

Original Research

Plankton community in the western waters of North-Sumatera during the onset monsoon of Asian winter

Mochamad Ramdhan Firdaus *, Nurul Fitriya, Praditya Avianto, Hanif Budi Prayitno, A'an Johan Wahyudi

Research Center for Oceanography, Indonesian Institute of Sciences, Jl. Pasir Putih 1, Ancol, Jakarta 14430, Indonesia

ARTICLE INFO

ABSTRACT

Article history:

Submitted 24 January 2020

1st Revision 9 February 20202nd Revision 8 April 20203rd Revision 3 May 2020

Accepted 30 June 2020

Published online 31 July 2020

Keywords:

Phytoplankton

Zooplankton

Sumatera

death phase

Bengal bay water

Indian equatorial water

The western waters of North-Sumatera experience dynamic environmental changes during the onset monsoon of the Asian winter. Those changes certainly will affect the distribution of marine organisms, especially the plankton. Plankton is the foundation of the aquatic food chain and plays an important role as the entry gate of solar energy to the water trophic systems. This study aims to investigate the plankton community and its correlation with the environmental factors during the onset monsoon of the Asian winter. Plankton samples were collected, along with water samples and in-situ measurement for environmental parameters determination from western waters of North-Sumatera (95°E – 93°N) in November-December 2017. Plankton samples were taken by vertically hauling (500 m) using Modified Twin Plankton Net with 80 µm mesh size for phytoplankton and 300 µm for zooplankton. Temperature, salinity, and density of waters were measured using CTD SBE 911 – Plus. The nutrients, including orthophosphate, nitrate, and silicate, measured using autoanalyzer Skalar SAN++. Thirty genera of phytoplankton and 44 taxa groups of zooplankton were found. The phytoplankton community dominated by *Thalassionema*, while the zooplankton dominated by Calanoida. There was a difference in the composition of plankton communities between the north and south parts of the study area. It was probably influenced by different water masses between those two regions indicated by the dissimilarity of their water characteristics. Based on the analysis of the T-S diagram, it is likely that the north community influenced by Bengal Bay Water while the south community influenced by the Indian Equatorial Water.

©2020 Indonesian Institute of Sciences (LIPI).

1. Introduction

The western waters of North-Sumatra, based on its location, strongly influenced by the Asian Monsoon system (Wyrтки, 1961; Tomczak *et al.*, 2001; Chang *et al.*, 2006). The Asian Monsoon is the world's biggest weather system, and it plays a significant role in large-scale climate variability over large part of the world. The Asian monsoon system driven by reversal heating between the northern and southern hemispheres, and is associated with the atmospheric interactions between the Asian continent and the ocean (Indian Ocean and Pacific Ocean) (Webster, 2006; Chang *et al.*, 2006; Trenberth *et al.*, 2006; Gordon *et al.*, 2016). Asian monsoon has two periods

based on the summer (dry) and winter (wet) seasons that occur in the Asian continent. The Asian summer monsoon generally begins in June and fades away in October, while the Asian winter monsoon starts in December and fades away in April (Tomczak *et al.*, 2001). There are transitional periods between them, namely the onset monsoon of Asian summer (May) and the onset monsoon of Asian winter (November) (Wyrтки, 1973; Tomczak *et al.*, 2001).

The onset monsoon of Asian winter is the transitional period from the Asian summer monsoon to the Asian winter monsoon (Tomczak *et al.*, 2001). The onset monsoon of Asian winter is stronger and has a longer duration than the onset monsoon of Asian summer (Mardiansyah *et al.*, 2014; Chang *et al.*, 2006). During the onset monsoon of Asian winter, the winds on the Indian Ocean equator dominated by the westerly wind (Wyrтки, 1973). This wind drives the formation of the jet-like

* Corresponding Author

M.R. Firdaus: ramdhan.ekologi@gmail.com

current in the equator that flows eastward at high speed, about 64 cm/sec (Wyrski, 1973; Schott & McCreary, 2001; Duan et al., 2016; Prerna et al., 2019). Mardiansyah et al., (2014) found that the jet spread along the equator from east of about 50°E up to the eastern boundary of the Indian Ocean. When the equatorial jet current reached the western waters of Sumatera, the current separated into three directions (Mardiansyah et al., 2014). The first flows back to the Indian Ocean as Rossby waves. The second flows southeasterly along the western waters of Sumatra and southern waters of Java, while the third flows northerly along western waters of North-Sumatera toward the Bay of Bengal. The latter will meet with the current from the Andaman Sea in the western waters of North-Sumatera. Hence, the onset monsoon of Asian winter, through an Equatorial Jet current, will affect both the physical and chemical characteristics of the western waters of North-Sumatera.

