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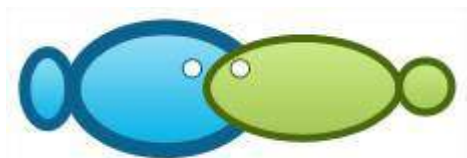


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Abundance and biovolume of gelatinous zooplankton in Inner Ambon Bay during the northwest monsoon 2022

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Abstract. Gelatinous zooplankton (GZ) is a group of zooplankton that consists of various organisms which have a vital role in marine ecosystems. This study aims to investigate the abundance and biovolume of GZ, especially during the northwest monsoon season (February and March) in the inner part of Ambon Bay. Zooplankton samples were obtained using a plankton net, towed vertically. Influences of environmental drivers on abundances and biovolumes were analyzed using the principal component analysis (PCA) loading plot. Approximately 16 genera of zooplankton were found in the inner waters of Ambon Bay, of which *Thalia* sp. was the dominant genus that occurred with highest abundances and biovolume. The range of GZ abundance and biovolume were 0.71 to 106.86 ind m⁻³ and 0.05 to 1262.35 mm³ m⁻³, respectively. Nutrients were found as the driver that governed the GZ community in Ambon Bay waters.

Key Words: diversity, gelatinous zooplankton, Inner Ambon Bay, marine invertebrates.

Introduction. Gelatinous zooplankton (GZ) community is composed by a diverse range of organisms, containing high percentage of water in their tissues (> 90%). This community includes representatives of several phyla of marine invertebrates from grazers (pelagic tunicate) to predators (medusae, siphonophores, and ctenophores) (Madin & Harbison 2001; Diaz Briz et al 2017). The GZ is an abundant group of zooplankton community and has a widespread distribution in coastal and oceanic waters (Palma et al 2014). In the marine realm, GZ has an important role in pelagic food web, providing a vital food source for other organisms such as the leatherback turtle, *Dermochelys coriacea* (Brotz et al 2012), and as a critical component in nutrient cycling in the aquatic food web (Sweetman & Chapman 2015). Under suitable environmental conditions, GZ can grow rapidly and form bloom conditions (Lucas et al 2014). To date, studies of GZ have been focused on the increasing populations in some disturbed areas around the world (Ingram 2015). The composition of gelatinous assemblages can be used to monitor marine environment, specifically because of their rapid responses to the changes of hydrological conditions, which alter their species diversity (Zaldua-Mendizabal et al 2021).

Ambon Bay is a shallow-silled fjord, located in Ambon Island (Eastern Indonesia), which is divided into two parts known as Inner Ambon Bay (IAB) and Outer Ambon Bay

(OAB). OAB has oceanic characteristics since it is directly connected to Banda Sea, while the IAB is a shallow semi-enclosed estuary. A narrow sill in the bay restricts water circulation and flushing from the inner to outer part. Consequently, nutrient enrichment is likely occurred in the IAB, showed by higher concentration of chlorophyll-*a* comparing to the OAB (Basit et al 2015). Increasing population, land clearing and agricultural activities also affect the condition of the waters in IAB (Likumahua 2020). This can be seen during the rainy season, during which high sedimentation through run-offs enters the IAB. High run-offs can cause nutrient enrichment in the IAB. This condition causes several phenomena such as the occurrence of algal blooms (Likumahua 2020) and the degradation of marine ecosystems such as the decline in coral abundance and diversity (Limmon & Marasabessy 2019).

Despite an increasing interest in GZ organisms in the context of climate change, overfishing, and ecosystems alterations, knowledge about their distribution and abundance patterns remain lacking, especially for estuaries such as the IAB. GZ community in Ambon Bay has been observed in previous studies (Mulyadi & Radjab 2015; Mulyadi & Saputra 2019), yet their abundances were calculated generally as zooplankton. Thus, research specifically addressing Ambon Bay's GZ has to be done. In these waters, a swarm of *Thalia sibogae* has also been reported which occurred in 1976 (Troost et al 1976).

In the present study, we analyzed the abundance and biovolume of GZ in the IAB. Objectives of the study were to analyze the composition, abundance and biovolume of GZ in the IAB, and their relationship with environmental factors.

