Distribution and diversity of gelatinous zooplankton in the southern South China Sea

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Abstract. Although gelatinous zooplankton are widely distributed in many ocean ecosystems, they have been understudied due to their fragility nature, difficulties to sample or handle and a lack of expertise. This study gives an insight into the distribution and diversity of gelatinous species in the Southern South China Sea. Species composition, distribution and abundance of gelatinous zooplankton were investigated along the East Coast of Peninsular Malaysia. A total of 37 species were recorded from 10 locations along 4 transects at 5.10° N and 6.80° N extending from 103.2° E to 105.3° E in August 2016. Seven medusae, six siphonophores, four appendicularians, six chaetognaths, six salps, four doliolids and four pteropods were identified from the study area. Appendicularia with 201 ind/m³ was found to be the most dominant taxa recorded, followed by chaetognaths with 197 ind/m³. Scyphomedusae were the least represented group in the study, with an abundance of 8 ind/m³. Stations near the inshore region show higher abundance and diversity of gelatinous zooplankton compared to offshore regions. The evenness index between stations revealed that the gelatinous zooplankton were evenly distributed. According to Principal Component Analysis (PCA), the diversity and distribution of gelatinous zooplankton are driven by depth and temperature.

Keywords: East Coast Peninsular Malaysia, gelatinous zooplankton, South China Sea

1. Introduction
Gelatinous zooplankton (GZ) is characterised by delicate, transparent, and fragile bodies without a hard skeleton or thick muscles. They are also defined by their high percentage of water in their tissue (>90%), large surface area relative to organic contents and also weak swimmers that passively drift with the water current [1].

GZ comprises diverse marine organisms, including medusae, siphonophores, appendicularians, chaetognaths, pteropods, salps, and doliolids. They represent one of the driving forces of marine ecosystems [2], as their components undergo seasonal pulses in response to favourable conditions and produce biomass rapidly that can sustain the marine pelagic food webs [3-4] and increase deep carbon transfer efficiently [5-6]. Hence, they play an important role in marine trophic webs and structuring coastal and estuarine ecosystems [7].

Understanding the spatial and temporal variability of the GZ provides good insight into the environmental processes affecting them in terms of ecological, physiological, survival and reproductive cycle [8]. There are many factors that can affect the species composition, abundance, distribution and diversity of GZ. Physico-chemical parameters are one of the sources of variations affecting the distribution pattern of GZ. According to [2], the distribution of GZ was determined by environmental factors such as temperature, salinity, Chl-a and nutrients. Changes in environmental parameters will affect the distribution of zooplankton.
Although GZ are found in all of the oceans of the world, they are the least understood compared to other planktonic groups [9]. Despite their ecological importance and bloom events, GZ were neglected in ecological surveys, possibly due to their fragile nature and inadequate sampling technology [10], making them poorly understood. Hence, our general knowledge about GZ is scarce. In this study, we investigate GZ species composition, distribution and abundance along the east coast of Peninsular Malaysia and compare the diversity of the GZ in the nearshore and offshore regions.

2. Materials and methods
Peninsular Malaysia is located in the southern region of the South China Sea, attached to the shallow Sunda Shelf, with a maximum depth of 100 m. Malaysia faces two monsoon wind seasons, the Southwest monsoon from late May to September and the Northeast monsoon from October to March.

The sampling was carried out during the Southwest Monsoon of Ekspedisi Pelayaran saintifik Kebangsaan (EPSK) cruise in August 2016. Following the cruise designated sampling locations, the samples were collected by the RV Discovery from 10 stations along four transect lines, Line 5.10° N and 6.80° N extending from 103.2° E to 105.3° E (Figure 1). The stations can be categorised as inshore and offshore regions.

![Figure 1. The study area.](image)

2.1. Field sampling
GZ samples were collected using a Bongo net of 100μm mesh size with a mouth area of 0.5 m, which was hauled vertically through the water from 5 m above the bottom to the surface. The samples were fixed in 4% buffered formaldehyde for further laboratory analysis.

A conductivity, temperature and depth (CTD) instrument was used to measure environmental variables including salinity, temperature, oxygen and turbidity at each sampling site. The data were
recorded for each meter throughout the water column and stored in the internal memory of the instruments. These data were transmitted with a cable to a computer and post-processing program.

2.2. Sample analysis
In the laboratory, the samples were split with a plankton splitter called Motoda box [11] that contained two compartments. The samples were split into two halves. The fraction of zooplankton was counted and used for the calculation of the abundance of GZ per cubic meter.

