Plankton abundance and diversity north of Lembata Island, Indonesia

[1]Sara Unbekna, [2]Undang Hernawan, [1]Eko Setyobudi, [1]Lady A. S. Wijayanti, [1]Tony B. Satriyo, [1]Candra Aryudiawan, [1]Riza Y. Setiawan

[1] Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia; [2] The Geological Survey Center, Ministry of Energy and Mineral Resource of the Republic of Indonesia, Bandung, Indonesia. Corresponding author: R. Y. Setiawan, riza.y.setiawan@ugm.ac.id

Abstract. Plankton is a pivotal organism of marine ecosystems due to its major role in primary productivity and consumer abundance. Given the important role of plankton as a fishery resource, investigating plankton distribution north of Lembata Island is a high priority, as it is a fishing hotspot for pelagic fish. The abundance and diversity of plankton in the region is investigated in this study. 25 plankton samples were collected from 3 different layers: surface layer, thermocline layer, and deep layer, during the OTEC field campaign with the Indonesian RV GEOMARIN III in 2017. Temperature and salinity were measured using Conductivity Temperature Depth (SeaBird 19+). This study found 45 genera of phytoplankton and 25 genera of zooplankton throughout the water column. Phytoplankton from the diatom class was found in all depths, the dominant genera being *Chaetoceros* and *Thalassionema*. The zooplankton genera *Globigarinella*, *Nauplius*, and *Favella* are found in all depths, the most abundant genus being *Sagena*. Furthermore, phytoplankton abundance decreases with depth, with cell abundance of 45500-8517750 cells m^{-3} observed in the surface, 901875 cells m^{-3} in the thermocline, and 257125 cells m^{-3} in deep water. Zooplankton abundance decreased in the thermocline and increased in the surface layer. Our study suggests that water temperature may have played a dominant role in determining plankton abundance north of Lembata Island during the study period.

Key Words: community composition, Lembata waters, phytoplankton, zooplankton.

Introduction. Lembata is a district in the province of East Nusa Tenggara, Indonesia, and it is mainly surrounded by deep waters, but with relatively narrow and shallow waters in its western and northern parts (Wudianto et al 2004). The ocean surface conditions north of Lembata Island are influenced by the Australian-Indonesian monsoon system (Susanto et al 2006; Setiawan & Habibi 2010). During the southeast monsoon season (June-August), southeastern winds blow from Australia, carrying warm and dry air to the maritime continent (Gordon 2005). These winds commonly induce upwelling in the Indonesian seas (Setiawan et al 2019, 2020; Wirasatriya et al 2019). During the northwest monsoon season (December-February), northwestern winds blow from the Eurasian continent, bringing warm and moist air to the region of interest (Gordon 2005; Qu et al 2005). In general, the surface of Indonesian seas exhibits oligotrophic conditions during this season due to sea surface dynamics, dominated by the downwelling process (Wirasatriya et al 2020).

The region north of Lembata Island is known as a fishing hotspot for *Katsuwonus pelamis*, *Euthynnus affinis*, and small pelagic fish (Badrudin et al 2004). It is widely recognized that nearly all small pelagic fish and fish larvae feed mainly on plankton (Nontji 2008). Enhanced primary productivity increases consumer abundance or higher trophic level organisms in marine ecosystems. Phytoplankton is a part of primary producers and, through photosynthesis, it serves as the nutritional basis for all higher trophic levels. Plankton plays a fundamental role in marine ecosystems, especially phytoplankton, as it forms the foundation of the marine food web (Odum 1998; Zulfiandi et al 2014). Furthermore, the energy resulted from photosynthesis will be utilized by other organisms, including zooplankton, for growth (Asriyana & Yuliana 2012; Brierley

2017). Generally, zooplankton will become food for fish larvae. Thus, the abundance of plankton will be directly proportional to the presence of fish.