Material and Method

Description of the study sites. The study was performed in IAB, Ambon Island, Moluccas Province of Indonesia. Sampling was carried out on two trips during the northwest monsoon (February and March 2022). Eight stations were selected to cover a wide area of the IAB (Figure 1). This area has several estuaries and is strongly influenced by land activities such as sedimentation especially in rainy season.

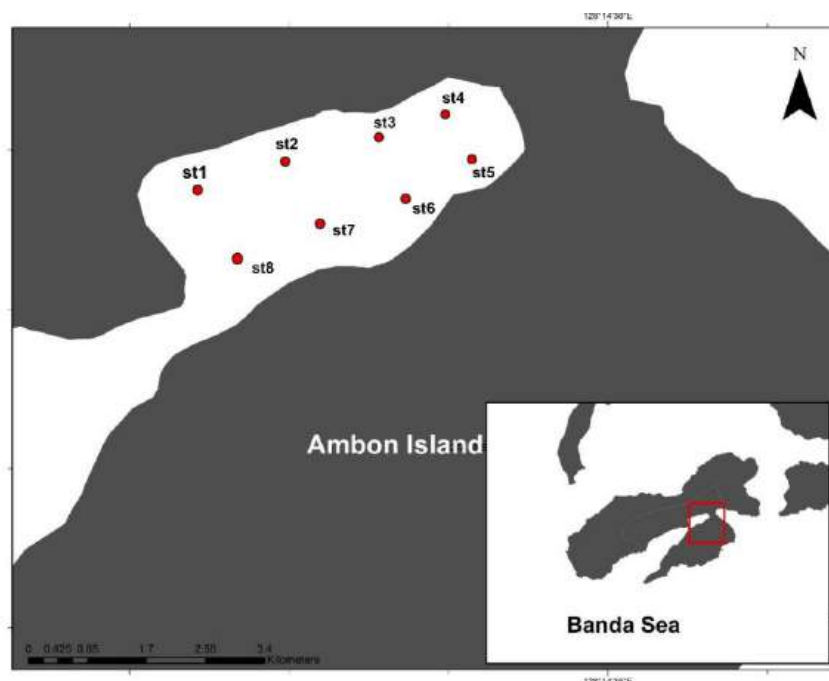


Figure 1. The location of sampling station at Inner Ambon Bay, Ambon Island, Indonesia.

Specimen collection and processing. GZ samples were collected vertically using a plankton net (Ø 30 cm, mesh size 300 µm and length 120 cm) from 10 m depth to the surface. The GZ samples were then placed in a 250 mL sample bottle and preserved using formalin to a final concentration of 4%. Subsequently, sample bottles were placed into an icebox.

The zooplankton samples were observed at the Central Marine Research Laboratory – BRIN. Prior to GZ determinations, zooplankton samples were first sorted to separate gelatinous from other zooplankton groups. The sorted samples were then observed under a microscope (Nikon NMZ150 integrated with Nikon D550 camera) to count group numbers, composition, abundance and to take pictures for individual biovolume calculation (mm^3). Body measurements such as length and diameter were determined using the ImageJ 4.5 software (Schneider et al 2012). The individual biovolume of GZ was calculated by the analogous of geometric models (Ma et al 2014). Taxa morphology identification was determined according to identification key books of Bouillon et al (2006) and Castellani & Edwards (2017).

Abundance, biovolume, and biodiversity index determination. The abundance and biovolume of GZ was computed based on the volume filtered. The abundance (ind m^{-3}) of sample was calculated as follows (Postel et al 2000):

$$N = n.k/V$$

where: N = abundance (ind m^{-3});
 n = the number of zooplankton (ind);
 k = the part of the sample counted;
 V = volume of water filtered (m^3).

The biovolume was calculated as follows:

$$B = b.k/V$$

where: B = biovolume ($\text{mm}^3 \text{ m}^{-3}$);
 b = individual biovolume (mm^3);
 k = the part of the sample counted;
 V = volume of water filtered (m^3).

Diversity index was calculated using the Shanon-Wiener index, as below:

$$H' = -\sum_{i=1}^s P_i \ln P_i$$

where: H' = diversity index
 $P_i = n_i/N$;
 n_i = number of individuals from genus i ;
 N = total number of individuals;
 s = number of genera.

