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COASTAL MESOZOOPLANKTON IN CORAL REEFS ECOSYSTEM, ITS BIODIVERSITY, MONSOONAL AND SPATIAL DISTRIBUTION

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Abstract: Planktons are well known for their abundance in the water column but their dynamic population has been less studied especially on a temporal basis. Coral reef ecosystems in 'Pulau Bidong' and 'Pulau Kara'h were chosen as the sampling point to study the mesozooplankton monsoonal distribution during the two main monsoons in the South China Sea, the southwest and the northeast together with their respective pre- and postseason. The usage of 200-micron mesh size plankton net for this study was intended to expand the tropical knowledge that would focus on smaller zooplankton net mesh size. Mesozooplankton bloom was onset on pre-southwest, peaked in density during post-southwest monsoon and showed a significant fluctuation pattern compared to northeast monsoons series. Seven mesozooplankton phylum was identified and Arthropoda with its predominant class Crustacea was the most abundant organisms in the sampling area. Copepoda community which dominated the water column consist of Copepodite (juvenile), Calanoida, Cyclopoida, Poecilostamatoida and Harpacticoida. Larvae from phylum Echinodermata showed a post-southwest monsoon preference, which was then recognized as its spawning season. Station 2 (north Pulau Bidong, N05º 37.809'; E103º 03.963') and station 3 (east Pulau Bidong, N05º 37.497'; E103º 04.193') were highlighted for their significantly high mesozooplankton density, while Station 1, the UMT's Research Station (west Pulau Bidong, N05º 37.299'; E103º 03.827') and station 5 (south Pulau Bidong, N05º 36.580'; E103º 03.963') were deemed important as a ground for marine productivity. Findings from this study could contribute to the establishment of baseline information for the ecological dynamics of mesozooplankton about the coral reefs ecosystem resilience in Bidong Archipelago.

Keywords: Pulau Bidong, Pulau Karah, coral reef, mesozooplankton, monsoon, South China Sea.

Introduction

The coral reef forms a vital habitat link between the primary producers and the different level of consumers in the food chain (Yebra *et al.*, 2006). The ecosystem of coral reefs are important as a nursery ground for juvenile of fish may from coral habitat (Arai *et al.*, 2015), as well as to the species from open seas (Oakley *et al.*, 2000). Zooplankton is an important component in coral reef whereas their distribution pattern will contribute to determining the ecosystem conditions (Nakajima *et al.*, 2006; 2008; 2014). Their abundance and fluctuations of the community structure will determine the interactive effects of coastal processes and food abundance which is referred to as monsoon seasons (Rezai *et al.*, 2011).

Planktonic larvae are an important meroplankton group that structuring the zooplankton community which comprises larval stages of cirripedian, brachyuran, macruran, molluscan, echinoderm, fish and polychaeta (Li *et al.*, 2000). Some of these planktonic larvae seasonally contribute high density into the zooplankton community due to their spawning season. For example, molluscan larvae that were abundant during the post-monsoon of the northeast season (Al-Barwani *et al.*, 2007; Husain, 2012). According to Moriarty and O'Brien (2013), mesozooplankton size ranges are between 200 micrometres (µm) to 2 millimetres (mm) comprising primarily crustacean copepods, diverse invertebrate larvae and small gelatinous zooplankton compared to microplankton (20-200 µm) and megaplankton (>20 mm). Planktonic Copepoda is the main holoplanktonic component in connecting trophic linkage between primary producers and higher trophic consumer (Zaleha *et al*., 2008). Copepoda and zooplankton community also play an important role in shaping the response and the pace of climate changes due to their short life cycles (Hooff & Peterson, 2006; Richardson, 2008).

Zooplankton community pose a big impact on the marine survey to both biodiversity and ecosystem functions. To the best of our knowledge, zooplankton studies in the tropical coast of Malaysia mainly used a smaller mesh size net ranged between 35 – 122 µm (Shamsudin, 1998; 2000; Shamsudin *et al*., 1998; Husain, 2012; Idris *et al*., 1995; 2000; Nakajima *et al*., 2014; 2008; Rezai *et al*., 2004; 2009; 2011; Zaleha *et al*., 2006; 2008) compared to the studies conducted in temperate areas as previewed by Harris *et al*. (2000). In addition to the scarce mesozooplankton study, there was no recent information found regarding their distribution in the tropical coastal ecosystem. Buitenhuis *et al*. (2006) stated that mesozooplankton have significant feedback to primary production as they directly feed on phytoplankton. Thus, this study was executed to study mesozooplankton important role poses in the pelagic food web, to explain their temporal distribution pattern in coastal reefs ecosystem. We hypothesized the abundance of the mesozooplankton community will vary on the monsoonal basis and their peak density reflects the phytoplankton distribution pattern which acts as food sources for mesozooplankton as studied by Khyril-Syahrizan and Bachok (2018).