Then, the split samples were put into sample containers and were preserved in 70% ethanol. The samples were identified under a dissecting microscope and sorted based on their groups. After that, the GZ were enumerated by viewing the specimen in the Bogorov tray under the dissecting microscope. All GZ were identified down to species or lowest possible taxon [12-14].

The abundances of gelatinous zooplankton as number per m³ were based on the formula:

\[ \text{Gelatinous zooplankton abundance (ind.}/\text{m}^3) = \frac{N}{V} \] (1)

where:
- \( N \) = number of the gelatinous zooplankton individual
- \( V \) = volume of water passed through the plankton net (m³)

\[ V = \pi r^2 D \] (2)

where:
- \( r \) = radius of Bongo net (m)
- \( D \) = depth of Bongo net hauled (m)

Diversity index was based on Shannon-Wiener index [15] were used to investigate the changes in the diversity of the GZ with the following formula:

\[ H = -\sum (pi) * \ln(pi) \] (3)

where:
- \( SUM \) = Summation
- \( pi \) = Number of individuals of species i/total number of samples

2.2.1. Statistical analyses. Map of location was produced using ArcGIS. Multivariate statistical analyses were performed using PRIMER version 6 and SPSS [16]. PRIMER 6 analysed the distributions of GZ in relation to environmental variables and sampling sites. Principal Components Analysis (PCA) was used to examine the relationships between four variables and the sampling sites where GZ were recorded. The Shannon-Wiener index and evenness were used to investigate the changes in the diversity of the GZ.

3. Results

3.1. Vertical distribution of CTD measurements
Figure 2 and Figure 3 show the temperature, salinity and dissolved oxygen (DO) distribution across the shelf of transects 1, 2, 3 and 4. At transect 1, the temperature at offshore regions (SM6) is warmer than inshore regions (SM2), while salinity and DO at SM2 is higher than SM6. Details on the depth of sampling stations were recorded (Table 1). There was a sign of the rise of thermocline, halocline and oxycline towards the inshore that reached up to 10m water depth. At transect 2, the temperature, salinity and dissolved oxygen are significantly different from the surface to the bottom layer of the water column near to inshore (SM8). This trend is different from offshore regions (SM12 and SM13). In addition, the thermocline, halocline and oxycline uplifting only reached 20 m water depth.

Transect 3 shows a similar trend to transect 2 where the temperature, salinity, and dissolved oxygen are significantly different from the surface to the bottom layer of the water column near the inshore (SM19 and 20). Moreover, the thermocline, halocline and oxycline uplifting towards the inshore were
also noted to have reached the 10 m water depth. Lastly, at transect 4, stratification was noted at the nearshore station (SM26), while the offshore station (SM30) was classified with well-mixed characteristics.

![Temperature, salinity, and DO depth profiles of Transect 1 and 2.](image)

**Figure 2.** Temperature, salinity, and DO depth profiles of Transect 1 and 2.

**Table 1.** Details on the depth of sampling stations.

| Stations | Depth (m) |
|----------|-----------|
| SM2      | 55        |
| SM6      | 59        |
| SM8      | 54        |
| SM12     | 64        |
| SM13     | 60        |
| SM19     | 51        |
| SM20     | 57        |
| SM25     | 64        |
| SM26     | 42        |
| SM30     | 70        |
3.2. Species composition, abundance and diversity of GZ

Altogether, 37 taxa of GZ were identified. There were seven medusae, six siphonophores, four appendicularians, six chaetognaths, six salps, four doliolids and four pteropods. The highest number of species was recorded at SM2 of transect 1 (28 species), while the least number of species (13 species) were recorded in SM30 (transect 4).

Generally, the abundance of GZ at inshore areas decreased in numbers from offshore (Figure 4), except for transect 2. Transect 4 recorded the highest abundance of GZ with 106 ind/m³ at SM26 and the lowest abundance of GZ at SM30, 15 ind/m³.

The top two abundant groups recorded in the study were appendicularia and chaetognath, with 201 ind/m³ and 197 ind/m³, respectively. The widely distributed appendicularia and chaetognath comprised 16-53% and 19-67% of total abundance, respectively (Figure 5). Scyphomedusae were the least represented and rarely distributed, with the number of abundances ranging from 1-6 ind/m³ and occurring at only four stations (SM2, SM6, SM8 and SM26).

The Shannon-Wiener diversity and evenness are shown in Figure 6. The Shannon-Wiener index varied between 1.80 and 2.85, and the evenness index ranged from 0.62 to 0.82 throughout all stations. The highest value of the diversity index was recorded in SM2, while the lowest was recorded in SM25. The highest evenness index was recorded in SM20, while the lowest was in SM25.
**Figure 4.** Total abundance of GZ at four transects.