Communities of phytoplankton and zooplankton are distributed horizontally and vertically in the oceans and both can be used as indicators of ecological change in aquatic ecosystems due to sensitivity to environmental stressors (Paerl et al 2007; Dutkiewicz et al 2019). According to Millero (2006), phytoplankton has limited mobility. Therefore, nutrients, ocean currents, and light determine its spatial distribution. Furthermore, water temperature and salinity affect the life of plankton. Extreme salinity can inhibit growth and increase the mortality of plankton (Odum 1998), while water temperature affects fecundity, length of life, and the adult size of zooplankton (Kennish 2017). Changes in temperature can cause the circulation and stratification of water, which influence the distribution of aquatic organisms, including plankton (Laevastu & Hayes 1981).

The altered ocean stratification due to changes in temperature and salinity will affect the vertical distribution of plankton. The distribution of plankton in oceans generally shows maximum biomass in the photic zone. Vertical migration of phytoplankton and zooplankton is also associated with predation. According to Liu et al (2003), predation is one of the factors that cause plankton to migrate vertically. Diversity measurements indicate the ecological status, since phytoplankton diversity is connected with productivity (Vallina et al 2014). The diversity and distribution of plankton over a wide depth range in the Lembata waters is poorly documented. In this study, the spatial distribution of plankton and its relationship to environmental factors in the region north of Lembata Island are investigated, along with plankton abundance and community structure across depth gradient.

Material and Method

Description of the study sites. The field campaign in the region north of Lembata Island was conducted from 23 September to 7 October 2017, using the Indonesian Research Vessel Geomarin III. There were 25 sampling stations (Figure 1). Water samples were collected from the surface (5 m), the thermocline (~49-230 m), and the deep layers with a maximum depth of 1146 m.

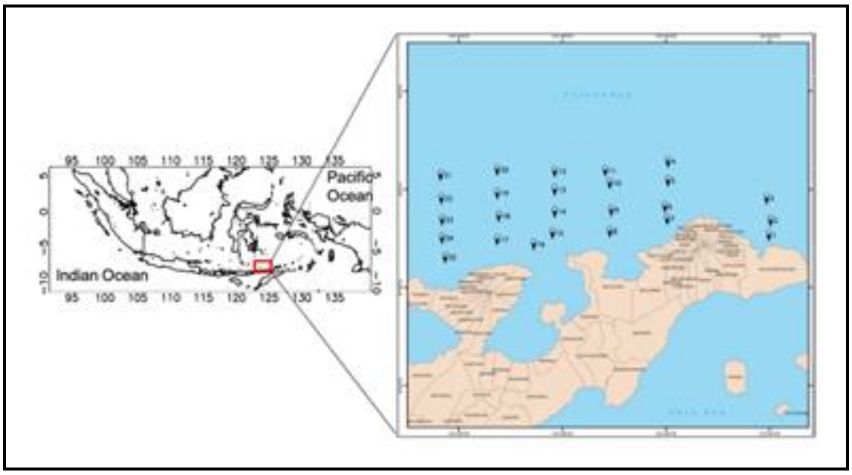

Figure 1. Sampling stations north of Lembata Island.

Plankton sampling. Water temperature and salinity were measured using Conductivity Temperature Depth (CTD), which is equipped with ten bottles of 8-liter Rosette Sampler. The water sample was filtered using 50 μm and 153 μm plankton net. The collected filtrate was transferred into a 260 mL sample bottle and preserved using 4% formalin. Plankton count was performed using a Sedgewick-Rafter under microscope with a magnification of 100X. Plankton samples were identified by a microscope, model Olympus CX22LED and classified following the taxonomic schemes of Tomas (1997) and Shirota

(1966). The thermocline layer was determined from the temperature-depth profile of each station.

Data analysis. Contour maps of plankton diversity indices were generated using Surfer with Kriging gridding method. Plankton identification was carried out at the Department of Fisheries, Universitas Gadjah Mada. Plankton abundance was expressed as individual per m³ and calculated using the equation proposed by Perry (2003) and modified by Huliselan et al (2006):

$$D = \frac{N_f \times V_p}{V}$$

Where: D is the plankton abundance (ind m^{-3}); N_f is the amount of plankton per 1 mL; V_p is the dilution volume; and V is the water-filtered volume (m^3).

