, M. H., Amin, S. M. M. N., Hamli, H., Sien, L. S., Al-Asif, A., & Abualreesh, M. H. (2021). Zooplankton species composition and diversity in the seagrass habitat of Lawas, Sarawak, Malaysia. *Biodiversity Data Journal*, *9*(1), e67449. https://doi.org/10.3897/BDJ.9.e67449

Jaccard, P. (1912). The distribution of the flora in the Alpine zone. *New Phytologist*, *11*(2), 37-50. https://doi.org/10.1111/j.1469-8137.1912.tb05611.x

Joshi, H., & Ghose, M. (2003). Forest structure and species distribution along soil salinity and pH gradient in mangrove swamps of the Sundarbans. *Tropical Ecology*, *44*(2), 197-206.

Joydas, T. V., & Damodaran, R. (2009). Infaunal macrobenthos along the shelf waters of the west coast of India, Arabian Sea. *Indian Journal of Marine Sciences*, *38*(2), 191-204.

Kanhai, A., & Juman, R. (2018). The effect of seasonal and human pressure on macrobenthic fauna in the Caroni Swamp Ramsar Site, Trinidad and Tobago. *Revista de Biologia Tropical*, *66*(3), 1101-1117. https://doi.org/10.15517/rbt.v66i3.31419

Kassim, Z., Ahmad, Z., & Ismail, N. (2018). Diversity of bivalves in mangrove forest, Tok Bali Kelantan, Malaysia. *Science Heritage Journal*, *2*(2), 04-09. https://doi.org/10.26480/gws.02.2018.04.09

Kitamura, H., Ishitani, H., Kuge, Y., & Nakamoto, M. (1982). Determination of nitrate in freshwater and sea water by a idrazine reduction method. *Japan Journal of Water Pollution Research*, *5*(1), 35–42. https://doi.org/https://doi.org/10.2965/jswe1978.5.35

Kodikara, K. A. S., Jayatissa, L. P., Huxham, M., Dahdouh-Guebas, F., & Koedam, N. (2018). The effects of salinity on growth and survival of mangrove seedlings changes with age. *Acta Botanica Brasilica*, *32*(1), 37-46. https://doi.org/10.1590/0102-33062017abb0100

Kristensen, E., Andersen, F., & Kofoed, L. (1988). Preliminary assessment of benthic community metabolism in a south-east Asian mangrove swamp. *Marine Ecology*

Progress Series, *48*, 137-145. https://doi.org/10.3354/meps048137

Kumar, P. S., & Khan, A. B. (2013). The distribution and diversity of benthic macroinvertebrate fauna in Pondicherry mangroves, India. *Aquatic Biosystems*, *9*(1), 1-18. https://doi.org/10.1186/2046-9063-9-15

Li, Y. F., Du, F. Y., Gu, Y. G., Ning, J. J., & Wang, L. G. (2017). Changes of the macrobenthic faunal community with stand age of a non-native mangrove species in Futian Mangrove National Nature Reserve, Guangdong, China. *Zoological Studies*, *56*(19), 1-14. https://doi.org/10.6620/ZS.2017.56-19

Liu, W., Tanimura, A., Imai, T., Kanaya, G., Niiyama, T., Maegawa, S., Kohzu, A., Kimura, T., & Toyohara, H. (2014). Distribution of gastropods in a tidal flat in association with digestive enzyme activities. *Plankton and Benthos Research*, *9*(3), 156-167. https://doi.org/10.3800/pbr.9.156

Lovelock, C. E., Feller, I. C., Ball, M. C., Engelbrecht, B. M. J., & Ewe, M. L. (2006). Differences in plant function in phosphorus- and nitrogen-limited mangrove ecosystems. *New Phytologist*, *172*(3), 514-522. https://doi.org/10.1111/j.1469-8137.2006.01851.x

Lucas, R., Van De Kerchove, R., Otero, V., Lagomasino, D., Fatoyinbo, L., Omar, H., Satyanarayana, B., & Dahdouh-Guebas, F. (2020). Structural characterisation of mangrove forests achieved through combining multiple sources of remote sensing data. *Remote Sensing of Environment*, *237*(November 2019), 111543. https://doi.org/10.1016/j.rse.2019.111543

Margalef, R. (1974). *Ecología*. Editorial Omega, Barcelona.

Matin, A., Hossain, B. M., Iqbal, M., Billah, M. M., Al-Asif, A., & Billah, M. M. (2018). Diversity and abundance of Macrobenthos in a subtropical estuary, Bangladesh. *Species*, *19*, 140-150.

