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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 of 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 having 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 bivalves 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; Duisan *et al*., 2021; Al-Asif *et al*., 2020, 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). While the first study was reported from Matang mangrove forest peninsular Malaysia (Sasekumar & Chong, 1998) and the baseline study from east Malaysia was conducted in Semantan mangrove forest Sarawak (Ashton *et al*., 2003). Studies by Mokhtari *et al*. (2016), Salleh-Mukri & Shuhaida, (2021), Sharif *et al*. (2019), Tan & Ng (1994) described on the different species of crab abundance from different mangrove habitats, including Sarawak and Sabah. While the overall study on seasonal dynamics of surface sediment macrobenthos in mangrove habitat was not conducted in Malaysian mangrove habitat 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 (Al-Asif et al., 2023; Al-Asif *et al.*, 2020; Ismail *et al*., 2020, 2021; Bujang *et al*., 2006). 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 studied, 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 were 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 were 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 (Abu Hena *et al*., 2016b; Ahmad-Kamil *et al*., 2013; Bujang *et al*., 2006; Gandaseca *et al*., 2014).

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 till 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 were collected on-site using a soil pH meter (DM-15) and hose pipe method, respectively.

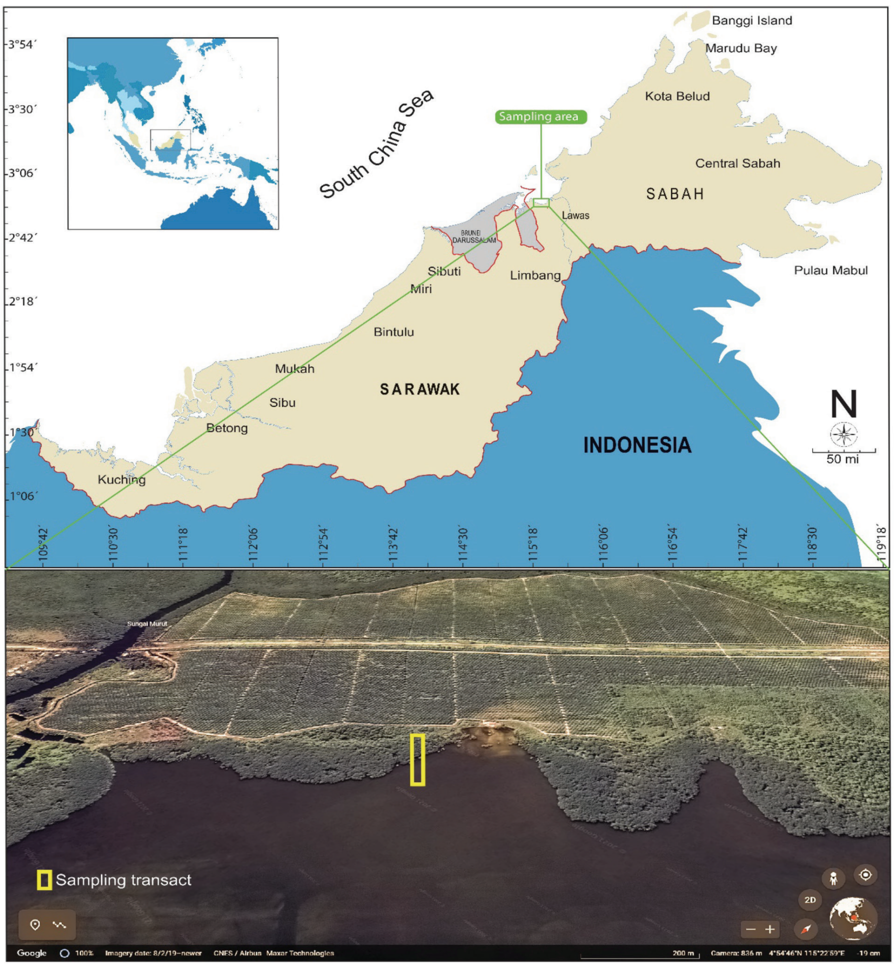

Figure 1: Study area showing the sampling site at the mangrove habitat in Lawas, Sarawak

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

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 Atomic Absorption Spectrophotometer (AAS) (Model: S/N 800S4010404) in Analytical Laboratory.