Changes in the marine environment due to monsoon dynamics are known to affect the distribution and abundance of marine organisms, especially plankton. Kadim et al., (2018) stated that the highest abundance of phytoplankton (cell size > 25 µm) in Gorontalo Bay occurred at east monsoon (July), compared to the west monsoon (May) and transition period (June). Khasanah et al., (2013) found that the nitrate, phosphate, silicate, organic matter, and chlorophyll, in the Bali Strait, were higher at the transition period (November) than the west monsoon (February). It followed with a higher abundance of phytoplankton (cell size > 20 µm) at the transition period (51.405 cells/L) than the west monsoon. Ye et al., (2020) found that the phytoplankton community during the monsoon transition period in the Lembah Strait is mainly affected by nutrient and showed lower abundance than the Southeast monsoon period (Tang et al., 2018). Schalk (1987) also found that the zooplankton (body size >320 µm and > 5 mm) abundance during southeast monsoon was higher than the northeast monsoon period.

Plankton is an organism that drift freely in the waters and roles as the base of the food chain in the marine ecosystem. The group of phytoplankton produces organic carbon compounds through photosynthesis, which is the primary food source for almost all organisms in the ocean. The synthesis rate of organic compounds by phytoplankton is estimated to half of the total global net primary productivity, around 40-60 PgC/year (Falkowski et al., 2000). Indian Ocean accounts of 15-20 % of total global ocean net primary productivity (Behrenfield & Falkowsky, 1999). The primary consumer of phytoplankton are zooplankton. They act as a trophic link between phytoplankton and the higher trophic levels such as fish. Hence, the distribution of plankton in the waters can describe the productivity of an aquatic ecosystem.

The distribution of plankton in the waters influenced by environmental factors, such as temperature, salinity, currents, nutrients, and light. Various studies have shown that environmental changes can affect the growth of plankton (Loiterton et al., 2004, Betsill et al., 2011; Chen et al., 2015). Silubun et al., (2015) found that the sea surface temperature in the western waters of Sumatra during 2002-2011 averaged 27.3 °C with chlorophyll concentration of 0.3 mg/m³. However, when the positive Indian Ocean Dipole mode took place in 2006, sea surface water decreased to 25.97 °C, and chlorophyll levels increased to 1.13 mg/ m³. Changes in temperature and

nutrients can affect the rate of photosynthesis and phytoplankton productivity (Schabhüttl et al., 2013; Chen et al., 2015). Also, changes in temperature can affect the metabolic rate and digestion of zooplankton (Loiterton et al., 2004; Betsill et al., 2011).

Environmental changes that include physical and chemical dynamics, as they are known to affect the distribution and abundance of planktonic organisms, are very relevant to be observed, especially to reveal the dynamics of waters at small and medium scale. The observed variables are the plankton community and water quality. This study aims to determine the plankton community in the western waters of the North-Sumatra during the onset monsoon of Asian winter. Analysis of plankton community based on the abundance, diversity, evenness, and similarity of community. Parameters of water quality were also measured, such as temperature, salinity, and nutrient distributions (phosphate, nitrate, and silica). Thus, it can be examined the correlation between nutrient, physical factor, and the dynamics of the structure of the plankton community in the western waters of North - Sumatra during onset monsoon of Asian winter.

2. Materials and Methods

2.1 Study Site

This study was conducted in the western waters of North-Sumatera in November - December 2017, coincided with the northeast winter monsoon. Plankton and water samples were taken at fifteen (15) locations as shown in Table 1 and Figure 1 using research vessel Baruna Jaya VIII, belonging to Indonesian Institute of Sciences (LIPI). This study was part of the Widya Nusantara Expedition 2007 hold by Research Center for Oceanography – LIPI.

2.2 Plankton identification

In this study, we investigated the plankton with the body size above 80 µm for phytoplankton and above 300 µm for zooplankton. Plankton samples were collected using a twin plankton net equipped with a flow meter (TSK) for recording the amount of filtered water. The mesh

Table 1. Coordinates of sampling stations

Stations	Longitude (°E)	Latitude (°N)
1	94,9922	5,1148
2	94,7312	4,7822
3	94,4654	4,4464
4	94,2507	4,1240
5	95,6166	3,7028
6	95,3489	3,3049
7	95,0938	2,9586
9	96,3145	3,4601
10	96,1584	3,2390
11	95,9712	2,9904
12	96,8944	3,3780
13	96,6177	3,0012
14	96,3950	2,7235
15	96,6888	2,3953
16	96,8802	2,6751