Univariate analysis is used as an ecological indicator through the diversity index of the identified plankton species. Plankton diversity index is calculated using the equation developed by Spellerberg & Fedor (2003):

$$H' = -\sum P_i lnP_i$$

Where: H' is the diversity index and P_i is the species proportion.

The diversity is categorized as follows: $H'<1$ indicates low diversity; $1<H'<3.322$ indicates medium diversity; $H'>3.322$ indicates high diversity (Krebs 1989).

Results and Discussion. The thermocline layer north of Lembata Island ranged from 49 m to 230 m during September-October 2017. The present research found phytoplankton from the surface to deep layers consisting of 45 genera belonging to 4 taxa: Diatoms (33 genera), Dinoflagellates (10 genera), Cyanobacteria (1 genus), and Silicoflagellata (1 genus) (Figure 2). The more frequent diatoms observed at the 3 depth points were *Thalassionema* and *Chaetoceros*, while those present in small numbers were *Navicula*, *Coscinodiscus*, and *Thalassiosira*. The most diverse genera were the dinoflagellates *Ceratium*, *Peridinium*, *Pyrocystis*, *Prorocentrum*, *Dinophysis*, *Ornithocercus*, *Goniodoma*, *Gonyaulax*, *Diplosalis*, and *Phalacroma*. The cyanobacteria *Trichodesmium* and the silicoflagellate *Dicthyocha* were observed in samples. The phytoplankton genus *Trichodesmium* was only found in the surface layer. *Trichodesmium* is known to be widely distributed in the photic zones of tropical and subtropical oceans (Jiang et al 2017).

The distribution of zooplankton north of Lembata Island varied significantly. Zooplankton found in the region belong to 9 phyla, 11 classes, 14 orders, 20 families, and 25 genera (Figure 2). Phyla of Arthropoda, Granuloreticula, and Ciliophora were found throughout the water column. The common genera were *Nauplius*, *Globigarinella*, *Globigerina*, *Favella*, and *Sagena*. There were several species of zooplankton that were only found in the surface layer, i.e. *Actinopoda* and *Chaetognatha* (Figure 2). Within the phylum Arthropoda, *Nauplius* was found from the surface to the deep layers. The genus *Favella* from the phylum Ciliophora was observed in all layers. The distribution of zooplankton is limited vertically due to a direct consequence of the distribution of phytoplankton abundance as well as primary production in the water column that peaked in the epipelagic zone (Stefanoudis et al 2019).

The results show that the total abundance of phytoplankton in the surface layer was 75926125 cells m^{-3}, whereas in the thermocline and deep layers it was 901875 cells m^{-3} and 257125 cells m^{-3}, respectively (Figure 3). The significant difference in the abundance values shows that the types of phytoplankton that dominated the surface layer differ from those of the thermocline and deep layers. The high abundance of phytoplankton in the surface layer was dominated by *Chaetoceros curvisetus* with a value of 90678.75 cells m^{-3}. The thermocline and deep layers were dominated by *Thalassionema nitzchoides* (2977125 cells m^{-3}) and *Fragilaria intermedia* (137500 cells m^{-3}).