Materials and Methods

Sampling Area and Experimental Design

Mesozooplankton samples were collected from seven fix stations related to coral reefs surrounding the Pulau Bidong and Pulau Karah (Bidong Archipelago). The sampling area is located towards the east of Terengganu coastal waters (N 5.61543; E 103.05976) (Figure 1). The area has regulative experiences of annual monsoon seasons in addition to recreational activities (tourism, snorkelling and diving) and extensive fish farming activity located in station 4 (St. 4) (Wan-Hussin, 2014). Samples were collected on 16th May 2014, 8th August 2014, 19th September 2014, 17th October 2014, 6th February 2015 and 6th March 2015, and classified as PreSW, SW, PostSW, PreNE, NE and PostNE, respectively. The sampling location experienced dry and warmer weather during southwest (SW) monsoon, while experienced rainfalls throughout the months of Northeast (NE) monsoon (Wang *et al*., 2007). We experienced rainfalls while collecting samples during PreNE which amounted to 56.5 mm where the area also experienced rainfalls 2 days before the sampling session (15.0 and 20.5 mm). Rainfalls data was provided by Jabatan Pengairan dan Saliran Ampang from the station of Kg. Merang (site 5529027).

Samples Collection and Analysis

Samples of mesozooplankton were vertically hauled one meter (m) from the sea bottom to the surface using a 200 µm mesh net with 30 centimetres (cm) diameter of mouth opening at each sampling station. Triplicate samples were collected for this purpose. Mechanical flow meter (General Oceanics model 2030R, Florida, USA) was attached to the net during collections for water filtered measurement as suggested by Harris *et al*. (2000). Samples collected were fixed with 3% of formaldehyde solution (Merck, USA). In laboratory analysis, one per sixteen aliquots of the sample were separated using a Folsom Splitter (Omori & Ikeda, 1984). Next, the samples were placed on Bogorov tray, enumerated and counted with the aid of dissecting Olympus SZX7 (Japan) microscope (2.5 x 10 magnification). The samples were identified as per the keys and references set by Arvin (1977) and Pechenik (2000). Mesozooplankton density then was calculated to the total of parts divided and presented in the mean of total density (±SD) as described by Allisson and Wisher (1986).

Data Analysis

Shannon-Weiner diversity index, Margalef's species richness and evenness analyses were examined to describe the diversity pattern of mesozooplankton and their distribution in the sampling area. All statistical analyses including two-way ANOVA were examined using MINITAB statistical software and were considered significant when $p < 0.05$.

Results and Discussion

Mesozooplankton Biodiversity

A total of 18 major taxa from 7 phyla were identified and separated to the holoplankton and meroplankton group respectively (Figure 2a; 2b). A non-major finding registered as others (Radiozoa and Unidentified Taxa) was excluded and a total of 64 genera that were present in the reef ecosystem of Bidong Archipelago is shown in Table 1. However, a study by Jivaluk (1998) only found 34 major groups of zooplankton in the South China Sea coastal waters. We also found phylum Arthropoda, its predominant class Crustacea consist sub-class of Copepoda was dominant in the water column of the study area (Table 2). This is similar to many previous studies on various zooplankton size and composition that is influenced by the South China Sea coastal current (Jivaluk, 1998; 2008; Shamsudin *et al*., 1998; Zaleha *et al*., 2006; Husain, 2012; Nakajima *et al*., 2014). Copepoda was structured by Copepodite, Calanoida, Cyclopoida, Poecilostomatoida and