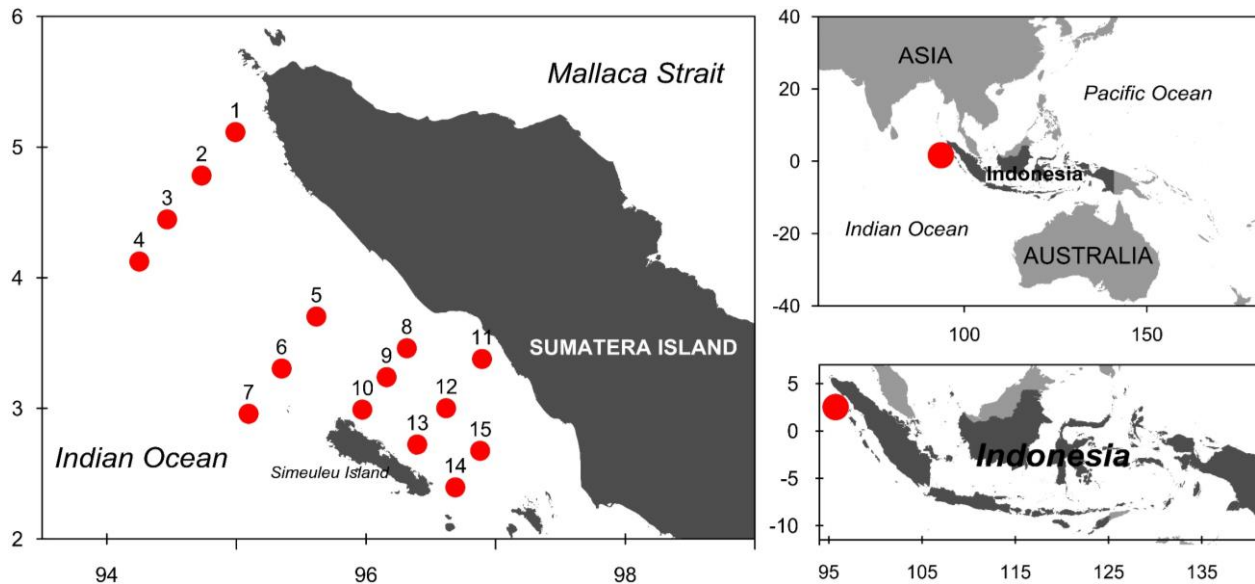


Figure 1. Maps of the study area and sampling locations in the western waters of North Sumatra

size of the plankton-net used was 80 μm for phytoplankton and 300 μm for zooplankton, which is according to plankton-net specification of Kitahara-Net and NORPAC-Net (North Pacific Standard Plankton Net) (Thoha & Rachman, 2013; Hirai *et al.*, 2015; Thoha, 2019; Rachman, 2019). Plankton-net was lowered to a maximum depth of 500 meters and then hauled vertically to the surface at a speed of 2 knots. Plankton samples were stored in the sample bottles (250 ml) and then added with 4% formalin as preservative. Samples were then identified at the Plankton Laboratory, Research Center for Oceanography, Indonesian Institute of Sciences. Plankton was observed and identified under a microscope using the Sedgwick Rafter Counting Chamber (SRCC) for phytoplankton and Bogorov counting plate for zooplankton. Identification and differentiation of plankton taxonomic groups were carried out by morphological observations based on several references such as Yamaji (1976), Wickstead (1965), and Newell *et al.*, (1963).

2.3 Environmental parameters determination

Environmental parameters observed in this study include nutrients, seawater, temperature and salinity. Seawater samples for nutrient analysis were collected in 500 ml polyethylene bottles and filtered immediately using cellulose acetate membrane with a porosity of 0.45 μm . The filtrates were then placed into a 15 ml polypropylene tubes and preserved with 100 μl solutions of saturated HgCl_2 . The sample bottles and tubes were cleaned with 1 M HCl solution and rinsed with Milli-Q water prior to sample collection. Samples for nutrient analysis were kept frozen in the dark until analysis at Marine Biogeochemistry Laboratory, Research Center for Oceanography, Indonesian Institute of Sciences. Nutrients including orthophosphate (PO_4), nitrate (NO_3), and silicate (SiO_4) were determined simultaneously using a Skalar SAN ++ Autoanalyzer (Grasshoff *et al.*, 1999). On the other hand, seawater temperature and salinity were measured *in-situ* using CTD (conductivity, temperature, and depth) SBE 911 - Plus.

2.4 Data analysis

By using the obtained data of plankton identification, the structure and of plankton community including abundance, diversity, evenness, and similarity were examined as follows:

2.4.1 Absolute abundance

Absolute abundance was determined by equation (1) (Heip *et al.*, 1998):

$$N = \sum_{i=1}^S N_i \quad (1)$$

where N is the total abundance of plankton per m^3 , N_i is the abundance of individual species per m^3 , and S is the number of species in the community.

2.4.2 Relative Abundance

Relative abundance was determined by equation (2) (Cox, 1976; Heip *et al.*, 1998)

$$P_i = \frac{N_i}{N} \quad (2)$$

where p_i is the relative abundance of species i (%), N_i is the number of individual species per m^3 , and N is the total abundance of plankton per m^3 .

2.4.3 Diversity

The diversity of plankton community determined by equation (3) (Shannon, 1948; Spellerberg *et al.*, 2003):

$$H' = -\sum_{i=1}^S P_i \cdot \ln P_i \quad (3)$$

where H' is Shannon index value, p_i is proportion of individual found in the i^{th} species, and S is the number of species in the community.

