Jurnal Riset Biologi dan Aplikasinya, Volume 5, Issue 2, September 2023

Jurnal Riset Biologi dan Aplikasinya
https://journal.unesa.ac.id/index.php/risetbiologi

Effect of Water Circulation on the Distribution of Zooplankton in the Southern Waters of Peninsular Malaysia

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Article History

Received	:	26 March 2023
Revised	:	15 August 2023
Accepted	:	18 September 2023
Published	:	30 September 2023

Keywords

Distribution, zooplankton, monsoon, Peninsular Malaysia

ABSTRACT

The waters of Peninsular Malaysia located between the South China Sea and the Straits of Malacca are greatly influenced by two different monsoons: the Southwest Monsoon (SW) and the Northeast Monsoon (NE). Zooplankton are known to be receptive to any environmental changes. Apart from biotic and abiotic changes, the movement of water currents also has an impact on the distribution and composition of zooplankton, as this group is considered a passive swimmer that is dependent on the movement of water currents. This study was conducted to determine the effect of water movement in the southern waters of Peninsular Malaysia on the distribution of zooplankton. Sampling was done in three main areas: Kukup, Pengerang, and Pulau Besar. A total of 16 stations with three replicates per station were performed using a plankton net with a mesh size of 140µm. Results show that zooplankton in Pengerang recorded the highest with 256.157 ind/ m^3, followed by Kukup (132.412 ind/m^3) and Pulau Besar (54.066 ind/m^3). There were seven dominant species of copepods recorded in this study, namely *Acrocalanus gracilis*, *Bestiolona similis*, *Euterpina acutifrons*, *Oithona nana*, *Oithona similis*, *Paracalanus aculeatus*, and *Paracalanus denudatus*. Generally, this study has shown a notable relationship between local current circulation patterns and zooplankton distribution.

How to cite: Shafie, B.B., Juneng, L. & Rahim, A.A. (2023). Effect of Water Circulation to the Distribution of Zooplankton in the Southern Waters of Peninsular Malaysia.*Jurnal Riset Biologi dan Aplikasinya*, 5(2):70-78. DOI: 10.26740/jrba.v5n2.p.70-78

INTRODUCTION

A tropical region that experiences hot and humid conditions throughout the year, Peninsular Malaysia is located at coordinates from 99°N to 105°N and 1°N to 7°N between the South China Sea (on the east coast) and the Straits of Malacca along the west coast (Yaacob, 2007). In general, there are two monsoons that affect the climate of the Peninsular Malaysian waters, namely the southwest monsoon (SW) and the northeast monsoon (NE). The NE monsoon brings heavy rain throughout November to March, while the SW monsoon is usually drier and brings little rain (May to September). The transition time between monsoons is known as intermonsoon which happens at the end of March to May and October to November (Schmoker et al., 2014). The wind direction varies according to the monsoon season. In the NE monsoon, the wind is stronger than in the SE monsoon. This results in a faster circulation of surface water currents in the NE monsoon than in the SW. The undercurrent water flow during the NE monsoon that flows from the Andaman Sea to the Straits of Malacca causes the occurrence of upwelling (Uktolseya, 1988). According to Rezai et al. (2009), the monsoon has a close relationship with changes in the distribution and abundance of zooplankton.

Plankton is interpreted as animals and plants that live freely in the water column and are divided into two main types, which are phytoplankton and zooplankton (Newell, 1963; Gibsons, 1999). Zooplankton are defined as organisms that drift in the water column with limited mobility (Newell, 1963), no or limited swimming ability (Alcaraz & Calbet 2009), and no ability to move horizontally against the current (Gibbons 1999). Because of that, the movement of water affects the distribution of zooplankton, especially during strong winds, since zooplankton are passive swimmers (George & Winfield, 2000). This is also discussed by Laily and Azman (2017), where the distribution of organisms, especially zooplankton, in the ocean is influenced by the NE monsoon and SW monsoon.

Zooplankton communities, especially those in tropical and sub-tropical regions, are characterized by high diversity, complex trophic networks, and small biomass changes throughout the year. In the tropics, the issue of seasonal changes is not significant, resulting in lower population dynamics. Therefore, the zooplankton population is also more stable (Twombly, 1983). Relatively large zooplankton are found in tropical waters but are in the surface layer of the water and have a low mass and jelly-like consistency, while organisms with a heavier mass, such as euphausids, are found more in deeper depths and colder layers (Raymont 1980). Currently, there are about 5700 identified holoplankton metazoan species, with an estimated additional 1600 species yet to be found and/or recorded (Bucklin et al. 2021). Southeast Asian waters contain more than 550 species of copepods, which comprise a quarter of the world's copepod species. In Malaysia, there are 256 copepod species that have been listed (Balqiah & Azman, 2021).