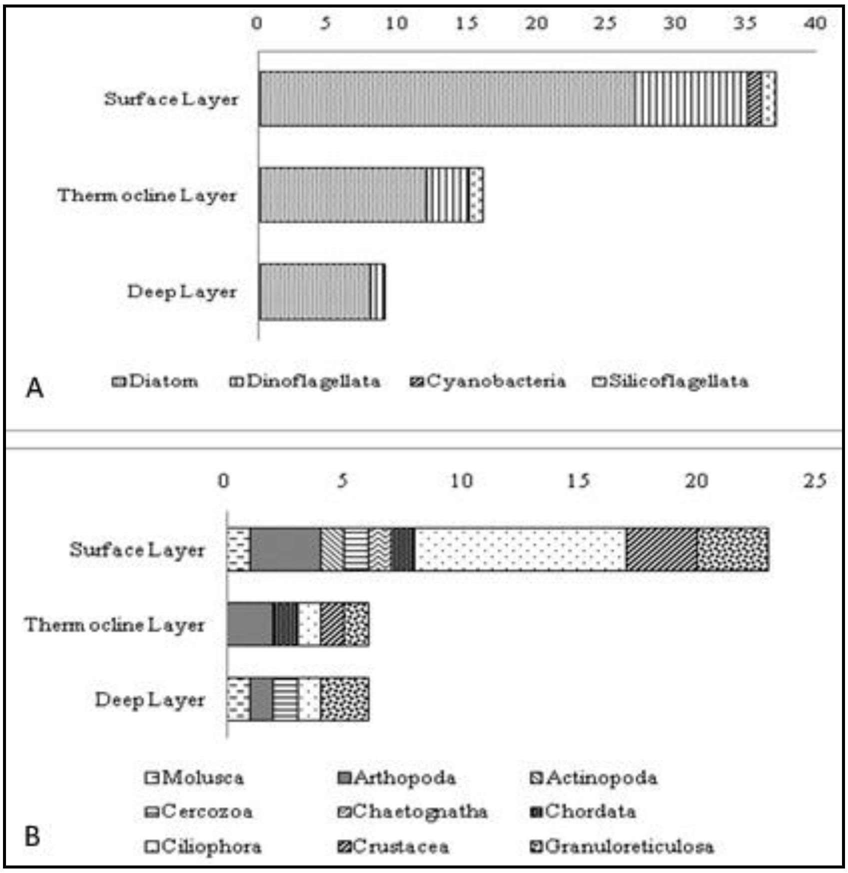

Figure 2. Taxonomic composition of phytoplankton (A) and zooplankton (B) north of Lembata Island during study period.

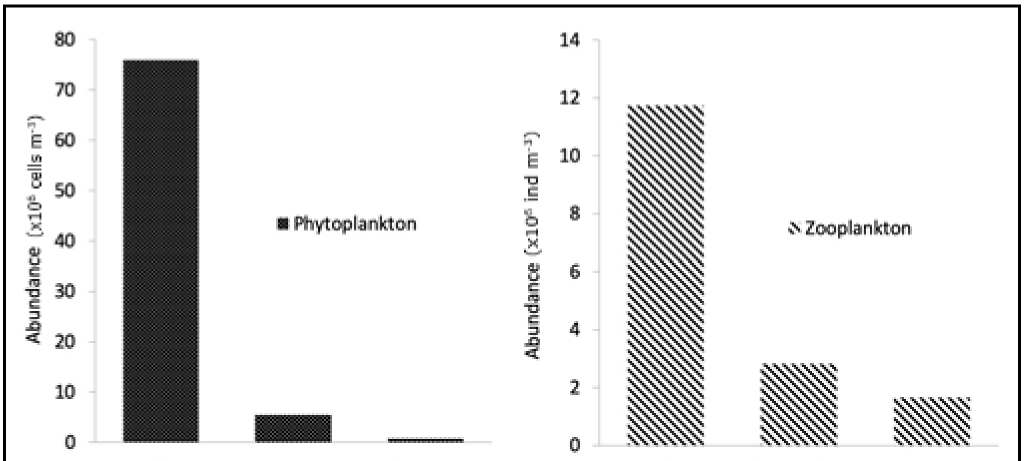

Figure 3. Total abundance of phytoplankton (A) and zooplankton (B) in the studied area.

The highest abundance of zooplankton observed in the surface layer had a total value of 11736687 ind m^{-3}. The abundances of zooplankton in the thermocline and deep layers were 348000 ind m^{-3} and 864875 ind m^{-3}, respectively (Figure 3). The abundances of zooplankton in the surface and deep layers was dominated by *Sagena ternaria* with 9275625 ind m^{-3} and 864875 ind m^{-3}, respectively. The results show that *Globigarinella aequilateralis* was frequently observed in the thermocline layer with a value of 1681625 ind m^{-3}.

Figure 4 exhibits the map of plankton diversity indices for phytoplankton and zooplankton in the region of interest. It is obvious that the highest indices observed were in the surface layer (Figure 4a and 4d) and were confined to the western Lembata waters. This might be a product of upwelling that occurred during June-September. Furthermore, the diversity index decreases in the thermocline (Figure 4b and 4e) and deep layers (Figure 4c and 4f).