Water quality measurements. Samples of seawater were collected using a 3.5 L Niskin bottle. The Niskin bottle was deployed at two depths: surface (0.3 m) and 10 m. Approximately 350 mL of water samples were placed in labeled black LDPE bottles. Water samples were immediately filtered through a 0.45 μm pore size (47 mm) Whatman nitrocellulose membrane filter using a vacuum pump with a maximum pressure of 0.3 bar and stored at -20°C until analysis. Samples were analyzed using a UV-Visible Spectrophotometer (Shimadzu type 1700 UV-Visible), to measure nitrate (NO_3) and nitrite (NO_2) with a wavelength of 543 nm, phosphate (PO_4) with a wavelength of 885 nm, and silicate with a wavelength of 812 nm according to Strickland & Parsons (1970). Surface temperature was measured using a mercury thermometer and salinity was measured using a hand refractometer.

Statistical analysis. The principal component analysis (PCA) was employed to analyze relationships between environmental parameters and the GZ community using the Minitab version 21. The analysis required the environmental parameters (temperature, salinity, nitrite, silicate, nitrate, and phosphate), considered as independent variables. At the same time, the GZ (abundance, biovolume, and biodiversity index) was classified as dependent variable.

Results

Environmental parameters. The sea surface temperature in IAB during observation ranged from 28 to 32°C with the average of 30°C. The sea surface salinity at the study site ranged from 24 to 30 ppt, and average value was 27. Nutrient concentration, such as nitrate concentration at the study site, ranged from 0 (undetected) to 0.067 mg L⁻¹, with the average of 0.014 mg L⁻¹. Phosphate ranged between 0.065 and 0.561 mg L⁻¹, nitrite ranged between 0 (undetected) and 0.084 mg L⁻¹, and silicate concentration ranged from 0 (undetected) to 0.084 mg L⁻¹.

Composition and biodiversity index of gelatinous zooplankton. A total of 16 GZ types were identified in the IAB, composed from three phyla such as Cnidaria, Ctenophora, and Chordata. Among all Phyla, the Cnidaria group occurred as a more diverse species than other groups, including siphonophore, anthomedusae, narcomedusae, and trachymedusae, with 12 species. Chordata was the second diverse group, which was represented by Salpida and Doliolida with three species and ctenophore with only one species (Beroida) (Table 1).

Table 1

Gelatinous zooplankton found in Ambon Bay during sampling period

Phyla	Zooplankton	February	March
Chordata	Doliolida		
	<i>Doliolum</i> sp.	+	+
	Salpida		
	<i>Thalia</i> sp.	+	
Cnidaria	<i>Brooksia</i> sp.	+	
	Siphonophora		
	<i>Lensia</i> sp.	+	+
	<i>Diphyes</i> sp.	+	+
	Eudoxid stage of Diphyidae	+	+
	Anthomedusae		
	<i>Turritopsis</i> sp.		+
	<i>Bougainvillia</i> sp.	+	
	<i>Corymorpha</i> sp.		+
	<i>Pandeida</i> sp.	+	
	<i>Oceanida</i> sp.		+
	Anthomedusae sp. 1	+	
	Anthomedusae sp. 2		+
	Trachymedusae		
	<i>Liriope</i> sp.		+
Ctenophora	Narcomedusae		
	<i>Cunina</i> sp.		+
	Beroida		
	<i>Beroe</i> sp.		+

Note: "+" = present.

According to Figure 2, the diversity index of the GZ across the stations ranged from 0 to 1.16. This implied that the stability of the GZ community in IAB ranged between low and moderate condition (Krebs 1989). In addition, the biodiversity index was higher in February than in March.