The movement of water evidently affects the distribution of zooplankton, especially during strong winds (George & Winfield, 2000), and Ekman (1953) also discusses the distribution of zooplankton that is caused by geographical conditions. The spatial distribution of organisms in the ocean (from as small as zooplankton to as large as predators) is largely influenced by the interaction of the organism itself with the physical structure and processes of oceanographic conditions (McManus & Woodson 2012). Therefore, apart from determining which sea current factors affect the distribution of zooplankton, this study also determines the differences in zooplankton composition in the southern waters of Peninsular Malaysia.

MATERIALS AND METHODS

Study area

Zooplankton samples were taken at three areas; 1) Kukup, 2) Pengerang, and 3) Pulau Besar (Figure 1). A total of 16 sampling stations were selected for this study, with 6 stations at Kukup and Pengerang and 4 sampling stations at Pulau Besar. Samples were collected by vertical hauls through the whole water column with 140 µm mesh plankton net and samples were then fixed in a 4% formalin-seawater solution for morphological examination. Samples taken at Kukup were taken in March 2020 during the Northest Monsoon, while Pengerang and Pulau Besar were both taken during the Southwest Monsoon in October 2020 and 2021, respectively. Sorting and identification were conducted using a Leica D EZ4 dissecting microscope. Temperature and salinity in the surface water were measured using a multiparameter water quality meter (Aquaread water monitoring system –AP-2000).

Data analysis

The Shannon-Wiener index, Pielou index, Simpson index, and Margalef index were calculated using the PAST 3.20 software. This study applied both univariate and multivariate statistical analyses, using MINITAB 2.0. The normality test, Levene's test, the ANOVA test, and the Kruskal-Wallis's test were the four tests used in the univariate approach. Multivariate analysis was used to get the Bray-Curtis cluster results and the nMDS (non-metric multidimensional scaling) results, which show the relationship between the stations in a single sampling area. This study was also using two statistical analyses (univariate and multivariate) analyzed by MINITAB 2.0. The univariate method uses four tests, the normality test, Levene's test, ANOVA test and Kruskal-Wallis's test. Multivariate analysis used to give result for Bray Curtis cluster and nMDS (non-Metric Multidimensional Scaling) to see the relationship between stations in one sampling area. The, chlorophyll-*a* wavelengths were analyzed by spectrophotometer, and chlorophyll-*a* concentrations were measured with the fluorometric method (Parsons et al., 1984).

Monthly water movement data is taken from HYCOM (Global Hybrid Coordinate Ocean Model) and analyzed using VMware Workstation software starting from January 2019 until January 2022. HYCOM is an oceanographic model that provides forecasts for several parameters such as salinity, sea surface temperature, and seawater circulation current.

RESULT AND DISCUSSION

Figure 2 shows the comparison of chlorophyll-*a* concentration reading and an average of in situ