**Figure 5.** Percentage abundance of GZ group in the study area.
3.2.1. Statistical analyses. Principal Component Analysis (PCA) was used to examine the relationships between the sampling sites and the four environmental variables: temperature, salinity, dissolved oxygen and depth (Table 1). According to the PCA (Figure 7), the top two drivers of GZ abundance in ECPM were depth and temperature. Depth played a major role in driving GZ abundance in sampling sites. Depth has a value of 3.42 and represents 85.5% of the total variability, while temperature has a value of 0.567 and represents 14.2% of the total variability. The third variable was salinity with 0.3%, followed by dissolved oxygen with 0%. 

![Figure 6. Diversity index and evenness of gelatinous zooplankton.](image6)

![Figure 7. PCA shows the relationship between the sampling sites and the environmental variables.](image7)
4. Discussions

Relationships between the distribution and diversity of GZ and environmental parameters in ECPM were examined using the BIOENV (Biology-Environment) procedure of PRIMER, which highlighted that the distribution patterns in ECPM were influenced by variability in environmental parameters.

4.1. Higher abundance of GZ in the nearshore area

Based on the results on the total abundance of GZ, most stations at nearshore show a higher abundance of GZ than the offshore regions. Higher primary production and more food are available nearshores due to high nutrient inputs related to anthropogenic activities [17], leading to a better environment and condition for GZ. This result, also similar to a previous study by [18-19], showed that the highest densities and diversity of GZ were found in the coastal area with higher salinity.

In terms of abundance, appendicularia were the dominant group. Oikopleura spp. and Fritillaria spp. were the most identified species in the study. According to [20], Oikopleura and Fritillaria species are abundant pelagic tunicates in coastal waters. Furthermore, appendicularia shows higher growth rates in response to an increase in food [21]. Likely, appendicularia showed higher abundance at the nearshore stations where more food is available.

Chaetognaths is one of the gelatinous groups that contribute to higher abundance at each station. They are the second most abundant group of zooplankton after copepods and considered as of great and top predators of the pelagic community [22]. This is also possibly due to the vertical hauled sampling method because chaetognath can be found all the way from the surface to the above seafloor, with some species that have special features to live at the bottom of the ocean [23].

Scyphomedusae were found only at the nearshore stations. Coastal protection increases the presence of polyps, which might explain the occurrence of small individuals in the nearshore regions [24]. In terms of group abundance, they were the least group of GZ recorded in this study. This might be due to the larger size of scyphomedusae, and they are in the form of aggregates [25]. Therefore, large Scyphomedusae are more adequately sampled with large net types.

Shannon-Wiener diversity index has been used widely in environmental studies to estimate ecosystems’ species richness and abundance [26]. The diversity is considered to be low if only one or a few species are dominant, followed by rapidly decreasing numbers of other species. Moreover, the high number of taxa recorded in the nearshore stations were related to the high diversity of gelatinous zooplankton due to anthropogenic activities. Additionally, the diversity of gelatinous zooplankton was influenced by physical parameters (Figure 2 and 3). Diversity is usually influenced by natural system function where the physical parameters and ecosystem of species structure determines the diversity value [27].

4.2. Influence of water column depth and primary productivity

In general, water column depth increases as near to the offshore regions. Offshore stations, SM30, have the lowest depth with 70 m depth and show the lowest abundance of GZ. On the other hand, most stations with shallow depth and nearshore show higher abundances of GZ. Indeed, depth plays an important role in determining the distribution and abundances of GZ corresponding with the findings of [28], who illustrated depth might show many of the significant factors contributing to GZ diversity and abundance.

Moreover, the intensity of water column mixing is high in the offshore regions. For instance, SM30 shows well-mixed characteristics in the offshore regions. According to [29], the depth of the water column and the intensity of mixing influence the population dynamics of pelagic primary producers by affecting the average light climate, sedimentation loss, and the availability of nutrients. In other words, under well-mixed conditions, phytoplankton can be found low in the entire water column, and primary production decreases with increasing water column depth [30]. Thus, food availability for GZ in the offshore region is low. Consequently, the abundance of GZ will decrease.

5. Conclusion

This study presents an overview of the GZ distribution and diversity in the ECPM. A total of eight groups of GZ were observed, including appendicularia, chaetognaths, salps, doliolids, hydromedusae,
scyphomedusae, pteropods and siphonophores. We found that the diversity and abundance of gelatinous species can be found higher at stations near inshore regions compared to offshore regions. This was influenced by water column mixing and stratification that might influence the primary productivity in the study area.

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