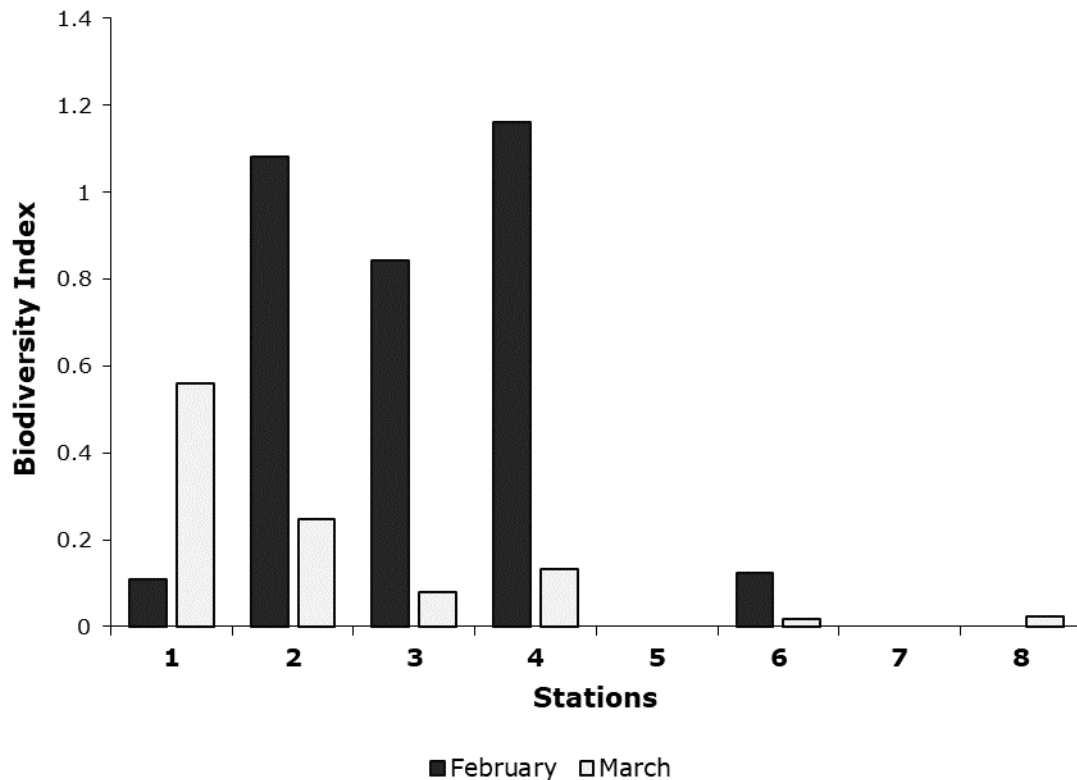


Figure 2. The biodiversity index of gelatinous zooplankton at each station.

Abundance and biovolume of gelatinous zooplankton. The data presented in Figure 3 showed that the abundance and biovolume of GZ varied among stations. The average abundance and biovolume of GZ in the IAB were in the range of 0.71 to 106.86 ind m^{-3} (average 33.09 ± 57.19 ind m^{-3}) and 0.05 to 1,262.35 $mm^3 m^{-3}$ (average 243.73 ± 424.26 $mm^3 m^{-3}$) respectively (Figure 3). The maximum abundance was 215.15 ind m^{-3} (station 1) and the maximum biovolume was 2513.95 $mm^3 m^{-3}$ (station 8) (Figure 3). Individual biovolume ranged from 0.1164×10^{-3} (*Turritopsis* sp.) to 90.199 mm^3 (*Thalia* sp.). In general, high abundance and biovolume of the GZ in the IAB were dominated by *Thalia* sp. (Salpida) (Figure 3). The maximum biovolume and abundance of *Thalia* sp. was 2,513.95 $mm^3 m^{-3}$ and 210.90 ind m^{-3} , respectively. In February, *Thalia* sp. was found dominating the GZ in the IAB but was not found in March. The subsequent most considerable high abundance was the eudoxid stage of Diphyidae (Siphonophore), with the highest abundance of 21.23 ind m^{-3} (average 2.39 ind m^{-3}). Other GZ groups had low abundances (< 1 ind m^{-3}).

Relationship between environmental parameters and the gelatinous zooplankton. PCA analysis showed that each environmental parameter affected a different species (Figure 4). *Thalia* sp., *Doliolum* sp., and *Beroe* sp. correlated with surface nitrate concentrations. *Bougainvillia* sp. correlated with nitrite and nitrate. *Lensia* sp. and eudoxid stage of Diphyidae correlated with phosphate concentrations.