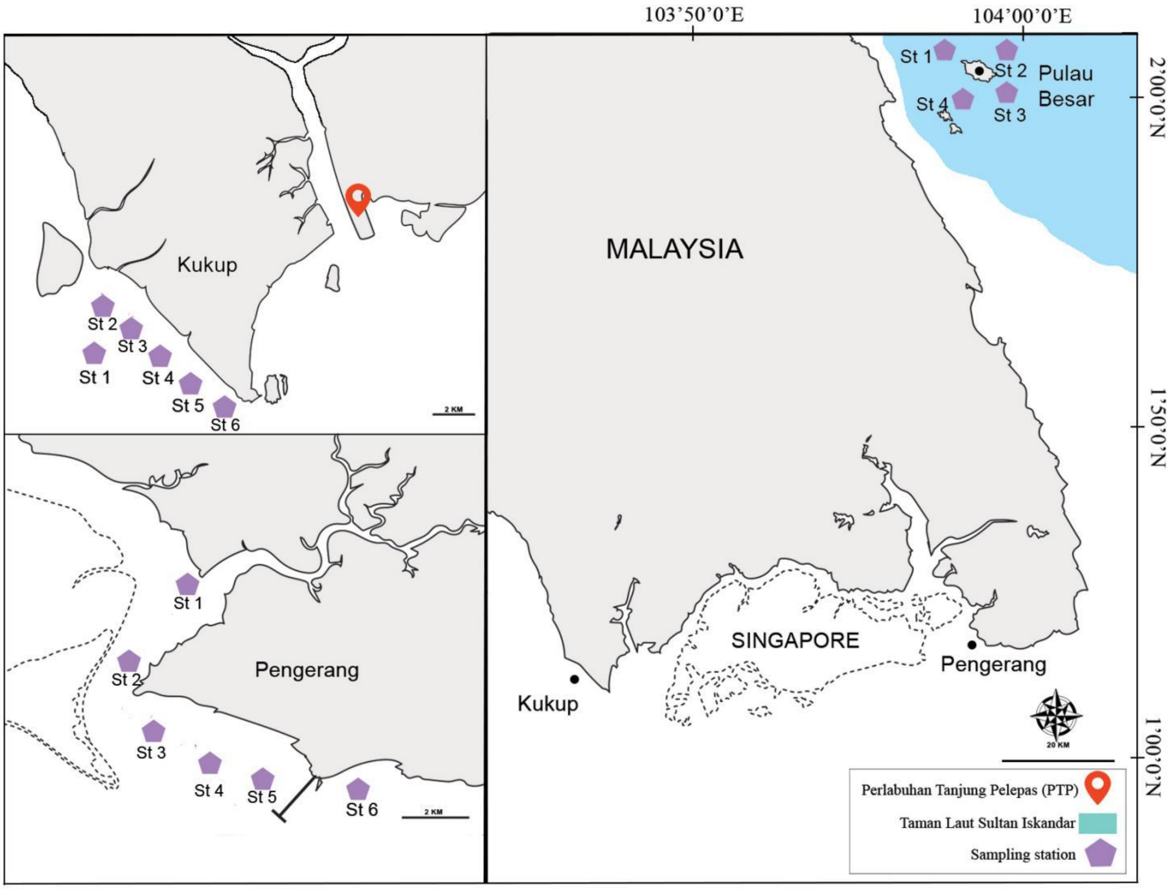

Figure 1. Sampling stations at each sampling area at waters of Kukup, Pengerang and Pulau Besar

values in the 3 study areas. Overall, Pengerang has the highest chlorophyll-*a* concentration reading of 26µg/L, while Kukup recorded the lowest reading at 14.4 µg/L and Pulau Besar with 23.08µg/L.

phytoplankton is the main producer in the food chain and a source of food for zooplankton, the presence of chlorophyll-*a* in the ocean is an indication of the presence of phytoplankton; hence, chlorophyll-*a* concentrations can influence the quantity of zooplankton (Sachoemar & Hendiarti, 2011). According to Chew's (2012) research, places with mangroves and areas close to the coast have higher chlorophyll-*a* concentrations than offshore areas. Pengerang has the highest level of chlorophyll-*a* due to its proximity to mangroves, followed by Pulau Besar and Kukup.

The study by Muthurajah et al. (2021) also revealed that there is a high concentration of chlorophyll-*a* from March to May and from October to November. According to Hashim et al. (2011) and Shaari & Ahmad Mustapha (2017)'s remote sensing study findings, the concentration of chlorophyll-*a* is higher during the SW monsoon than NE monsoon. The findings of this study are supported by earlier research, where high chlorophyll-*a* concentration readings were recorded in Pengerang followed by Pulau Besar where sampling was carried out during the SW monsoon (October). Pulau Kukup, located on the west coast recorded the lowest where sampling was carried out in March during the NE monsoon.

The total abundance of zooplankton in Kukup was recorded at as much as 132.412 ind/m^3 and of that 97.215 ind/m^3 were copepods and 35.197 ind/m^3 were non-copepods (Figure 4) with 41 species, 30 genera, 24 families and 3 orders. Order Calanoida was the most abundant with 63% (Figure 3) with 19 species, followed by Cyclopoida with 6 species (20%) and Harpacticoida 17% with 5 species. There were seven dominant copepod species in total in Kukup: namely *Acrocalanus gracilis* (7.935 ind/m^3), *Bestiolina similis* (5.278 ind/m^3), *Euterpina acutifrons* (16.265 ind/m^3), *Paracalanus aculeatus* (13.175 ind/m^3), *Paracalanus denudatus* (7.266 ind/m^3), *Oithona nana* (7.820 ind/m^3) and *Oithona similis* (6.706 ind/m^3).

Pengerang recorded as much as 256.157 ind/m^3 with 227.996 ind/m^3 for copepods and 28.161 ind/m^3 for non-copepods (Figure 4). There