Collection and Analysis of Macrofauna on the Surface Sediment

A 10 m transact 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 transact line, mid of transact line and end of the transact 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 & 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)Hamli H, Abu Hena MK, Idris MH, Gerusu GJ, Ismail JB, Karim NU. 2020. Benthic macrofaunal assemblage in seagrass-mangrove complex and adjacent ecosystems of Punang-Sari Estuary, Lawas, Sarawak, Malaysia. Biodiversitas 21: 4606-4615. Present study dealt with the on faunal and in faunal assemblage from seagrass bed, mangrove area, and adjacent non-mangrove and seagrass (NMS

- 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, 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 (nine species), pre-monsoon (seven species) and intermediate-September (six species); while the number of the individual 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 habitat, 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).

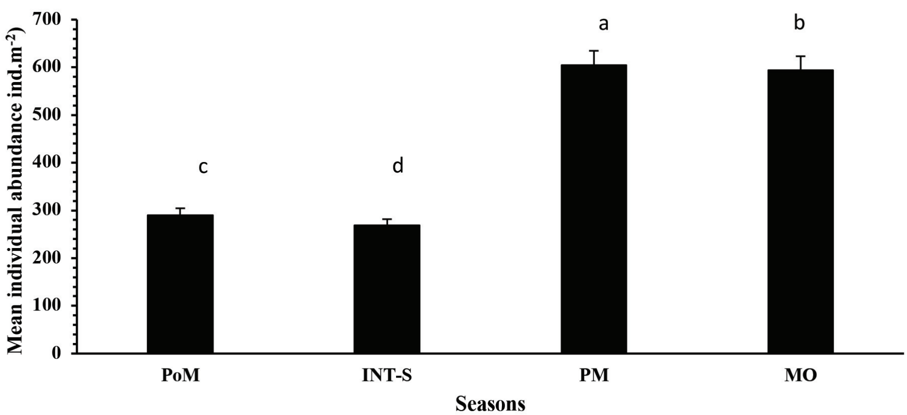

Figure 2: Seasonal on-faunal abundance in the mangrove habitat of Lawas, Sarawak (PoM = Post-monsoon, INT-S = Intermediate-September; PM=Pre-monsoon; MO = Monsoon). Different alphabetical letters within columns indicate significant differences $P < 0.05$

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

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).

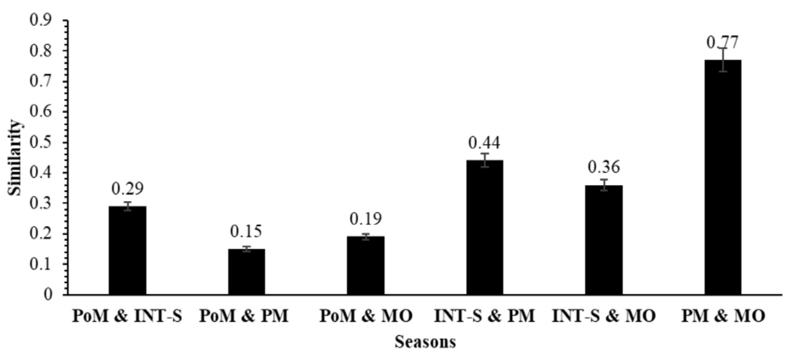

Figure 3: Comparison of on-faunal Jaccard similarity index among seasons in mangrove habitat (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

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) found 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

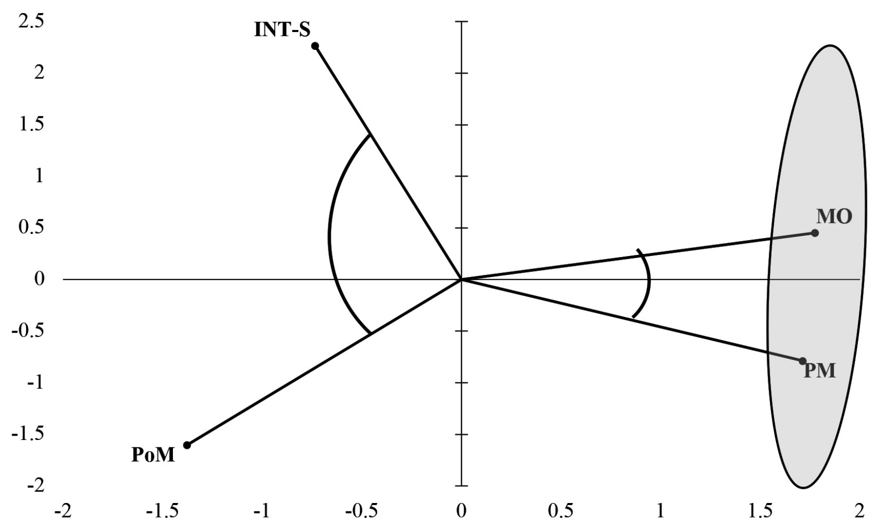

Figure 4: PCA of on-faunal abundance in the mangrove habitat of Lawas (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

nMDS 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 habitat (Figure 5). The Shepard diagram referred that the MDS result of on-faunal abundance in the Lawas mangrove habitat was reliable (Figure 6).