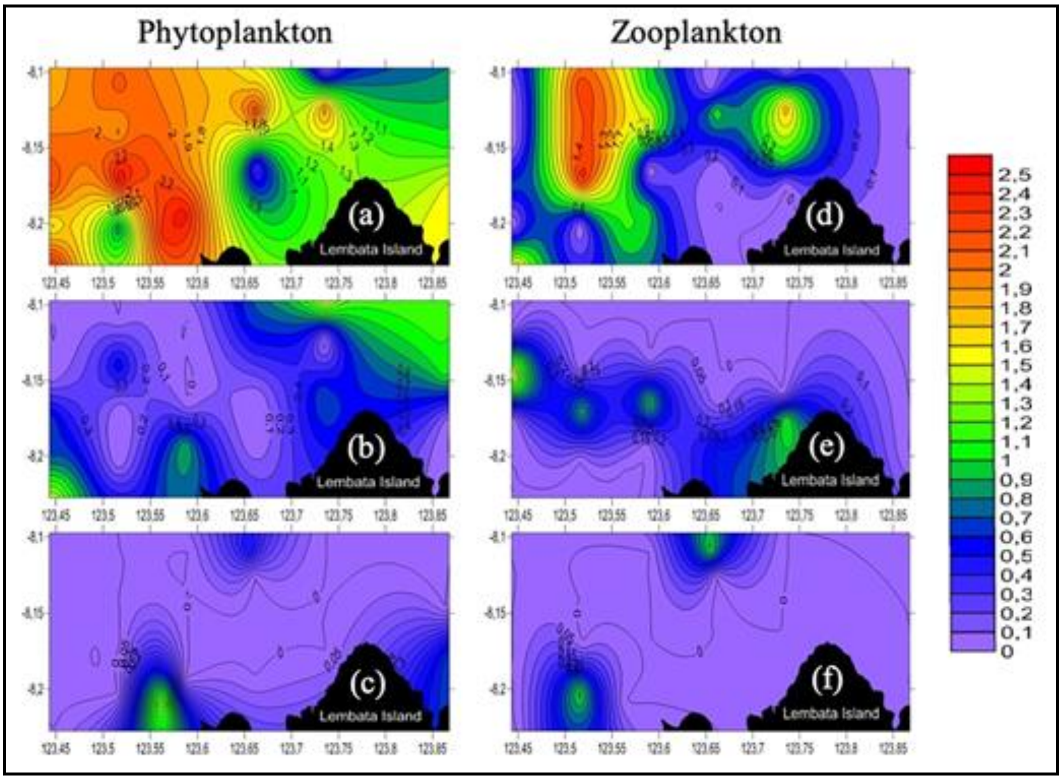

Figure 4. Plankton diversity indices of phytoplankton (left) and zooplankton (right) for surface (a and d), thermocline (b and e), and deep layers (c and f) north of Lembata Island, during September-October 2017.

Figure 5 shows the profiles of temperature and salinity north of Lembata Island during the field campaign. Water temperature and salinity ranged from 4.17 to 28.86ºC and from 33.89 to 34.61‰, respectively. The thermocline layer ranged from 49 to 230 m, whereas the halocline layer ranged from 35 to 200 m.

This study is one of the few that investigates plankton community and its characteristics including composition, abundance, and diversity in the region north of Lembata Island at different depths. One factor that influences this observation is the water column stratification and thermocline. Phytoplankton composition in the studied area is dominated by diatoms. It is a type of phytoplankton that is commonly found from the surface to the deep layers (Agusti et al 2015).