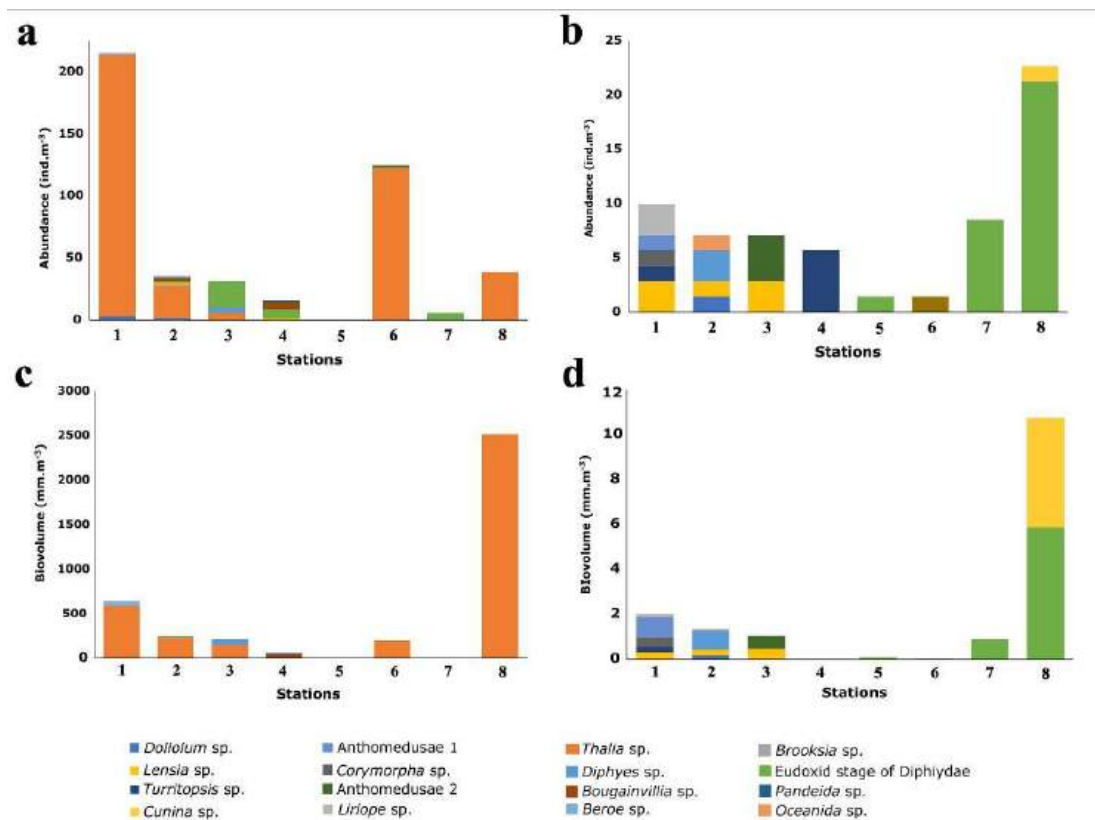


Figure 3. Abundance and biovolume of gelatinous zooplankton: a. abundance in February; b. abundance in March; c. biovolume in February; d. biovolume in March.