2.4.4 Evenness

Evenness of community was determined by following formula (Pileou, 1966):

$$J' = \frac{H}{H_{\max}} \quad (4)$$

where J' is the Pielou's index of evenness, H' is the Shannon's index, and H'_{max} is the maximum of H' .

2.4.5 Similarity

Similarity of communities was determined by Bray-Curtis method and used to cluster the plankton communities. Clustering was conducted using software BioDiversity Pro. Ver. 2.0. Similarity index was measured by the following formula (Bray-Curtis, 1956):

$$IS = 1 - \frac{2W}{a+b} 100\% \quad (5)$$

where IS is the similarity index of Bray Curtis, W is the number of species in community a and b, a is the number of species in community a, and b is the number of species in community b.

2.4.6 Temperature – salinity diagram

The diagram of temperature – salinity generated using Ocean Data View (ODV) Ver. 5.1.7. The identification of water masses types in the study area based on the water characteristics of temperature, salinity, and density of the global water masses list (Emery, 2003; Makarim *et al.*, 2019).

2.5 Principal component analysis

We used the Principal Component Analysis (PCA) to examine the influence of environmental parameters on the plankton community. The PCA was conducted using the statistical software, namely PAST Ver. 4.02.

3. Results

3.1 The plankton community structure

Our study showed that there were 30 genera of phytoplankton in the western waters of North-Sumatra. Twenty of them were the diatom class (Bacillariophyceae)

while ten other genera were dinoflagellate class (Dinophyceae). Diatoms dominated the phytoplankton community with a proportion of 96% while the dinoflagellates were only 4%. Phytoplankton distributed with an average abundance of $19,041 \pm 26,768$ cells/m³ and ranged from 302 to 96,329 cells/m³ (Figure 2). *Thalassionema* of the diatom class was the most abundant genus, ranged from 163 to 87,815 cells/m³.

Forty-four groups of Zooplankton were also identified in this study. The zooplankton abundance ranged from 71 to 282 individuals/m³ with an average of 123 ± 60 individuals/m³. The lowest abundance was found at station 4 (71 individuals/m³) and station 7 (71 individuals/m³), while the highest was at station 1 (282 individuals/m³). The zooplankton community was dominated by the Calanoida group. Figure 3 shows that Calanoida has a highest abundance and ranged from 37 to 125 individuals/m³.

The diversity levels of phytoplankton species in the western waters of North-Sumatra were low ($H' < 1$) to moderate ($1 < H' < 3.3$) (Krebs, 1989). Shannon's index values ranged from 0.49 to 2.12, with an average of 1.58 ± 0.47 (Figure 4). The lowest diversity was found at station 11 (0.49), and the highest was at station 2 (2.12). The zooplankton diversity index ranged from 1.22 to 2.15 with an average of 1.75 ± 0.23 . The lowest diversity was found at station 7 (1.22) and the highest was at station 1 (2.15). The average evenness of the phytoplankton community was 1.75 ± 0.3 ranging from 1.22 - 0.98 (Figure 4). Station with the highest evenness was Station 14 (0.98), and the lowest was Station 12 (0.17). The zooplankton evenness index ranged from 0.38 to 0.64 with an average of 0.53 ± 0.069 . The lowest evenness was found at station 7 (0.38) and the highest was at station 9 (0.64).

Figure 4. Index of diversity, abundance, and evenness of the plankton community in the western waters of North-Sumatra (Brown line: Phytoplankton; Blue line: Zooplankton).

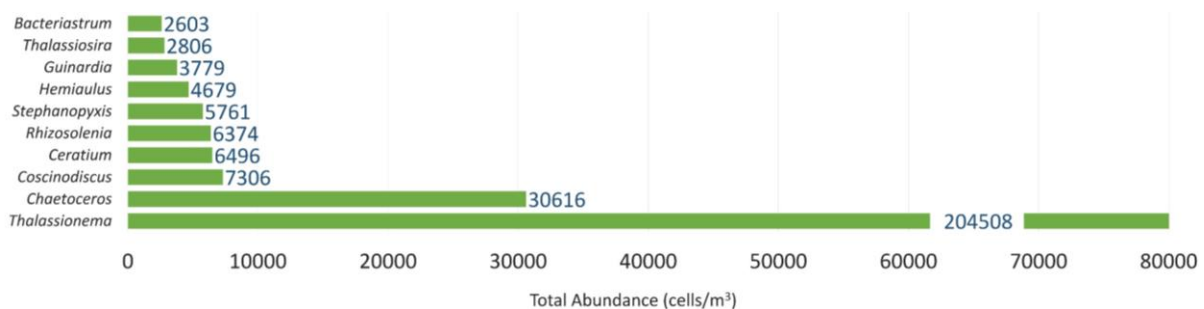


Figure 2. The ten most dominant phytoplankton in the western waters of North-Sumatra