Earlier studies on the composition and abundance of phytoplankton have stated that diatoms and dinoflagellates are the major groups of the phytoplankton community (Jasprica et al 2012; Dursun & Tas 2019). According to Arinardi (1997), diatoms can perform cell division rapidly (in about 4 hours) under optimal condition. The dominance of diatoms in most of the oceans is due to their capability to acclimate to the environment (Malviya et al 2016). The results of this study reveal that *Thalassionema* and *Chaetoceros* were commonly found from the surface to the deep ocean layers, with higher numbers than other types of phytoplankton. Wulandari et al (2014) suggest that *Chaetoceros* can be found abundantly in the oceans, because its body shape is like a chain or collection of cells and it presents chaeta that enable it to sink slowly, being less favored by herbivorous predators. Karthik et al (2012) also found that *Chaetocerotaceae* is a family of diatoms found abundantly in the coastal waters of Port Blair, the southern part of Andaman Island (Bengal). The genus *Chaetoceros* is also dominant in the waters of Glacier Bay, Alaska (Hannam 2008). *Chaetoceros* domination is also found in the Indonesian Seas, in the Taka Bonerate waters (Febrina 2005), Belitung waters (Widianingsih et al 2007), Sangihe-Sangir Talaud waters (Thoha & Fitriya 2010), Mata Siri waters (Thoha & Amri 2011), and Natuna Sea (Fitriya et al 2011). In addition, Fitriya & Lukman (2015) discovered that 5 diatom genera dominate the waters of Lamalera with a frequency above 80%: *Chaetoceros*, *Rhizosolenia*, *Nitzschia*, *Thalassiosira*, and *Thalassiothrix*.

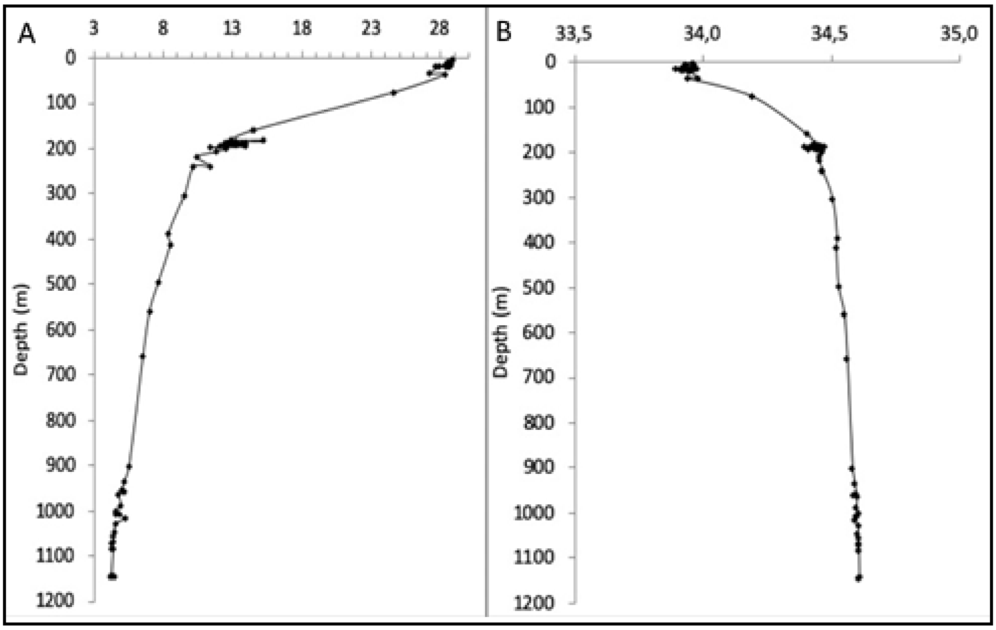

Figure 5. Vertical profiles of temperature (A) and salinity (B) north of Lembata Island.

The composition of zooplankton varied considerably, some types inhabiting one water layer and some being observed in all water layers. The genus *Globigerina* is planktonic foraminifera that is commonly found throughout the water column compared to *Nauplius* and *Favella*. *Globigerina* is typically widespread in the tropics. Previous studies showed that the genus *Globigerinoides* and *Globorotalia* were found abundantly in the Makassar Strait from 1884 m to 2966 m depth (Rositasari 2010). Furthermore, the results of this study demonstrate that the phylum Actinopoda (*Hexalonche amphisiphon*) and Chaetognatha (*Sagita* spp.) were only found in the surface layer. This finding is in accordance with statement of Andreu et al (1989), that Chaetognatha is epiplanktonic or lives only in the upper layer of water (Andreu et al 1989).