Mendoza, A. R. R., Patalinghug, J. M. R., & Divinagracia, J. Y. (2019). The benefit of one cannot replace the other: Seagrass and mangrove ecosystems at Santa Fe, Bantayan Island. *Journal of Ecology and Environment*, *43*(1), 1-8. https://doi.org/10.1186/s41610-019-0114-7

Mohamamad, A., & Jalal, K. C. A. (2018). Macrobenthic diversity and community composition in the Pahang Estuary, Malaysia. *Journal of Coastal Research*, *82*(4), 206-211. https://doi.org/10.2112/si82-030.1

Mokhtari, M., Ghaffar, M. A., Usup, G., & Cob, Z. C. (2016). Effects of fiddler crab burrows on sediment properties in the mangrove mudflats of Sungai Sepang, Malaysia. *Biology*, *5*(1). https://doi.org/10.3390/biology5010007

Muskananfola, M. R., Purnomo, P. W., & Sulardiono, B. (2020). Impact of environmental factors on macrobenthos distribution and abundance in mangrove ecosystems on the Northern coast of Java. *AACL Bioflux*, *13*(5), 2745-2756.

Nielsen, T., & Andersen, F. (2003). Phosphorus dynamics during decomposition of mangrove (*Rhizophora apiculata*) leaves in sediments. *Journal of Experimental Marine Biology and Ecology*, *293*(1), 73-88. https://doi.org/10.1016/S0022-0981(03)00200-4

Omar, H., Misman, M. A., & Linggok, V. (2018). Characterizing and monitoring of mangroves in Malaysia using Landsat-based spatial-spectral variability. *IOP Conference Series: Earth and Environmental Science*, *169*(1), 012037. https://doi.org/10.1088/1755-1315/169/1/012037

Pan, S. H., Ho, C. W., Lin, C. W., Huang, S. C., & Lin, H. J. (2021). Differential response of macrobenthic abundance and community composition to mangrove vegetation. *Forests*, *12*(10), 1-21. https://doi.org/10.3390/f12101403

Pazi, A. M. M., Gandaseca, S., Rosli, N., Hamzah, A. H., Tindit, A. E., & Nyangon, L. (2016). Soil pH and carbon at different depth in three zones of mangrove forest in Sarawak, Malaysia. *Malaysian Forester*, *79*(1–2), 164-173.

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, *13*(C), 131-144. https://doi.org/10.1016/0022-5193(66)90013-0

Poutiers, M. (1998). The living marine resources of the Western central Pacific. In K. Carpenter & V. Niem (Eds.), *FAO species identification guide for fishery purposes. The living marine resources of the Western Central Pacific. Volume 2. Cephalopods, Crustaceans, Holothurians and Sharks*. USA: Food and Agriculture Organization of the United Nations.

Putri, R., Sumardi, Irawan, B., Agustrina, R., & Tugiyono. (2021). Isolation and properties of ammonia-oxidizing bacteria from mangrove sediment, hanura lampung beach. *Journal of Physics: Conference Series*, *1751*(1), 012054. https://doi.org/10.1088/1742-6596/1751/1/012054

Qiu, G. Y., Zhou, F., & Shi, X. (2015). Effects of mangrove forest on the biodiversity of macrobenthos under the condition of severe water pollution. *Ecohydrology*, *8*(7), 1262-1271. https://doi.org/10.1002/eco.1579

Rahman, M. H., Hossain, M. B., Habib, A., Noman, M. A., & Mondal, S. (2021). Mangrove associated macrobenthos community structure from an Estuarine island. *Biodiversitas*, *22*(1), 247-252. https://doi.org/10.13057/biodiv/d220130

Rao, Y., Cai, L., Zhou, X., Fu, S., Peng, W., Chen, X., & Zheng, B. (2021). Changes of community structure and functional feeding groups of benthic macrofauna after mangrove afforestation in a subtropical intertidal zone, China. *Wetlands*, *41*(8), 1-11. https://doi.org/10.1007/s13157-021-01489-4

Reef, R., Feller, I. C., & Lovelock, C. E. (2010). Nutrition of mangroves. *Tree Physiology*, *30*(9), 1148-1160. https://doi.org/10.1093/treephys/tpq048

Saifullah, A. S. M., Abu Hena, M. K., Idris, M. H., Halimah, A. R., & Johan, I. (2014). Composition and diversity of phytoplankton from mangrove estuaries in Sarawak, Malaysia. *Journal of Biological Sciences*, *14*(5), 361-369.