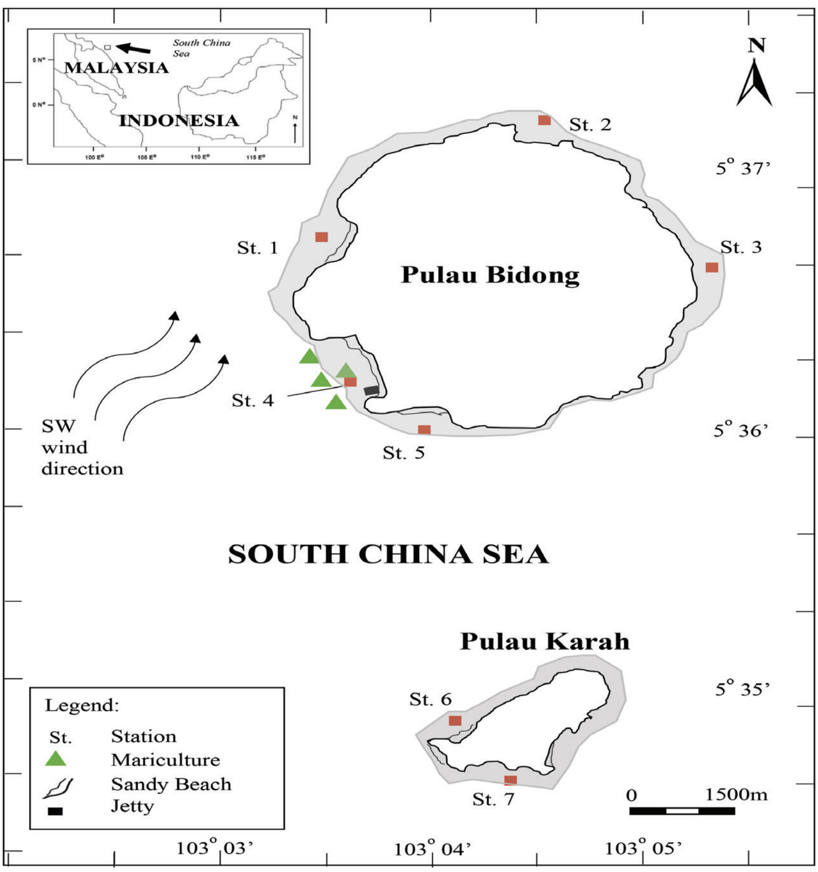

Figure 1: Sampling stations and wind direction (Daud & Akhir, 2015) in Pulau Bidong and Pulau Karah (Bidong Archipelago), Terengganu, South China Sea. Grey area is coral reef cover

Harpacticoida while we found Copepodite, Calanoida and Poecilstomatoida distribution were relatively similar (*p>0.05*; Table 2) in the sampling area throughout the monsoonal periods. Copepoda was also found to be dominant in coral reefs ecosystem besides being known to vertically migrate between daytime and night time as studied by Nakajima *et al*. (2006). This is undeniable as Copepoda is widely known as 'water insect' with a mass density in the water column. The remaining 6 phylum were Mollusca, Chaetognatha, Annelida, Cnidaria, Chordata and Echinodermata (Table 1).

A group of meroplankton Branchipoda, Thaliacea and Osteichthyes have spatially existed (*p<0.05*; Table 2) in sampling station throughout temporal monsoons (Figure 2; Table 1). Osteichthyes was highest during NE monsoon, however, appeared relatively high during SW and PSW monsoons (Figure 2b). Further investigation is necessary to conclude fish spawning season in Bidong Archipelago. Thaliacea can adapt to low food concentration and is known to be an important food source for deeper water organisms (Acuna, 2001). However, this also requires further surveys since they showed no preference for any

Table 1: Mesozooplankton genera and biodiversity list present in Bidong Archipelago

Phylum	**Class**	**Sub-class**	**Order**	**Family**	**Genus/taxa**
Arthropoda					
	Crustacea				Nauplii
		Copepoda			Copepodite
			Calanoida		
				Calanidae	Calanus
					Canthocalanus
					Undinula
				Acartidae	Acartia
				Paracalanidae	Paracalanus
					Calocalanus
				Candaciidae	Candacia
				Centropagiidae	Centropages
				Eucalanidae	Eucalanus
				Euchaeta	Euchaeta
				Pseudodiaptomidae	Pseudodiaptomus
				Pontellidae	Pontella
				Temoridae	Temora
				Clausocalanidae	Microcalanus
					Pseudocalanus
				Tortanidae	Tortanus
			Cyclopoida		
				Oithonidae	Oithona
			Poecilostomatoida		
				Oncaecidae	Oncaea
				Corycaeidae	Corrycaeus
					Corycella
				Sapphirinidae	Sapphirina
					Copilia
			Harpacticoida		
				Harpacticidae	(un-identified)
				Clytemnestrinae	Clytemnestra
				Euterpinidae	Euterpina
				Ameiridae	Nitocra
				Ectinosomatidae	Microsetella
				Miraciidae	Macrosetella
					Miracia
					Pseudotenhelia
				Laopontidae	Laoponthe
		Malacostraca			
			Decapoda		Larvae
				Brachyura	Brachyura Zoea
				Anomura	Anomura Zoea
			Amphipoda		(un-identified)
				Lestrigonidae	Lestrigonus