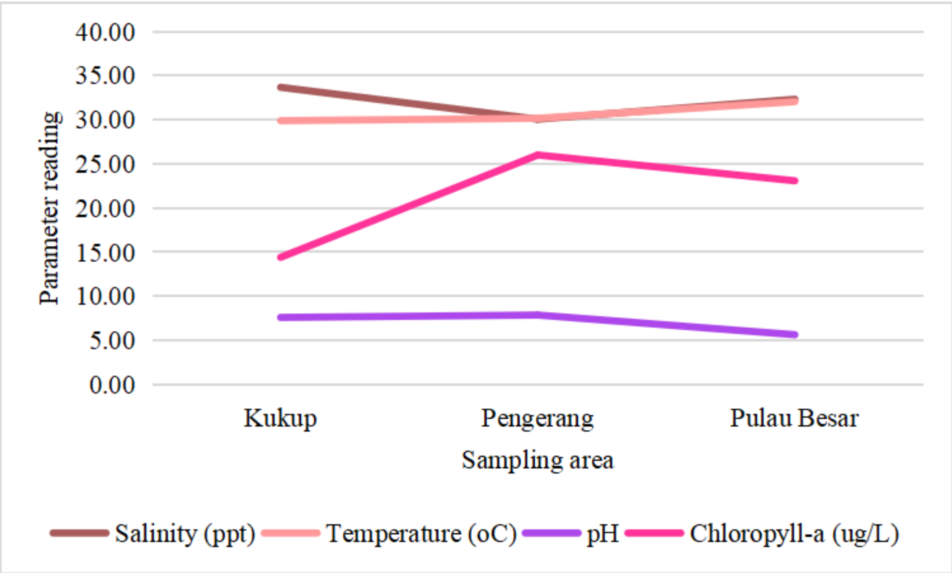

Figure 2. Average reading of in situ parameters at Kukup, Pengerang and Pulau Besar

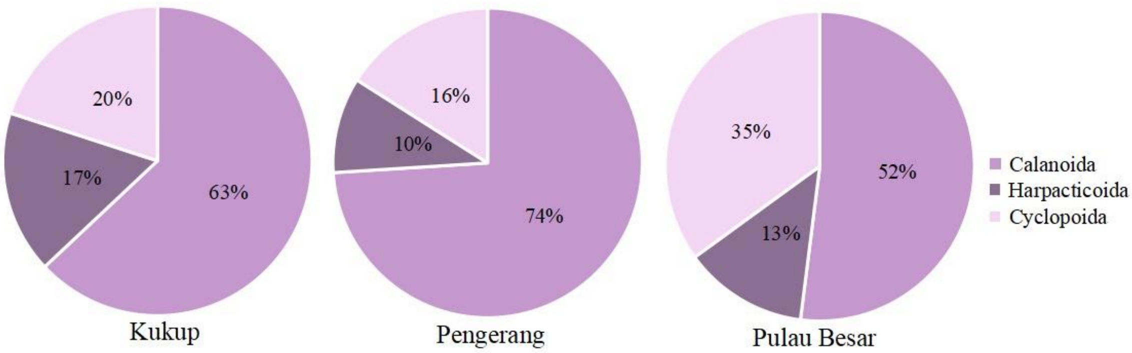

Figure 3. Percentage of three dominant copepod group at Kukup, Pengerang dan Pulau Besar

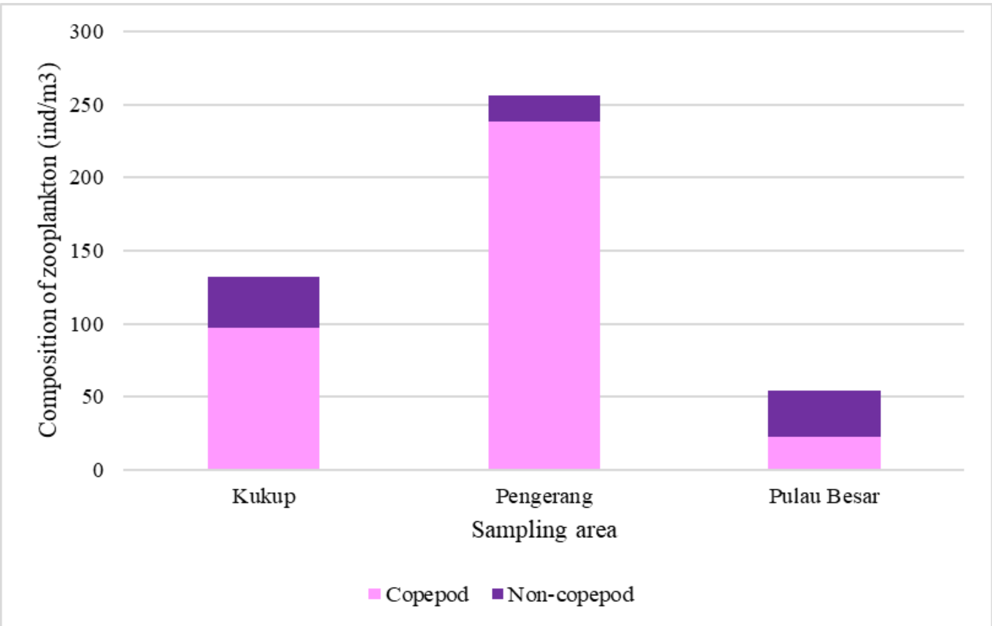

Figure 4. Comparative value of zooplankton abundance (ind/ m^3) and diversity (H') of zooplankton in Kukup, Pengerang and Pulau Besar