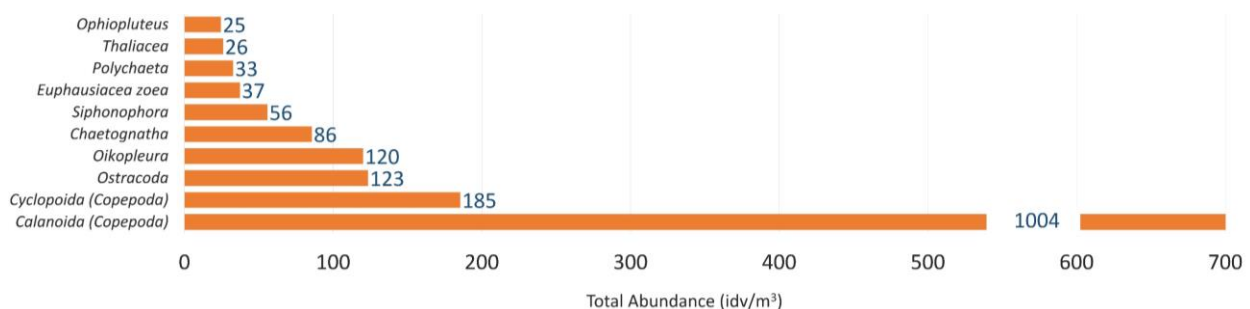


Figure 3. The ten most zooplankton community in the western waters of North-Sumatra

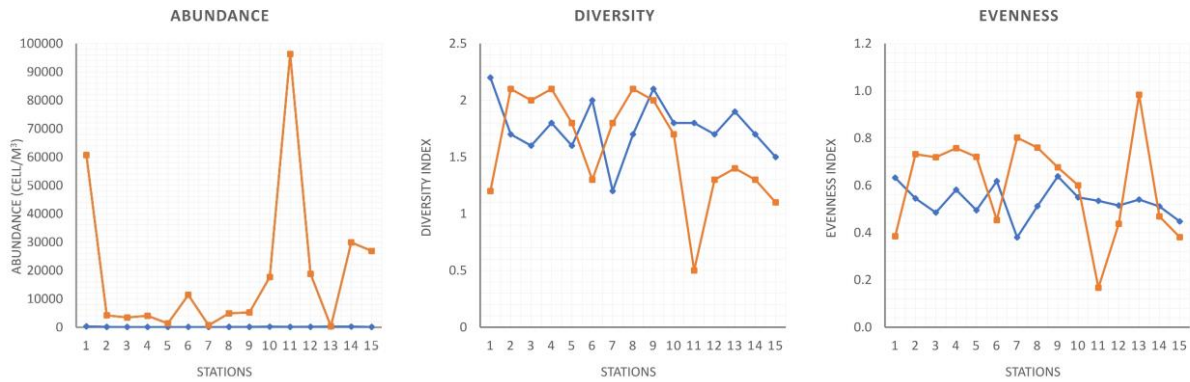


Figure 4. Index of diversity, abundance, and evenness of the plankton community in the western waters of North-Sumatra (Brown line: Phytoplankton/Blue line: Zooplankton)

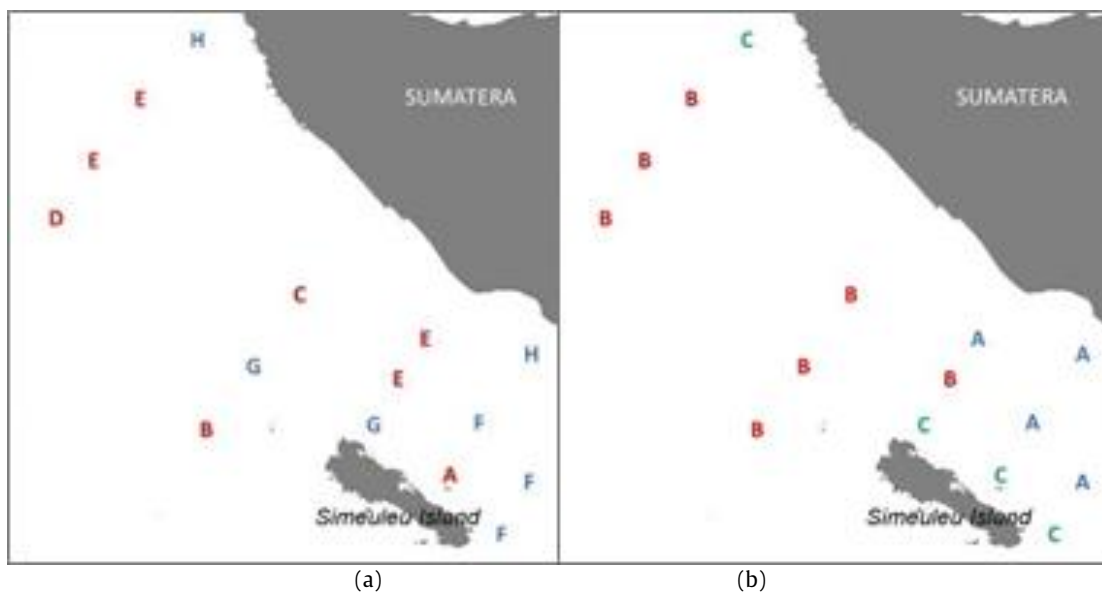


Figure 5. Distribution of phytoplankton (a) and zooplankton (b) community groups in the western waters of North-Sumatra