Phylum	**Class**	**Sub-class**	**Order**	**Family**	**Genus/taxa**
		Branchiopoda			
			Diplostraca (super-order)		
			Cladocera		
				Podonidae	Evadne
				Sididae	Penilia
		Ostracoda			(un-identified)
		Cirripedia			Moult
					Nauplii
					Cypris larvae
Echinodermata					
	Stelleroidea				
		Asteroidea			Asteroidea Larvae
		Ophiuroidea			Ophiuroidea Larvae
	Echinoidea				Echinoidea Larvae
Mollusca					
	Gastropoda				Gastropoda Larvae
	Bivalvia				Bivalvia Larvae
	Cephalopoda				(Juvenile)
Annelida					
	Polychaeta				Polychaeta Larvae
				Tomopteridae	(un-identified)
Chaetognatha					
	Sagittoidea				
			Aphragmophora		(un-identified)
Cnidaria					
	Hydrozoa				Siphonophora
			Hydroida		Anthomedusae
					Leptomedusae
					Trachymedusae
Chordata					
	Ostheichthyes				Fish Egg
					Fish Larvae
	Tunicata (sub-phylum)				
	Larvacea				Fritillaria
					Oikopleura
	Thaliacea				Thaliacean Larvae
			Salpida		Salpa
			Doliolida		(un-identified)
OTHERS					
Radiozoa					
	Acantharia				
			Arthracanthida		(un-identified)
Unidentified Taxa					Eggs (un-identified)

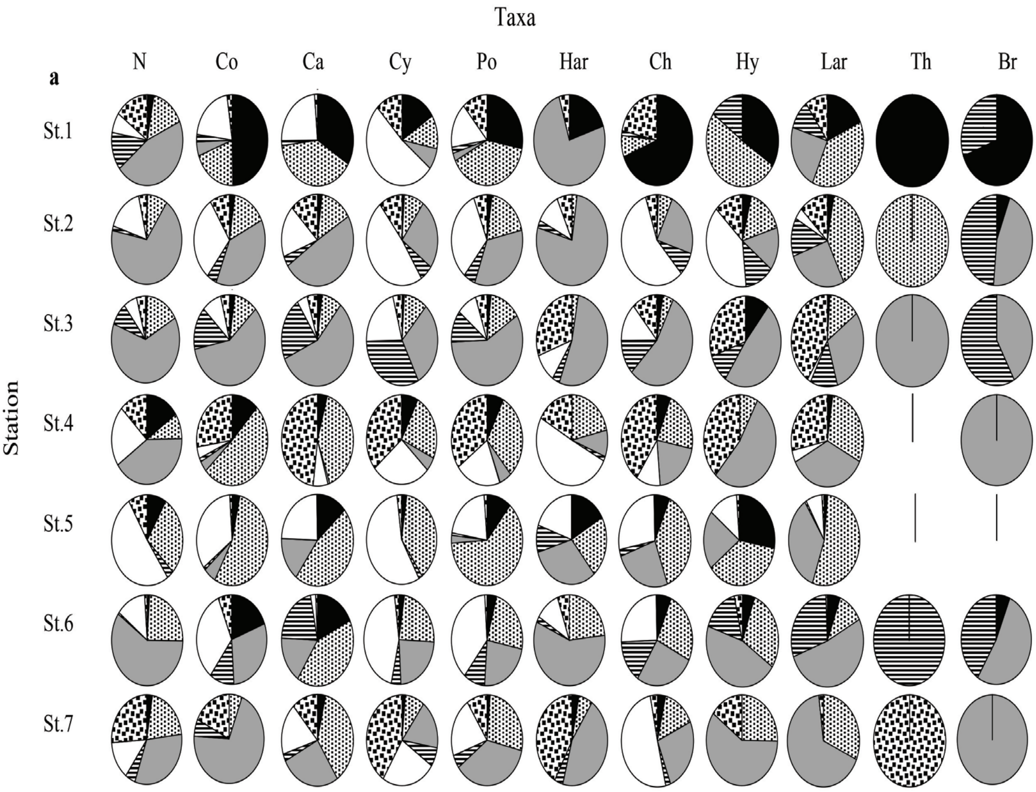

Figure 2a: Mesozooplankton temporal taxa distribution to their holoplankton group in Bidong Archipelago; n=3. (N, Nauplii; Co, Copepodite; Ca, Calanoida; Cy, Cyclopoida; Po, Poecilostomatoida; Har, Harpacticoida; Ch, Chaetognatha; Hy, Hydrozoa; Lar, larvacea; Th, Thaliacea; Br, Branchiopoda). The legend refers to figure 2b.

monsoon season as they are consistently being low in number throughout the monsoons. Finally, we found Echinodermata (larvae) showed a preference to PostSW monsoon (5 out of 7 stations), occurred as high as 93% from its monsoonal distribution at St. 1 (Figure 2b; Table 2). This indicated their spawning season as found by Falkner and Byrne (2003) and Dahms (1993), as occurred from May to September/ October.