Phytoplankton abundance north of Lembata Island declined with increasing water depth and it is correlated to the photic zone with warmer water in the surface layer. A similar condition occurred in the abundance of zooplankton. The highest and lowest abundances of zooplankton were in the surface and deep layers, respectively. The overall pattern here is similar to the pattern of phytoplankton abundance and primary production in the water column that generally attained maximum in the epipelagic zone. Zooplankton abundance is influenced by phytoplankton abundance (Heneash et al 2015). Furthermore, as zooplankton vertical migration is highly dependent on environmental factors like temperature and salinity (Steinberg et al 2002), the water column stratification during the sampling period may have been responsible for determining the number of zooplankton in the water column.

The index of plankton diversity is affected by the composition of its constituent types. The diversity index value in the region of interest is classified as low to moderate. Low diversity index values were observed in the thermocline and deep layers, whereas moderate diversity was observed in the surface layer. The low diversity index is perhaps due to the several genera predominant in particular layers with an abundance higher than 5%. For example, the zooplankton genus *Sagena* dominated the surface layer (80.12%) compared to other zooplankton species. The phytoplankton genus *Chaetoceros* showed an abundance of 11.94% compared to other phytoplankton. Therefore, this condition affects the diversity value in the region north of Lembata Island. The members of predominant groups are able to survive in a wide environmental variability and are resistant to extreme conditions, with high reproduction rates. It is likely that lower temperatures in combination with limited food resources in the deep layer led to lower taxon diversity. Similar depth-related decreases in phytoplankton and zooplankton diversity might be linked to decrease in temperature and organic matter. It is likely that the composition and abundance of phytoplankton and zooplankton vary among all depth layers depending on the changing environmental conditions, different responses of the organisms, their limiting factors and life requirements. The presence of phytoplankton has been suggested to be associated with the photic zone, warmer water layers, and nutrient availability. A number of factors influence the distribution and composition of zooplankton including nutrients, temperature, salinity and dissolved oxygen. Furthermore, vertical migrations of zooplankton have been related to the daily light cycle and food sources.

Conclusions. The plankton distribution north of Lembata Island was investigated during September-October 2017. The results revealed 45 genera of phytoplankton and 25 genera of zooplankton throughout the water column. *Thalassionema*, *Chaetoceros*, *Navicula*, *Coscinodiscus*, and *Thalassiosira* are phytoplankton found in all depth layers, with the most abundant genus being *Chaetoceros*. Meanwhile, *Globigarinella*, and *Favella* are zooplankton found in all layers, with the most abundant genus being *Sagena*. Within the phylum Arthropoda, *Nauplius* was found from the surface to the deep layers.

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Authors:
Sara Unbekna, Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Bulaksumur, 55281 Yogyakarta, Indonesia, e-mail: unbekna_sara@yahoo.com
Undang Hernawan, Center for Geological Survey, Geological Agency of Indonesia, Ministry of Energy and Mineral Resources, Jl. Diponegoro No. 57 Gedung C, 40144 Bandung, Indonesia, e-mail: uhernawan@gmail.com
Eko Setyobudi, Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Bulaksumur, 55281 Yogyakarta, Indonesia, e-mail: setyobudi_dja@ugm.ac.id
Lady Ayu Sri Wijayanti, Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Bulaksumur, 55281 Yogyakarta, Indonesia, e-mail: ladyladywijayanti@gmail.com
Tony Budi Satriyo, Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Bulaksumur, 55281 Yogyakarta, Indonesia, e-mail: tonysatriyo@ugm.ac.id
Candra Aryudiawan, Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Bulaksumur, 55281 Yogyakarta, Indonesia, e-mail: candradiawan@ugm.ac.id
Riza Yuliratno Setiawan, Department of Fisheries, Faculty of Agriculture, Universitas Gadjah Mada, Bulaksumur, 55281 Yogyakarta, Indonesia, e-mail: riza.y.setiawan@ugm.ac.id

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