were 31 species, 26 genera, 18 families and 3 orders of copepods. Calanoida dominated with 23 species (74%), followed by Cyclopoida with 16% (5 species) and Harpacticoida, 3 species (10%) (Figure 3). The most dominant copepod species were *Acrocalanus gracilis* (24.516 ind/m^3), *Bestiolina similis* (41.702 ind/m^3), *Paracalanus aculeatus* (19.936 ind/m^3), *Paracalanus denudatus* (37.313 ind/m^3), *Oithona nana* (43.725 ind/m^3) and *Oithona similis* (35.756 ind/m^3).

Pulau Besar on the other hand, recorded 54.066 ind/ m^3 of zooplankton abundance, of which 22.713 ind/ m^3 are copepods and 31.353 ind/ m^3 are not copepods (Figure 4). There were 23 species, 16 genera, 12 families and 3 orders listed for copepods. Order Calanoida, has the highest species diversity with a total of 12 species (52%), followed by Cyclopoida with 35% (8 species) and Harpacticoida with 2 species (13%) (Figure 3). There were 4 dominant copepod species, *Acrocalanus gracilis* (2.102 ind/m^3), *Euterpina acutifrons* (2.319 ind/m^3), *Paracalanus aculeatus* (5.887 ind/m^3) and *Oithona similis* (3.349 ind/ m^3).

In all study areas, the variation in zooplankton composition (Figure 4) is evidently influenced by the geographical features, sampling period (monsoons), water quality parameters, as well as physical elements that might influence the dispersal of zooplankton, such as the flow of water currents. The lowest zooplankton composition value in Pulau Besar (54.066 ind/ m^3) was influenced by the conditions during sampling, where heavy rain and strong sea currents were prevalent. Kukup recorded the second highest zooplankton composition value with 132.412 ind/ m^3.

Acrocalanus gracilis, *Bestiolina similis*, *Euterpina acutifrons*, *Oithona nana*, *Oithona similis*, *Paracalanus aculeatus*, and *Paracalanus denudatus* are the seven major copepod species found in this study (Table 1). Based on the checklist from Balqiah & Azman (2021), there are 9 dominant species in Malaysian waters (*Acartia erythraea*, *Acartia pacifica*, *Bestiolina similis*, *Euterpina acutifrons*, *Microsetella norvegica*, *Paracalanus aculeatus*, *Oithona nana*, *Oithona simplex* and *Temora discaudata*) throughout the year and 4 species were recorded in this study (*B. similis*, *E acutifrons*, *P. aculeatus* and *O. nana*). The fact that these tiny copepods are important for biological production in tropical environments explains their great abundance (Yoshida et al. 2006).

The two monsoon seasons involved in this study are the northeast (NE) monsoon during the sampling in Kukup and the southwest (SW)