Monsoonal and Spatial Distributions of Mesozooplankton

In general, density fluctuation of mesozooplankton between the two major SW and NE monsoons were remarkably different (Figure 3). It was supported by two-way ANOVA that mesozooplankton density within the sampling seasons was significantly different and dependent on each sampling station ($p<0.05$). Mesozooplankton density was found highest during PostSW monsoon with 39% (5,586±1,979 and.m^{-3}) from the total of mean density as portrayed in figure 3. A clear bloom pattern was also portrayed in the distribution, onset on PreSW monsoon. The result was significant to the study by Shamsudin (1998) in Tumpat coastal water, indicated that mesozooplankton and zooplankton shared the same monsoonal preference. Besides, both studies were influenced by the South China Sea coastal currents. Besides, this finding is also similar to the fluctuation pattern of primary producers (phytoplankton and chlorophyll-*a*) in Pulau Bidong (Khyril-Syahrizan & Bachok,

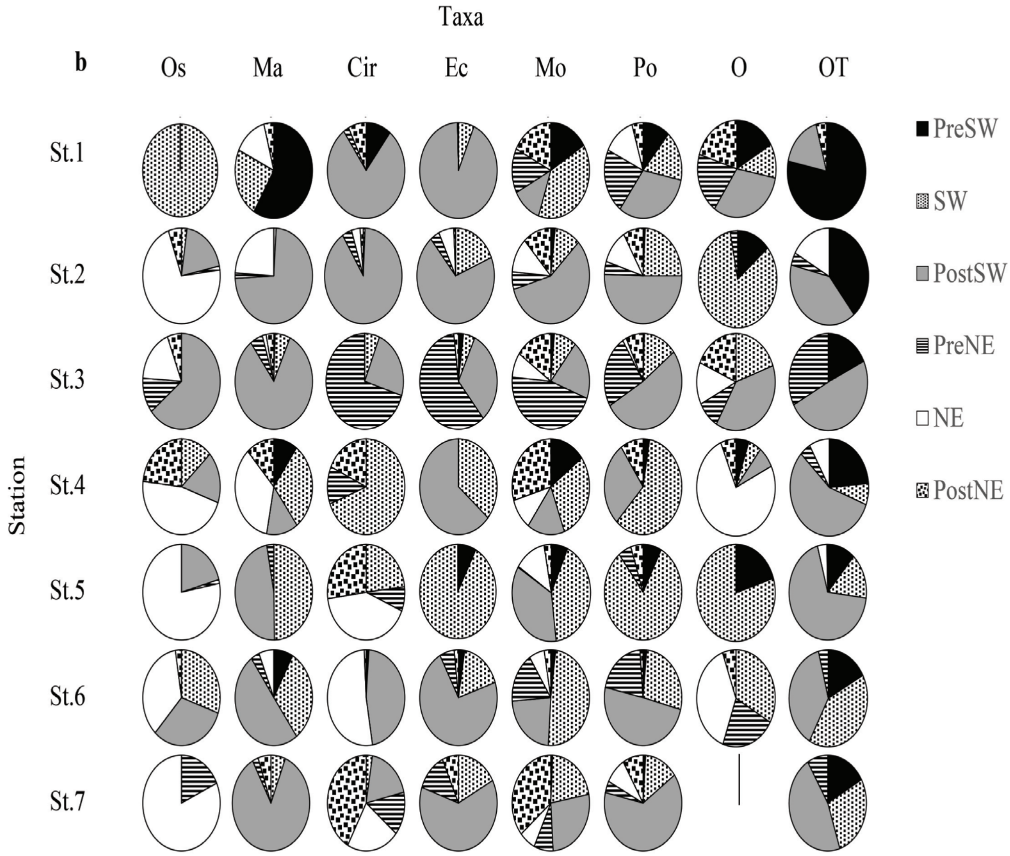

Figure 2b: Mesozooplankton temporal taxa distribution to their meroplankton group in Bidong Archipelago; n=3. (Os, Ostracoda; Ma, Malacostraca; Cir, Cirripedia; Ec, Echinodermata (larvae); Mo, Mollusca (larvae); Po, Polychaeta (larvae); O, Osteichthyes; OT, Others)

2018) thus indicate that mesozooplankton also has a close association with the availability of phytoplankton.