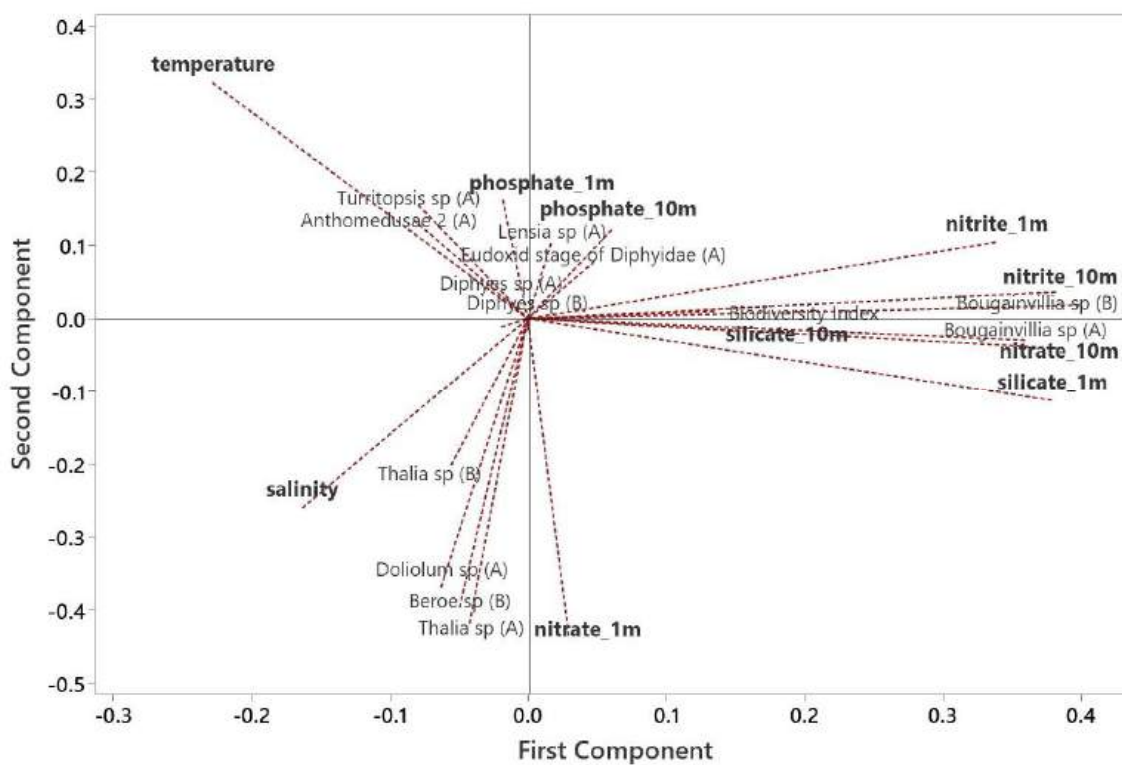


Figure 4. PCA analysis.

Discussion. This is the first study conducted to specifically discuss the GZ group in the IAB. The results of this study indicated that there were three groups of GZ from the study area. They were Thaliacea, Ctenophora and Cnidaria (Figure 5). In Indonesia waters, Thaliacea, Ctenophora and Cnidaria have been reported by several authors (Cornils et al 2010; Wang et al 2018). Furthermore, several studies have reported about the existence of GZ in Ambon Bay such as Siphonophora and Thaliacea (Troost et al 1976; Mulyadi & Saputra 2019).

There were fifteen genera and eudoxid stage of Diphyidae of GZ in study area. The number of genera identified in this study was comparable to that described by Balqis et al (2019), who also found 16 genera in the coastal ecosystem of Malacca Strait. Furthermore, the diversity of GZ in the IAB waters is lower than other location in Indonesia. In the Lembeh Strait, Wang et al (2018) found 37 genera of GZ consisting of 28 Cnidaria, 5 Thaliacea and 4 Ctenophora. The anthropogenic pressure and closed location in Ambon Bay were thought to be the cause of low diversity index and diversity of GZ. According to Lucas et al (2014), anthropogenic pressure can cause changes in the ecology and biogeography of marine species. Furthermore, Gusmão et al (2015) stated that in the term of biodiversity, the oceanic region was higher than the neritic zone. Hence, the GZ diversity in our study is low in the study area, since the region was a shallow water area. However, the abundance of GZ in this present study revealed higher density than other locations. For instance, Gusmão et al (2015) observed GZ density (1.4 to 23.5 ind m^{-3}) in the tropical southwestern Atlantic. Vansteenbrugge et al (2015) studied GZ population dynamics in the North Sea and an adjacent estuary and reported that the GZ density remained below 3.0 ind m^{-3} in the estuary and up to 18.0 ind m^{-3} in the near coastal and open seas. In terms of biovolume, at the study area it was also quite high compared to other studies. The existence of the *Thalia* sp. which is quite abundant also causes a high GZ biovolume value in the waters of the inner Ambon Bay. It is even higher with the total zooplankton found by Dai et al (2016) in the subtropical North Pacific where the maximum biovolume of zooplankton was 231.7 mm m^{-3} .