Salleh-Mukri, M., & Shuhaida, S. (2021). The habitat preference of mangrove crabs in different mangrove forests of Penang, North Peninsular Malaysia. *IOP Conference Series: Earth and Environmental Science*, *736*(1), 012062. https://doi.org/10.1088/1755-1315/736/1/012062

Samidurai, K., Saravanakumar, A., & Kathiresan, K. (2012). Spatial and temporal distribution of macrobenthos in different mangrove ecosystems of Tamil Nadu Coast, India. *Environmental Monitoring and Assessment*, *184*(7), 4079-4096. https://doi.org/10.1007/s10661-011-2245-x

Santos, T. M. T., & Aviz, D. (2019). Macrobenthic fauna associated with *Diopatra cuprea* (Onuphidae: Polychaeta) tubes on a macrotidal sandy beach of the Brazilian Amazon Coast. *Journal of the Marine Biological Association of the United Kingdom*, *99*(4), 751-759. https://doi.org/10.1017/S0025315418000711

Sasekumar, A., & Chong, V. C. (1998). Faunal diversity in Malaysian mangroves. *Global Ecology and Biogeography Letters*, *7*(1), 57-60. https://doi.org/10.2307/2997697

Schloss, P. D., & Handelsman, J. (2006). Introducing SONS, a tool for operational taxonomic unit-based comparisons of microbial community memberships and structures. *Applied and Environmental Microbiology*, *72*(10), 6773-6779. https://doi.org/10.1128/AEM.00474-06

Shah, K., Mustafa Kamal, A. H., Rosli, Z., Hakeem, K. R., & Hoque, M. M. (2016). Composition and diversity of plants in

Sibuti mangrove forest, Sarawak, Malaysia. *Forest Science and Technology*, *12*(2), 70-76. https://doi.org/10.1080/21580103.2015.1057619

Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, *27*(4), 623-656. https://doi.org/10.1002/j.1538-7305.1948.tb00917.x

Sharif, N. A. M., Shaiful Kahar, N. A., Syed Hussein, M. A., Ransangan, J., & Yong, A. S.-K. (2019). Species diversity and distribution of mud crab in Marudu Bay mangrove forest reserve, Sabah, Malaysia. *Borneo Journal of Marine Science and Aquaculture (BJoMSA)*, *3*(1), 18-24. https://doi.org/10.51200/bjomsa.v3i1.1709

Shiau, Y. J., Lee, S. C., Chen, T. H., Tian, G., & Chiu, C. Y. (2017). Water salinity effects on growth and nitrogen assimilation rate of mangrove (Kandelia candel) seedlings. *Aquatic Botany*, *137*, 50-55. https://doi.org/10.1016/j.aquabot.2016.11.008

Simpson, E. H. (1949). Measurment of diversity. *Nature*, *163*(1943), 688. https://doi.org/10.1038/163688a0

Sippo, J. Z., Maher, D. T., Tait, D. R., Holloway, C., & Isaac R. Santos1. (2016). Are mangroves drivers or buffers of coastal acidification? Insights from alkalinity and dissolved inorganic carbon export estimates across a latitudinal transect. *Global Biogeochemical Cycles*, *30*(Dic), 753-766. https://doi.org/10.1111/1462-2920.13280

Sow-Yan, C., & Lup, L. W. (2020). Confirmation of the occurrence of the snail, *Assiminea nitida*, in Singapore. *Singapore Biodiversity Records*, *March*, 34-36.

Srisunont, C., Thongsanit, N., Suttiwichai, J., & Boonjan, A. (2016). Diversity index of macrobenthos and environmental factors in mangrove and mudflat areas at Klong Khone, Samut Songkhram Province. *The 3rd National Meeting on Biodiversity Management in Thailand*, *3*(2016), 239-245.

Stiepani, J., Gillis, L. G., Chee, S. Y., Pfeiffer, M., & Nordhaus, I. (2021). Impacts of urbanization on mangrove forests and Brachyuran crabs in Penang, Malaysia. *Regional Environmental Change*, *21*(3), 69. https://doi.org/10.1007/s10113-021-01800-3

Tan, C. G. S., & Ng, P. K. L. (1994). An annotated checklist of mangrove brachyuran crabs from Malaysia and Singapore. *Hydrobiologia*, *285*(1-3), 75-84. https://doi.org/10.1007/BF00005655

Tan, S. K., & Clements, R. (2008). Taxonomy and distribution of the Neritidae (Mollusca: Gastropoda) in Singapore. *Zoological Studies*, *47*(4), 481-494.