As this present study was the first to tackle this topic in our region, we can only consider that mesozooplankton abundance in reef ecosystem has a close association with monsoon season, and differ in distribution between dry and wet season. Chew and Chong (2011) stated that rainfall pattern was the most influential factor controlling zooplankton and their community structure by changing the water salinity level. Therefore, a relatively lower mesozooplankton total of mean density was found during temporal NE monsoons (5,213 ind.m^{-3}) compared to temporal SW monsoons (9,135 ind.m^{-3}) (Figure 3). The fluctuation of salinity was important as when salinity appeared high, zooplankton density will also become high (Li *et al*., 2000; Zaleha *et al*., 2008; Husain, 2012). However, a slight increase of mesozooplankton density during NE monsoon might be caused by the rainy condition that darkens the cloud and upwelling (Tan *et al*., 2006).

Results of the present study also showed a significant high mesozooplankton density occurred at St. 2 (11x10^3 ± 4x10^3 ind.m^{-3}) and St. 3 (15x10^3 ± 5x10^3 ind.m^{-3}) during PostSW monsoon (Figure 4) comes with high Margalef richness index (R') of 2.66±0.0 and 3.30±0.2 nats respectively (Figure 5). Mesozooplankton density at St. 2 and St. 3 were significantly

Table 2: Monsoonal mesozooplankton density (ind.m^{-3}) between 7 sampling stations (n=21) and analysis of variance (ANOVA, Tukey's post-hoc) in Bidong Archipelago. Values are mean ± SD from 7 stations. -, absent; *, *p<0.05*; **, *p<0.01*; *ns*, not significant

Phylum	PreSW	SW	PostSW	PreNE	NE	Post NE	*p*	Tukey's posthoc
Arthropoda (Crustacea)	585±204	2026±50	4201±158	1061±363	2075±648	994±275	*ns*	-
Copepoda	561±195	1937±50	3577±137	801±298	1894±600	950±250	*ns*	-
Copepodite	267±112	617±173	1184±511	259±135	622±253	304±100	*ns*	-
Calanoida	130±63	486±193	774±312	204±65	263±140	225±74	*ns*	-
Cyclopoida	30±29	155±76	236±111	132±47	392±179	155±66	*	PreSW-NE*
Poecilostomat	116±48	560±128	802±311	163±82	508±266	168±64	*ns*	-
Harpacticoida	5±8	19±21	109±78	7±8	25±35	37±27	**	PreSW-PostSW**, SW-PostSW**, PostSW-PreNE**, PostSE-NE*, PostSW-PostNE*
Nauplii	13±17	100±60	472±221	35±19	85±79	61±32	**	PreSW-PostSW**, SW-PostSW**, PostSW-PreNE**, PostSW-NE**,PostSW-PostNE**
Malacostraca	19±16	50±24	287±132	13±8	41±40	10±3	**	PreSW-PostSW**, SW-PostSW*, PostSW-PreNE**, PostSW-NE*, PostSW-PostNE**
Branchiopoda	3±5	-	31±49	26±30	-	-	**	-
Ostracoda	-	7±12	34±25	5±5	69±48	7±7	*	PreSW-NE*
Cirripedia	2±4	33±17	273±114	217±45	70±67	27±23	*ns*	-
Mollusca	24±22	147±52	198±96	82±38	55±47	108±52	*ns*	-
Chaetognatha	30±34	82±39	195±138	52±18	198±102	51±35	*ns*	-
Annelida (Polychaeta larvae)	12±16	137±52	280±113	71±48	35±39	39±20	**	PreSW-PostSW**, PostSW-PreNE**, PostSW-NE**,PostSW-PostNE*
Echinodermata	4±5	65±40	239±97	58±23	6±5	7±7	**	PreSW-PostSW**, SW-PostSW**, PostSW-PreNE**, PostSW-NE**, PostSW-PostNE**
Cnidaria (Hydrozoa)	12±16	26±23	41±38	9±10	11±13	16±8	*	PostSW-PreNE*, PostSW-NE*
Chordata	33±25	261±76	302±143	84±63	45±52	131±75	**	PreSW-SW*, PreSW-PostSW*, SW-NE*, PostSW-PreNE*, PostSW-NE*
Others	63±42	41±18	130±67	14±13	10±17	1±1	**	SW-PostSW*, PostSW-PreNE**, PostSW-PostNE**, PostSW-PostNE**

different ($p < 0.05$), also reflecting a similar mesozooplankton bloom onset (Figure 4) and a similar post-hoc significant different density pattern (Table 3). The richness of mesozooplankton at the stations may be influenced by tidal and currents that brought in the community from the surroundings and enrich the food particle phytoplankton (Shamsudin *et al*., 1998; Trigueros & Orive, 2000; Cloern *et al*., 2014) into the stations. Food availability is a noteworthy important locator for mesozooplankton (Takahashi & Uchiyama, 2008). Furthermore, the location of the stations was in the ideal direction of north-eastward wind flows during SW monsoon (Daud & Akhir, 2015). Somehow, the higher density of mesozooplankton in St.3 may cause by lower water turbulence as studied by Maar *et al*. (2003) due to the area is directly protected from SW monsoon wind and currents flow.