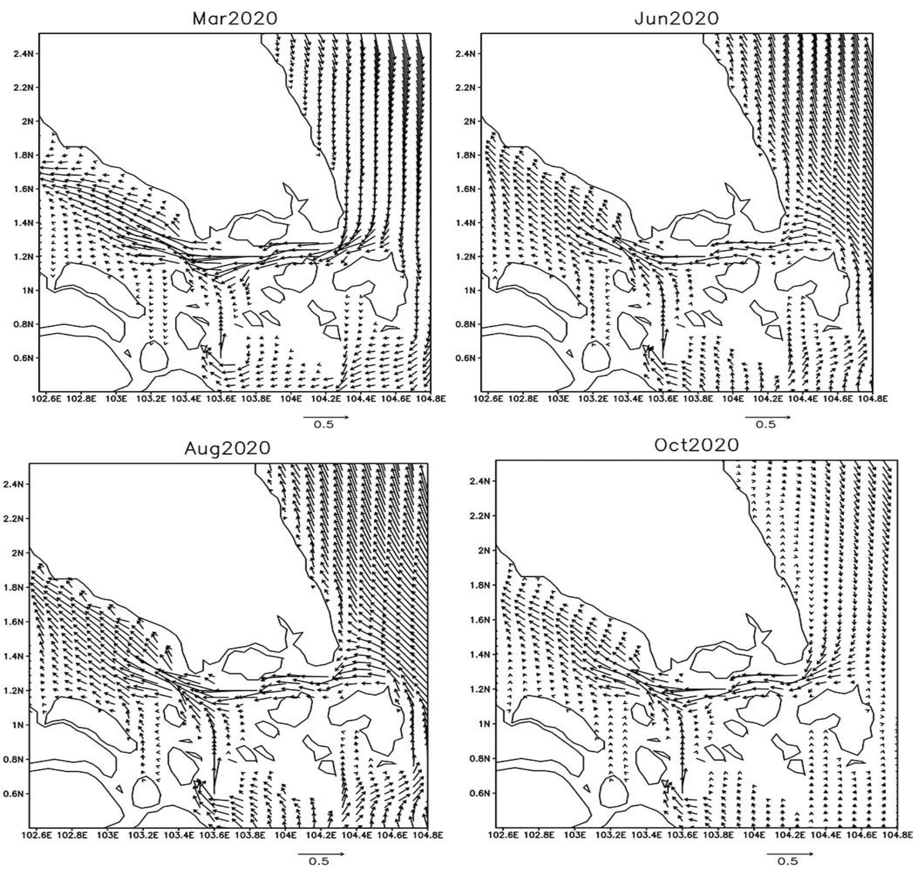

Figure 5. Sea current flow in Peninsular Malaysia's southern waters during the sampling periods at Pengerang and Kukup in March 2020 and October 2020, respectively

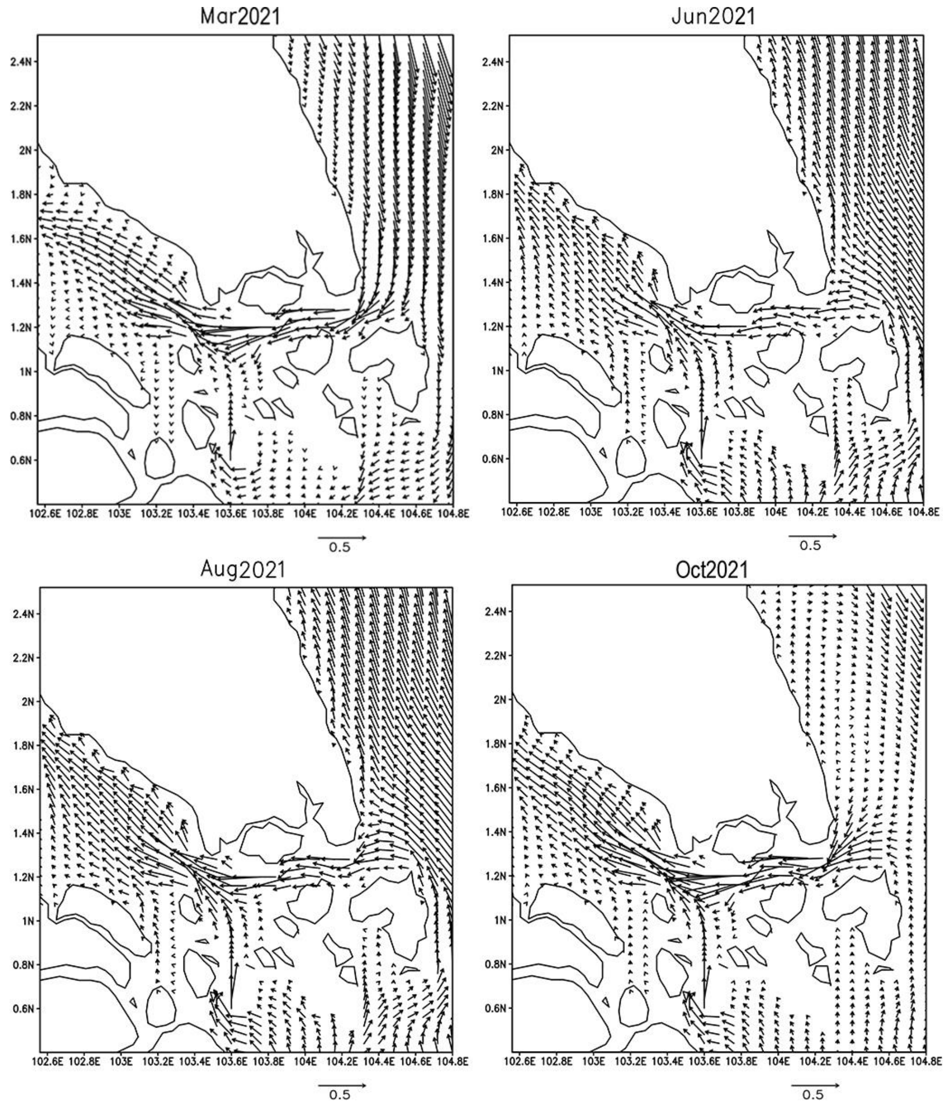

Figure 6. Sea current flow in the southern waters of Peninsular Malaysia during the October 2021 sampling period at Pulau Besar

monsoon during the sampling in Pengerang and Pulau Besar. In contrast, during the NE monsoon, the wind blows steadily from the northeast to the southwest, causing strong waves and intensifying sea currents (Wong,1981). During the SW monsoon, the wind blows strongly towards the north, flowing through the eastern boundary current at a speed of 0.6-0.7 ms-1 (Daryabor et al., 2014). The shifting monsoon conditions have a direct impact on changes in environmental parameters and the distribution of zooplankton (Muthurajah et al., 2021).