Figure 5 shows the distribution of phytoplankton and zooplankton in the western waters of North-Sumatra. The average \pm SD of similarity index of the phytoplankton community was $31.7\% \pm 23.40$ (Figure 6). The phytoplankton community formed eight different community groups based on the minimum similarity of 70% (Figure 6). Despite their random pattern, the eight groups were divided into two main groups with 6.8% similarity (Figure 6). The first group (A, B, C, D, E) is more distributed in the open sea area, while the second group (F, G, H) is more distributed in the waters between Sumatra and Simeuleu Island (Figure 5(a)). The zooplankton community was divided into three groups, namely groups A, B, and C (Figure 7). Group A (stations 8, 11, 12, 15) was distributed between Sumatra and Simeuleu Islands. The individual number was increasing with decreasing distance to Sumatera Island. Group B was distributed within the open seas. It was the most widely distributed group, including stations 2, 3, 4, 5, 6, 7, and 9 (Figure 5). Group C consisted of 4 stations, namely stations 1, 10, 13, and 14. This group was distributed on the eastern part of Simeuleu Island and located near the coastline (Figure 5(b)).

3.2 Spatial patterns of plankton community, nutrients, temperature, and salinity

Spatial analysis of the plankton community structure in the western waters of North-Sumatra showed a gradation pattern seaward (Figure 8). It means, the plankton abundance, both phytoplankton and zooplankton, increase gradually shoreward. In addition, spatial patterns of diversity and evenness were generally consistent, both phytoplankton and zooplankton, where stations with high diversity were associated with high evenness. It proved by the high correlation between the diversity and evenness, both phytoplankton ($r = 0.79$) and zooplankton ($r = 0.93$) (Table 2). The spatial distribution of the diversity and evenness of phytoplankton increased seaward (Figure 8). Accordingly, high abundance of phytoplankton did not correspond to high diversity and evenness. On the other hand, the abundance of zooplankton which was higher nearshore conformed to its diversity and evenness. Based on spatial distribution (Figure 8), phytoplankton was more concentrated in two locations, namely stations 1 and 11. At station 1, high abundance of phytoplankton was associated with high levels of phosphate, nitrate, and silicate. In contrast, high