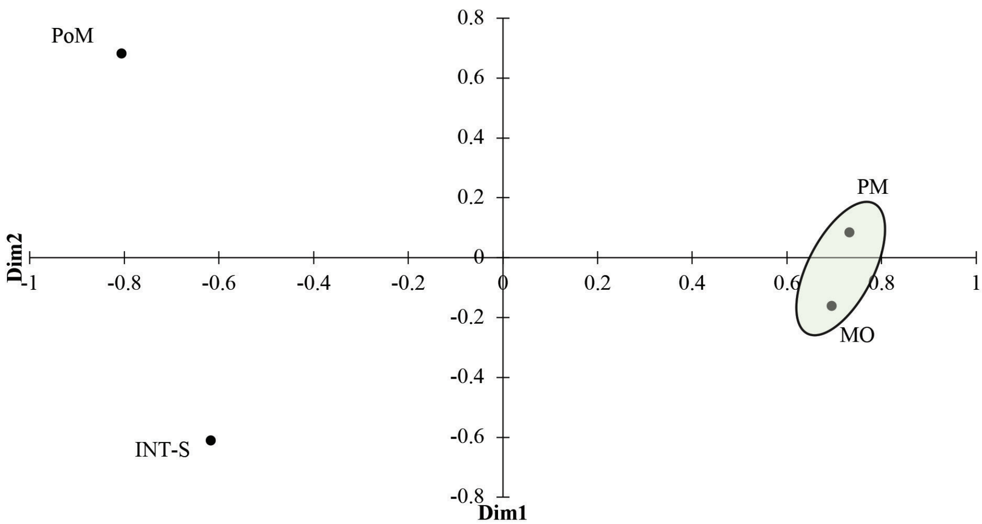

Figure 5: Seasonal Multidimensional Scaling (MDS) of on-faunal abundance in Lawas mangrove habitat, Sarawak (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

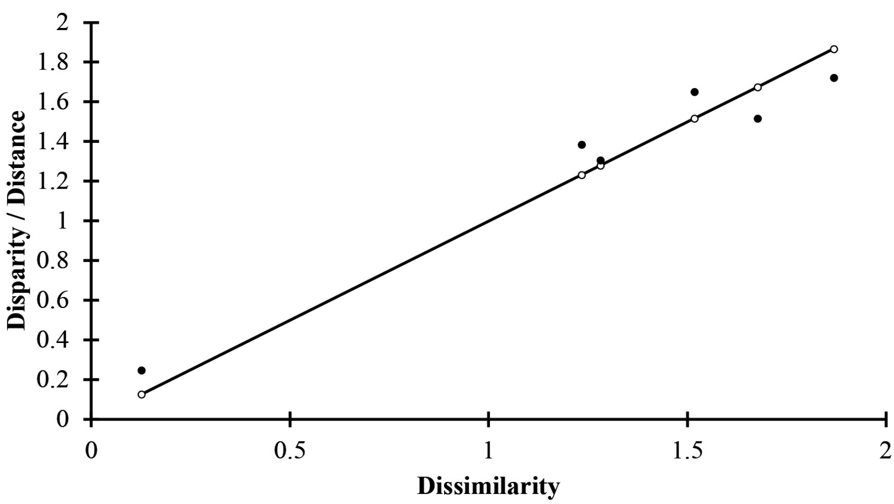

Figure 6: Seasonal on-faunal Shepard diagram of Multidimensional Scaling (MDS) analysis of mangrove habitat in Lawas, Sarawak

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 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).