The water moves in from the South China Sea to the Straits of Malacca through the Straits of Johor and the Straits of Singapore with a maximum speed of 0.5 m/s driven by the NE monsoon winds during sampling in Kukup (Figure 5). Also, the movement of water in the South China Sea appeared quite strong during the sampling of Pengerang and Pulau Besar (Figure 6). Nevertheless, the movement of sea currents in the Johor Strait seems to be moving quite fast. Nakajima et al. (2015) noted that the wind speed in December to March is always more than 10 m/s, while, relatively calm <10 m/s in other months. This is due to heavy rain during the SW monsoon period and less sunlight due to increased cloud formation. Therefore, the temperature of the sea surface is decreasing while at the same time causing an increase in wind speed and the movement of seawater currents (Mohd Akhir et al., 2014).

Based on Figure 5, water currents flow from the South China Sea (SCS) to the Malacca Strait from east to west during the Kukup sampling period. The outcome (Figure 7) shows that the same species is present but less numerous. Rezai et al. (2004) mention that the Malacca Strait's unstable

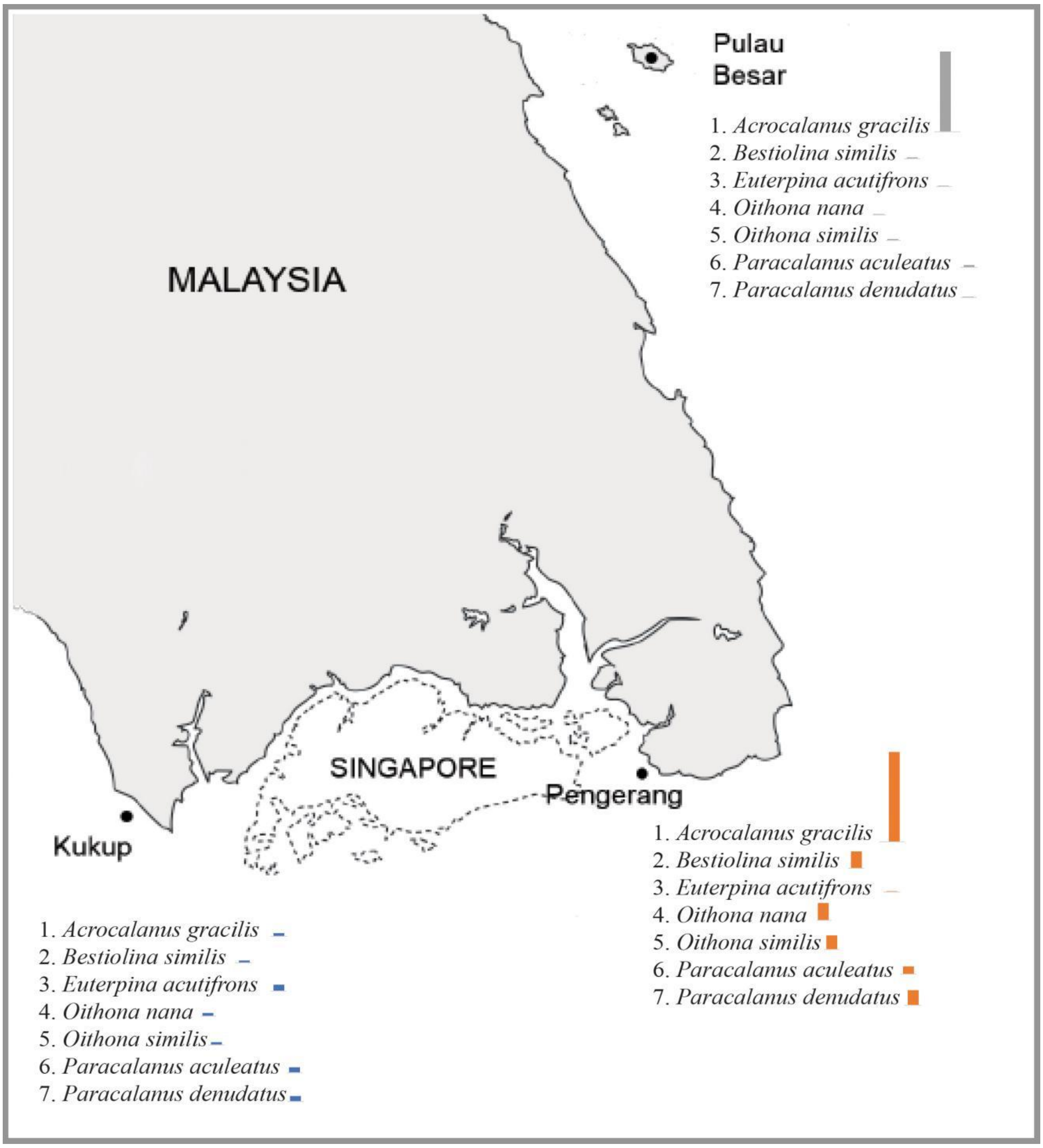

Figure 7. Comparison of composition of zooplankton of 7 dominant species at Kukup, Pengerang and Pulau Besar

Table 1. Composition of dominant zooplankton species at the three study areas

Species	Kukup	Pengerang	Pulau Besar
Acrocalanus gracilis	7.935	224.516	201.2
Bestiolina similis	5.278	41.702	1.481
Euterpina acutifrons	16.265	2.001	2.319
Paracalanus aculeautus	13.175	19.936	5.887
Paracalanus denudatus	7.266	37.312	0.216
Oithana nana	7.82	43.725	1.88
Oithona similis	6.706	35.756	3.349

environmental situation is caused by the high salinity and poor water quality.

The southern region of the Malacca Strait recorded a lower distribution of zooplankton. On the other hand, since there were no physical barriers separating Pulau Besar from Pengerang, the zooplankton's composition was relatively higher. Pengerang also serves as a nursery since the mangrove-covered estuary there is an ideal location for breeding. Additionally, Figure 6 shows high-water flow from the Singapore Straits into the SCS in October 2021.

According to Arinardi et al. (1984), the range of zooplankton composition values is from 380 ind/m^3 to 500 ind/m^3 during the NE monsoon, whereas it is higher during the SW monsoon, from 670 ind/m^3 up to 840 ind/m^3. Rezai et al. (2004) research in the Malacca Strait found that the maximum mean composition value for copepods was 2927±1085 ind/m^3, and the minimum composition value was 2238±890 ind/m^3 during the NE monsoon. During the transition period from the NE monsoon to the SW monsoon, there are few zooplankton species recorded. According to Yoshida et al. (2006), zooplankton abundance peaks at the beginning of each monsoon season and then steadily decreases over the intermonsoon.