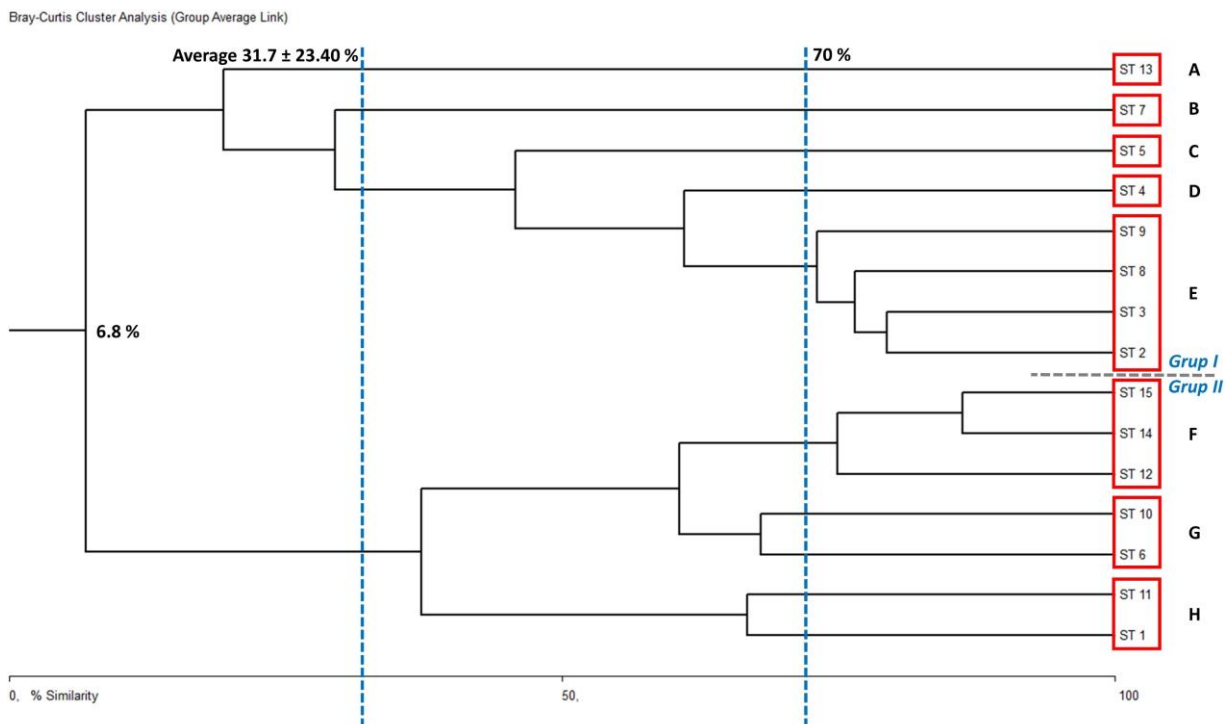


Figure 6. Dendrogram of the phytoplankton community in the western waters of North-Sumatra

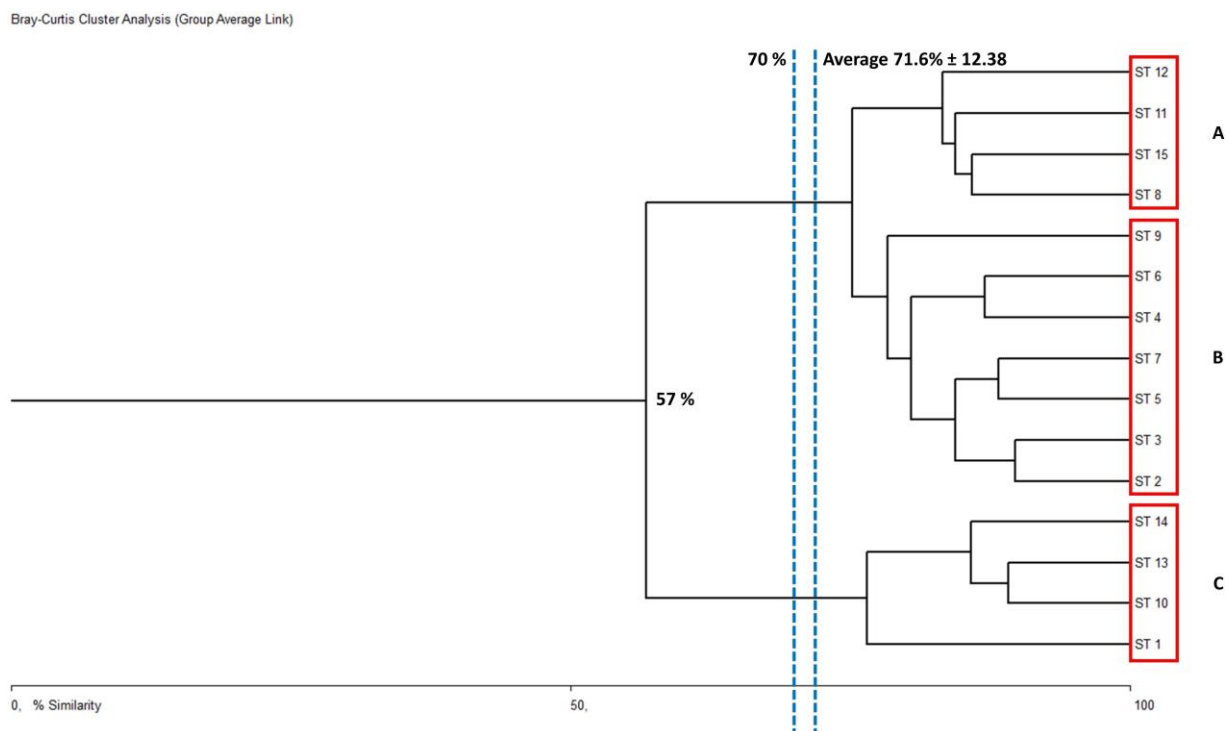


Figure 7. Dendrogram of the zooplankton community in the western waters of North-Sumatra

abundance of phytoplankton at station 11 did not correspond to nitrate, phosphate, and silicate levels. Additionally, high abundance of phytoplankton as a potential food source did not correspond to zooplankton either in station 11 (Figure 8).

Nutrient distribution was inconsistent between north part and south part regions of the study area. Phosphate, nitrate, and silicate levels were relatively higher at the north part than that of the south part. A low level of silicate in the south part region was observed at station 11

and 12. Temperature and salinity characteristics were also dissimilar between the north and south parts. It may indicate that there were two different water masses among the north and the south regions. According to the N: P ratio, nitrogen was the limiting factor for phytoplankton growth ($N:P < 16:1$). The average values of the N:P ratio were 7.2 ranging between 6.1 and 10.7. North parts of study area has a relatively lower and more homogenous N:P value than the south does (Figure 8).