In the Thaliacea group, two orders were found: Doliolida and Salpida. Doliolida was represented by *Doliolum* sp., and Salpida was represented by *Thalia* sp. and *Brooksia* sp. Thaliacea, especially the salp group, was one of the groups that commonly found to form blooms under favorable conditions (Ishak et al 2020). The genera *Thalia* and *Doliolum* are the most ubiquitous genera and being widely distributed in marine ecosystems (Hoffmeyer et al 2018). Several studies have reported the presence of these genera in Indonesia waters such as in Lembeh Strait (Wang et al 2018) and Ambon waters (Mulyadi & Radjab 2015). The *Brooksia* sp. was only found in one station with the average abundance of 0.25 ± 0.70 ind m^{-3} . The presence of *Brooksia* sp. is not as much as of *Thalia* sp. and *Doliolum* sp. Several studies in other locations also found low concentrations and abundance of this genus, such as in the eastern tropical North Pacific (Hereu et al 2010) and Southwestern Atlantic (Nogueira Jr. & Brandini 2018).

The Beroida (Ctenophora) was only represented by one genus *Beroe* (Figure 5). This genus is found in marine ecosystems both in coastal waters and open waters (Vansteenbrugge et al 2015; Balqis et al 2019). In our study, *Beroe* sp. was found in two stations with the average abundance of 0.18 ind m^{-3} . In other locations, *Beroe* sp. was also found in less abundant quantities. Balqis et al (2019) found an average abundance of *Beroe* in coastal ecosystem of Malacca Strait of 0.14 ind m^{-3} .

Cnidaria in our study area was composed by meroplankton and holoplankton. Meroplankton Cnidaria was represented by anthomedusae, while the holoplankton was represented by trachymedusae, siphonophore, and narcomedusae. The biodiversity of holoplankton cnidarians in this water was lower than meroplankton cnidarians. There were five genera of the holoplankton cnidarian in IAB (including the eudoxid stage of Diphyidae) and seven genera of meroplankton (Table 1). Given the fact that holoplankton cnidarian was distributed in oceanic and open sea waters (Nogueira Jr. & Brandini 2018), the present study showed their low biodiversity in the inner bay was likely due to the area was a shallow estuary. Ambon Bay is semi-enclosed waters with less regular water mass exchange. Therefore, meroplankton could be found to be more relatively abundant than holoplankton.

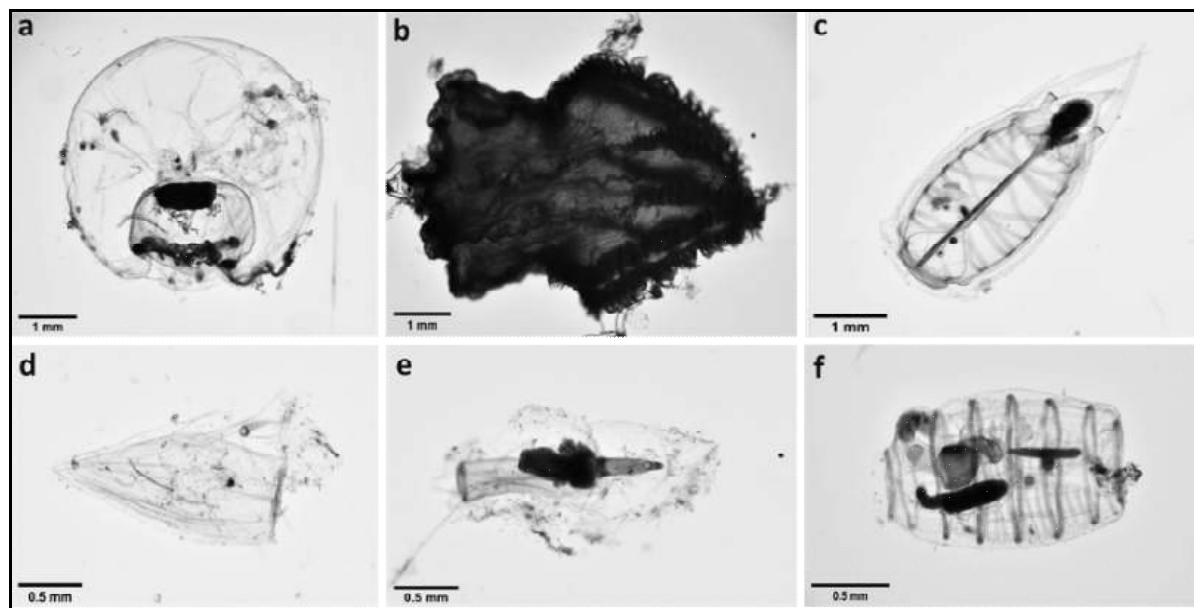


Figure 5. Gelatinous zooplankton found in Ambon Bay in the present study: a) *Bougainvillia*, b) *Beroe*, c) *Thalia*, d) *Lensia*, e) eudoxid stage of Diphyidae (Siphonophore), f) *Doliolum*.