Compared to the earlier results, respective St. 1 and St. 5 that faced a direct flow of currents and wind on SW monsoon showed a significant low diversity index (H'= 1.55 ± 0.4 and 1.90 ± 0.2 nats) and low species richness (R'= 0.76 ± 0.3 and 0.92 ± 0.2 nats) during the PostSW monsoon (Figure 5). Those stations also showed a similar fluctuation pattern throughout the monsoonal distribution (Figure 4) although their evenness index was found respectively high (0.77 ± 0.1 and 0.88 ± 0.0; Figure 5). This biodiversity pattern may be closely related to predation pressure (Chicharo & Chicharo, 2000). It is believed to greatly influence zooplankton species composition and abundance especially due to high availability of planktivorous fish in the area due to the presence of mariculture activity. Planktivorous fish eat and remove larger size zooplankton from the community due to their easily spotted size (Badosa *et al*., 2007). Therefore, we expect that the stations would also be an important nursery grounds for the small fishes and other invertebrates

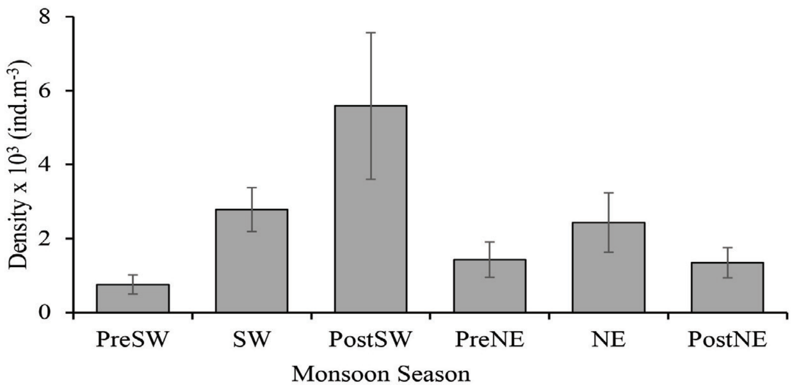

Figure 3: Density of mesozooplankton (ind.m^{-3}) at different sampling seasons in Bidong Archipelago from May 2014 to March 2015. Values are mean ±SD from all stations including replicates