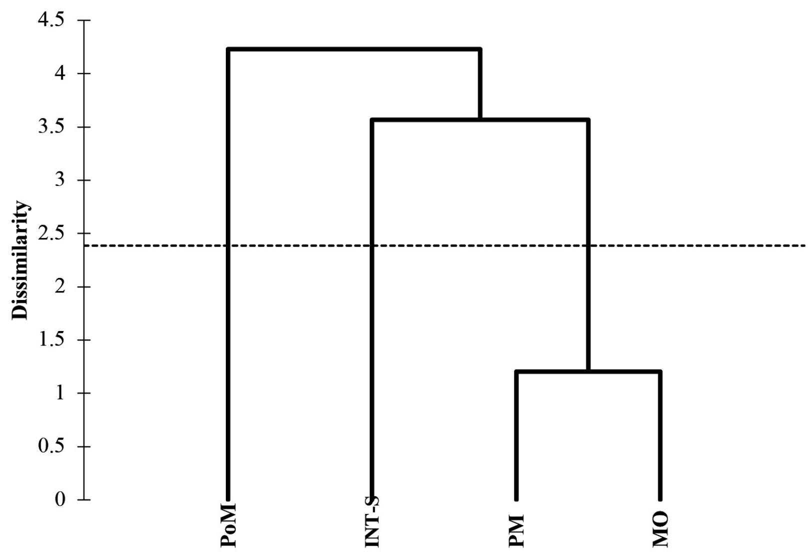

Figure 7: Seasonal cluster dendrogram of on-faunal abundance in mangrove habitat of Lawas, Sarawak (PoM = Post-monsoon, INT-S = Intermediate-September; PM = Pre-monsoon; MO = Monsoon)

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 $P < 0.05$

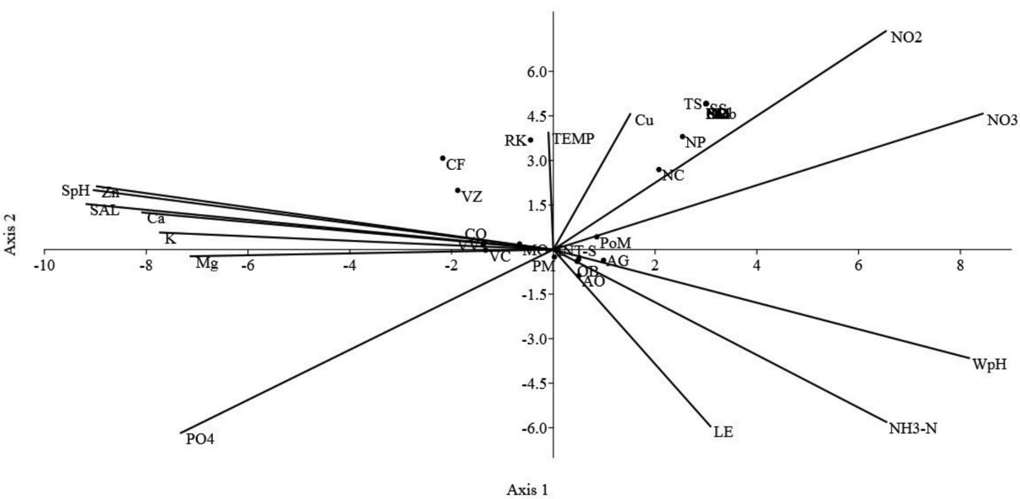

Figure 8: CCA ordination showed the relationship among different seasons, ecological parameters and on-faunal abundance in the mangrove habitat of Lawas, Sarawak

Discussion

The dominance index of on-faunal abundance in mangrove habitat was higher in intermediate-September with 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. The recent study from the mangrove-seagrass complex in Red Sea coast, 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)Sarawak, Malaysia. Methodology: Fishes were collected with an encircling gillnet net during the dry, wet and intermediate season of the year. Water characteristics were analyzed in-situ through analytical methods. Results: A total of 60 fish species from 37 families were recorded in the seagrass ecosystem. Dominant species with highest total abundance observed were Lethrinus lentjan (12.83% 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)Malaysia. However, little research has focused on the implications of urbanization onto the biodiversity within mangrove forests. This study investigates and compares both vegetation and crab assemblages between urban and rural mangrove forests. Collectively, 5853 trees were recorded including 15 species from six families: Acanthaceae, Arecaceae, Lythraceae, Malvaceae, Meliaceae, and Rhizophoraceae. Avicennia marina accounted for 88.6% of all trees in the study and held the highest species importance (IV, 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 result, the on-faunal species abundance in mangrove habitat in pre-monsoon and monsoon was found to be strongly correlated with each other, this result support the previous all analysis and similar analysis were done elsewhere to know the corelation within macrobenthos species abundace 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 (Cabañas-Mendoza *et al.*, 2020; Wakushima *et al*., 1994). 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 polycheata, 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 the certain concentration of these elements are essential for both mangrove plants and associated macrobenthos in the ecosystem (Yanti *et al.,* 2021; Thanh-Nho *et al.,* 2019; Alongi, 2017, 2021; Reef *et al.*, 2010).

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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