The result of this study shows that high abundance and biovolume of GZ in IAB were caused by the presence of the *Thalia* sp. Based on the PCA analysis, *Thalia* sp. abundance and biovolume correlated with nitrate levels. Thus, nutrient input from land through run-offs during the northwest monsoon was likely to trigger the dominance of GZ. The salp *Thalia* sp. typically occupies open coastal and offshore waters. Under certain conditions, *Thalia* sp. can be found in high abundances in the water because it is a fast-growing and developing species. In southeast Australia, the growth rate of *Thalia democratica* is between 0.3 and 28% in length per hour, and the population can increase by up to 2.5 times per day (Everett et al 2011). The IAB is known as an area with high concentrations of nutrients as it receives regular input from the land. The supply of nutrients from land to sea will affect the plankton community especially salp. Henschke et al (2014) reported in Tasmanian waters where *Thalia* sp. was found to bloom in spring, nutrient levels and phytoplankton were high. This condition was followed by a surge in *T. democratica*. Furthermore, Li et al (2011) stated that increasing chlorophyll-*a* was the main reason for the increased Thaliacea abundance, during which phytoplankton served as food for GZ growth. The present study also found similar results in the IAB, where salp developed rapidly when nutrient concentrations were high. Typical high abundance and biovolume of GZ in the IAB as coastal waters were similar with several locations, such as in the tropical southwestern Atlantic 1.4 ind m^{-3} (Gusmão et al 2015) and the coastal ecosystem of Malacca Strait from 0.8 to 15.0 ind m^{-3} (Balqis et al 2019). Vansteenbrugge et al (2015) studied population dynamics of GZ in the Red Sea and reported that the density of GZ was below 3.0 ind m^{-3} . The biovolume of GZ in those waters was higher than the total zooplankton in the subtropical North Pacific (Maximum $126.1 \text{ mm}^3 \text{ m}^{-3}$) (Dai et al 2016).

Our results suggested that environmental parameters have correlations with the GZ communities (Figure 4). Nutrient parameters were the most prominent parameters influencing the abundance and biovolume of zooplankton in the IAB. The existence of nutrient inputs from the mainland via rivers affects organisms that live in the IAB, such as phytoplankton which are also often found blooming. The present study also confirmed that nutrient levels had influences on the GZ community in IAB. Nutrients can increase the population of phytoplankton and other tiny zooplankton to develop and survive, providing food for GZ. The high densities of mesozooplankton, especially in northwest monsoon observed at Ambon Bay (Mulyadi & Saputra 2019), could also support high populations of GZ since the main food items of gelatinous were other zooplankton. GZ such as medusae, Siphonophora, and Ctenophora are predatory groups (Madin & Harbison 2001). Furthermore, since GZ can indirectly exploit the nutrient pool, high

nutrient concentrations in seawater have been linked to an increase in their population (Legovic 1987; Balqis et al 2019).

Even though this study is a considerable attempt to record species diversity, abundance and biovolume of GZ in IAB, further studies should encompass different seasons and compare the dynamic of GZ. Here, the GZ dynamics of different season can be obtained to gain a better understanding of their variation in Ambon Bay. This was because of our data was based on one sampling trip. The seasonal data collection of GZ and environmental parameter would lead us to reveal main factors and hydrology conditions that govern dynamics of GZ community.

Conclusions. The results of the study showed that there were 15 genera of gelatinous zooplankton and eudoxid stage of Diphyidae in Ambon Bay waters. The abundance and biovolume of gelatinous zooplankton in study area were 0.71 to 106.86 ind m⁻³ and 0.05 to 1262.35 mm³ m⁻³ respectively. *Thalia* was the genus with the highest abundance and biovolume. Nutrients were the main environmental parameter that governed the gelatinous zooplankton community in the inner Ambon Bay.

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Conflict of interest. The authors declare that there is no conflict of interest.

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