Tanimoto, T. (1958). *An elementarymathematical theory of classification and prediction: Internal IBM technical report*. http://dalkescientific.com/tanimoto.pdf

Thanh-Nho, N., Marchand, C., Strady, E., Huu-Phat, N., & Nhu-Trang, T. T. (2019). Bioaccumulation of some trace elements in tropical mangrove plants and snails (Can Gio, Vietnam). *Environmental Pollution*, *248*, 635-645. https://doi.org/10.1016/j.envpol.2019.02.041

Ukpong, L. E. (1995). Vegetation and soil acidity of a mangrove swamp in southeastern Nigeria. *Soil Use and Management*, *11*(3), 141-144. https://doi.org/10.1111/j.1475-2743.1995.tb00512.x

Vaezzadeh, V., Zakaria, M. P., Bong, C. W., Masood, N., Mohsen Magam, S., & Alkhadher, S. (2019). Mangrove Oyster (*Crassostrea belcheri*) as a biomonitor species for bioavailability of Polycyclic Aromatic Hydrocarbons (PAHs) from sediment of the west coast of peninsular Malaysia. *Polycyclic Aromatic Compounds*, *39*(5), 470-485. https://doi.org/10.1080/10406638.2017.1348366

Vahidi, F., Fatemi, S. M. R., Danehkar, A., A, M. M., & R, M. N. (2021). Patterns of mollusks (Bivalvia and Gastropoda) distribution in three different zones of Harra Biosphere Reserve , the Persian Gulf , Iran. *Iranian Journal of Fisheries Sciences*, *20*(5), 1336-1353. https://doi.org/10.22092/ijfs.2021.124955

Vijapure, T., Sukumaran, S., Neetu, S., & Chandel, K. (2019). Macrobenthos at marine hotspots along the northwest Indian inner shelf: Patterns and drivers. *Marine Environmental Research*, *144*(December 2018), 111-124. https://doi.org/10.1016/j.marenvres.2018.12.007

Wakushima, S., Kuraishi, S., & Sakurai, N. (1994). Soil salinity and pH in Japanese mangrove forests and growth of cultivated mangrove plants in different soil conditions. *Journal of Plant Research*, *107*(1), 39-46. https://doi.org/10.1007/BF02344528

Wang, Q., Song, L., Agusti, S., Duarte, C., Christakos, G., & Wu, J. (2021). Changes of the macrobenthos community with non-native mangrove rehabilitation (*Kandelia obovata*) and salt marsh invasion (*Spartina alterniflora*) in Ximen Island, Zhejiang, China. *Ocean Science Journal*, *56*(4), 395-405. https://doi.org/10.1007/s12601-021-00037-9

Wong, H. W. (2009). The Mactridae (Mollusca: Bivalvia) of East Coast Park, Singapore. *Nature in Singapore*, *2*(July), 283-296.

Wu, Z., Xie, L., Chen, B., Dhamawan, I. W. E., Sastrosuwondo, P., Chen, S., Rianta, P., Ernawati, W., & Chen, G. (2020). Carbon sources of sediment and epifaunal food sources in a tropical mangrove forest in North Sulawesi, Indonesia. *Journal of Ocean University of China*, *19*(5), 1169-1176. https://doi.org/10.1007/s11802-020-4401-9

XLSTAT. (2021). *XLSTAT: A complete statistical add-in for Microsoft Excel* (2019.2.2). Addinsoft. https://www.xlstat.com/en/

Yahya, N., Idris, I., Rosli, N. S., & Bachok, Z. (2020). Mangrove-associated bivalves in Southeast Asia: A review. *Regional Studies in Marine Science*, *38*, 101382. https://doi.org/10.1016/j.rsma.2020.101382

Yanti, G., Jamarun, N., Suyitman, S., Satria, B., & Sari, R. W. W. (2021). Mineral status of soil, sea water, and mangrove (*Avicennia marina*) forages in several coastal areas of West Sumatra. *Veterinary World*, *14*(6), 1594–1601. https://doi.org/10.14202/vetworld.2021.1594-1601

Zhang, Y., Zhang, L., Kang, Y., Li, Y., Chen, Z., Li, R., Tian, C., Wang, W., & Wang, M. (2021). Biotic homogenization increases with human intervention: Implications for mangrove wetland restoration. *Ecography*, 1-12. https://doi.org/10.1111/ecog.05835

Zhao, D., Cao, X., Zeng, J., Huang, R., & Yu, Z. (2017). Effects of macrobenthic bioturbation on the abundance and community composition of ammonia-oxidizing prokaryotes under different temperatures. *Journal of Freshwater Ecology*, *32*(1), 405-414. https://doi.org/10.1080/02705060.2017.1320307