Acartia erythraea, *Acrocalanus gracilis*, and *Bestiolina similis* are species that typically occur in August and October and are missing or less numerous in February and June (Nakajima et al. 2015). *A. erythraea* (0.2797 ind/m^3), *A. gracilis* (5.599 ind/m^3), and *B. similis* (3.724 ind/m^3) were all less abundant in Kukup than they were in Pengerang, where they were respectively recorded at 1.5642 ind/m^3, 17.299 ind/m^3, and 29.425 ind/m^3. This indicates that water circulation does influence zooplankton abundance and distribution. The main zooplankton species were collected from each sampling site, albeit the species composition varied since wind dynamics might have an effect.

In all three study regions, the circulation of regional sea currents clearly affects the diversity and composition of zooplankton. Further studies on the occurrence of certain species along the Strait of Johor also need to be conducted to better understand the physical influences on the movement of zooplankton. Since zooplankton are known to be sensitive to ambient biotic changes, one of their functions is as an indicator of ecosystem health. The composition of zooplankton in the ocean may vary in response to biotic and abiotic variables, including wind dynamics and water temperature. Four prominent zooplankton species were identified in this study: *B. similis*, *E. acutifrons*, *P. aculeatus*, and *O. nana*. The presence of these copepod species has also been recorded by Balqiah & Azman (2021) in the waters of Peninsular Malaysia, demonstrating the ecological stability of our waters. As a result, it is anticipated that the composition, abundance and distribution of zooplankton in the study areas will be influenced by the wind-driven forces. Additionally, with the recent reporting of *Centropages tenuiremis* (Hamdan & Azman, 2023) from Kukup, this present study would provide a better understanding of the occurrence of this invasive species and its ecological role that could impact their new ecosystem.

CONCLUSION

The distribution of zooplankton is also impacted by climate change, which increases ocean temperatures, eutrophication-causing nutrients, and acidification. These zooplankton organisms are continually impacted and must adapt to environmental changes, and as a result are negatively altered by the phenomenon of climate change. These changes can directly disrupt the food chain in the marine ecosystem.

ACKNOWLEDGMENT

This research was funded by research grant FRGS/1/2019/WAB13/UKM/02/3. Appreciation is also directed to the Malaysian Marine Department and the Johor National Park Corporation.

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