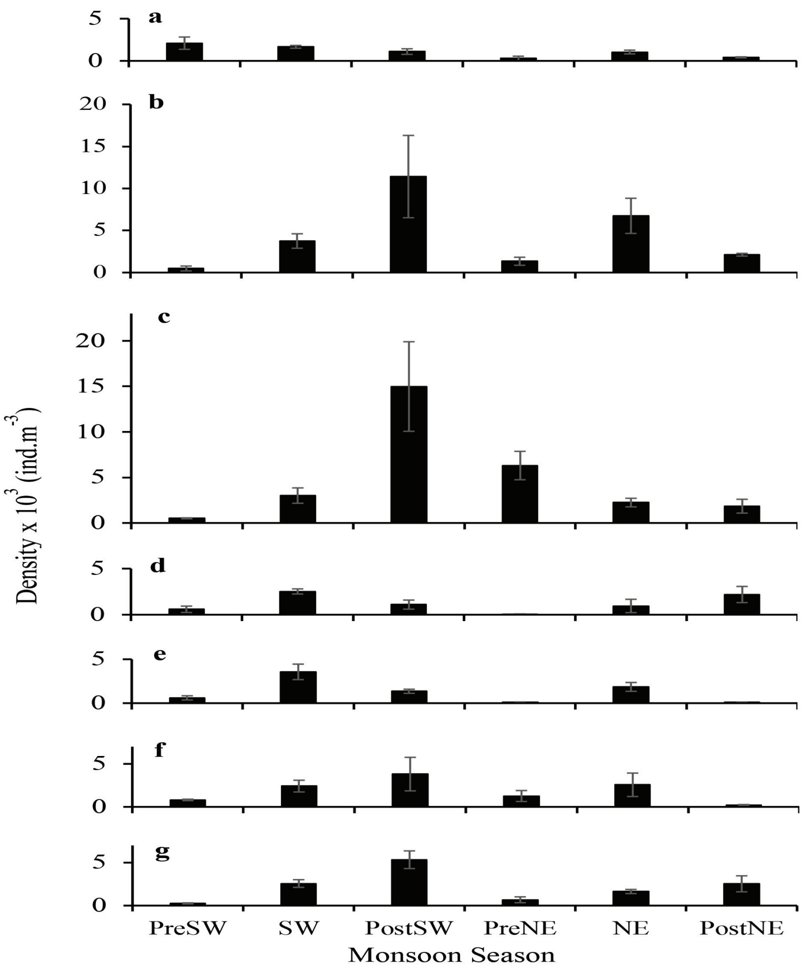

Figure 4: Temporal distribution of mesozooplankton at (a) St. 1, (b) St. 2, (c) St. 3, (d) St. 4, (e) St. 5, (f) St. 6, and (g) St. 7. Value in mean density ± SD; n=3

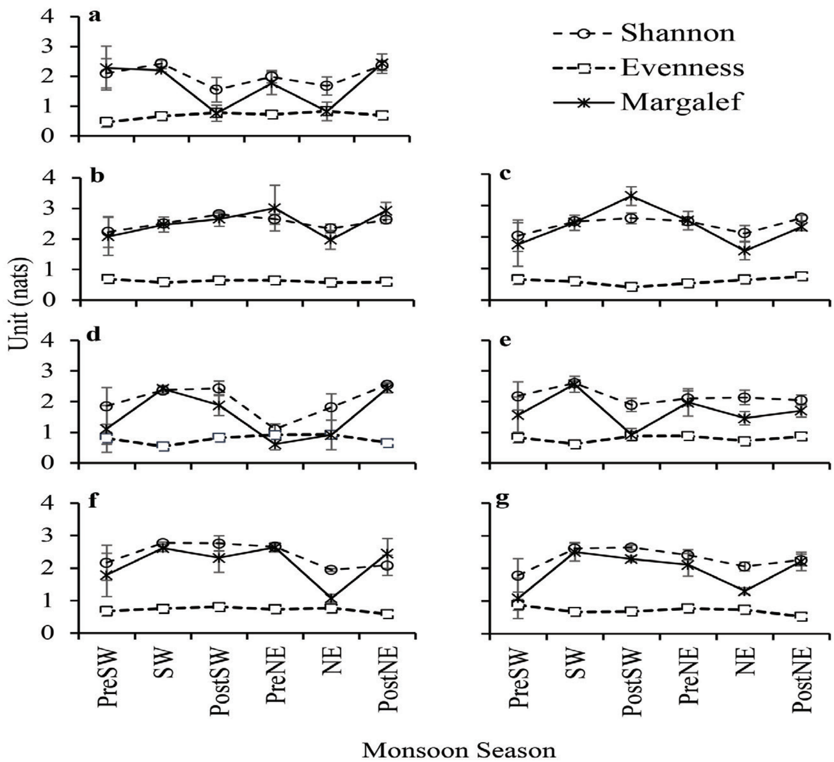

Figure 5: Mesozooplankton diversity indices at (a) St. 1, (b) St. 2, (c) St. 3, (d) St. 4, (e) St. 5, (f) St. 6, and (g) St. 7. Nats are natural digits used for diversity index using lne in calculation; n=3).

Table 3: Significance level from posthoc Tukey and ANOVA (one-way) analysis for monsoonal mesozooplankton density. -, absent; * p<0.05; ** p<0.01; ns, not significant

Station	*p*	Post-hoc Tukey
St.1	*ns*	-
St.2	**	PreSW vs PostSW**, SW vs PostSW*, PostSWvs PreNE**, PostSWvs PostNE**
St.3	**	PreSW vs PstSW**, SW vs PostSW**, PostSW vs PreNE**, PostSW vs PostNE**
St.4	**	PreSW vs SW*, SW vs PreNE**, PreNE vs PostNE*
St.5	**	PreSW vs SW**, SW vs PreNE**, SW vs PostNE**
St.6	**	PreSW vs PostSW**, SW vs PreNE**, SW vs PostNE**
St.7	**	SW vs PostSW**, PostSW vs PreNE**, PostSW vs NE*

Conclusion

The ecosystem of coral reefs in Bidong Archipelago consisted of diverse mesozooplankton community, which reached its seasonal peak density during post-southwest monsoon. However, community diversity is bound to be influenced by monsoon characteristics to the sampling station.

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