Table 2. Matrix correlation (Spearman's Correlation) between plankton and environmental factors

	Abundance of Zooplankton	Diversity of Zooplankton	Evenness of Zooplankton	Abundance of Phytoplankton	Diversity of Phytoplankton	Evenness of Phytoplankton
Abundance of Zooplankton	1.00					
Diversity of Zooplankton	0.51	1.00				
Evenness of Zooplankton	0.34	0.93	1.00			
Abundance of Phytoplankton	0.54	0.31	0.24	1.00		
Diversity of Phytoplankton	-0.46	-0.15	0.05	-0.68	1.00	
Evenness of Phytoplankton	-0.39	-0.11	-0.06	-0.90	0.79	1.00
N	0.04	-0.03	0.14	0.19	0.33	-0.10
P	-0.09	0.05	0.20	0.07	0.49	0.07
Si	0.10	0.23	0.35	-0.22	0.29	0.22
N : P	0.50	-0.03	-0.23	0.39	-0.62	-0.41
Temperature	0.46	0.18	0.16	0.10	-0.19	-0.14
Salinity	-0.22	-0.16	-0.06	-0.24	0.12	0.15
Value (+ / -)	0	0 < 1.9	2.0 < 3.9	4.0 < 5.9	6.0 < 7.9	8.0 < 1.0
Color						
Correlation	No Correlation	Very Weak	Weak	Moderate	Strong	Very Strong

4. Discussions

The micro-phytoplankton (cell size > 80 μm) community in the western waters of North-Sumatra dominance by diatom class with a proportion of 96% (Figure 9). Diatom dominance is found in many places in Indonesian waters. For instance, diatoms accounted for >90 % in the Gulf of Gili Manuk (size >80 μm) (Thoha, 2007), 96 % in Bangka Belitung (size >80 μm) (Thoha, 2004), >96.1 % in Banggai (size >80 μm) (Thoha *et al.*, 2013), Lembah Strait (size >80 μm) (Thoha *et al.*, 2019), Jakarta Bay (size >20 μm) (Sidabutar *et al.*, 2016), and >50% in Sangihe-Talaud (size >20 μm) (Sriwijayanti *et al.*, 2019). Uitz *et al.*, (2010), stated that the microplankton group is dominated by the diatom and dinoflagellate groups, while the picoplankton is dominated by the cyanobacteria group. However, based on primary production, micro-phytoplankton contributes only 32 % of the total global ocean primary production.

The smaller phytoplankton, namely nanophytoplankton (2-20 μm), contributes up to 44 %, while picophytoplankton (< 2 μm) contributes 24 % (Uitz *et al.*, 2010). Diatom has higher competitiveness, endurance, and reproduction rates than dinoflagellates (Odum, 1998). The diatoms can absorb phosphate three times faster (0.5 $\mu\text{mol/day}$) than dinoflagellates can (0.17 $\mu\text{mol/day}$) (Litchman *et al.*, 2006). For nitrate and ammonium, the absorption rate by diatoms is ten times higher than that of dinoflagellates (Litchman *et al.*, 2006). The ability of diatoms in nutrient uptake makes them superior competitors for nutrients when nitrogen is limited. Therefore, the diatom growth rate (1.47/day) is higher than dinoflagellates (0.52/day) (Odum, 1998 & Litchman *et al.*, 2006).

Plankton (phytoplankton and zooplankton) distribution in the western waters of North-Sumatra showed a gradual change seaward. Plankton abundance was decreasing seaward (Figure 8). This distribution pattern seemed to be associated with the distribution of nutrients which is relatively higher near coastal areas compared to the open sea (Ara *et al.*, 2009). Nutrients content in coastal areas mainly influenced by terrestrial factors. The occurrence of upwelling, anthropogenic activities, and input of various materials from the rivers increased nutrients in the coastal waters (Wyrтки, 1962; Valiela *et al.*, 1992; D'Elia *et al.*, 2011; Silubun *et al.*, 2015). High nutrient levels in the waters increased the growth rate of phytoplankton (Berdalet *et al.*, 1996 & Carter *et al.*, 2005). The high abundance of phytoplankton subsequently becomes an abundant food source for zooplankton. Therefore, the abundance of zooplankton in the western waters of North-Sumatra was also high near the Sumatera coastline.

Although the abundance of plankton was high near the Sumatera coastline, it did not followed by the high diversity and evenness of plankton (Figure 8). This happened since high nutrient levels only benefit certain types of phytoplankton, especially phytoplankton groups with high nutrient uptake ability, such as diatoms (Litchman *et al.*, 2006). This study confirms that the most dominant diatom species was *Thalassionema*. High nutrient input from the land may support the high population of plankton in stations 1 and 11. The presence of *Thalassionema* indicates aquatic system condition with high productivity (Schraeder *et al.*, 1990). However, diatoms groups do not always get benefit from the availability of nutrients. In low N level conditions, cyanobacteria often get benefit and dominates as they can

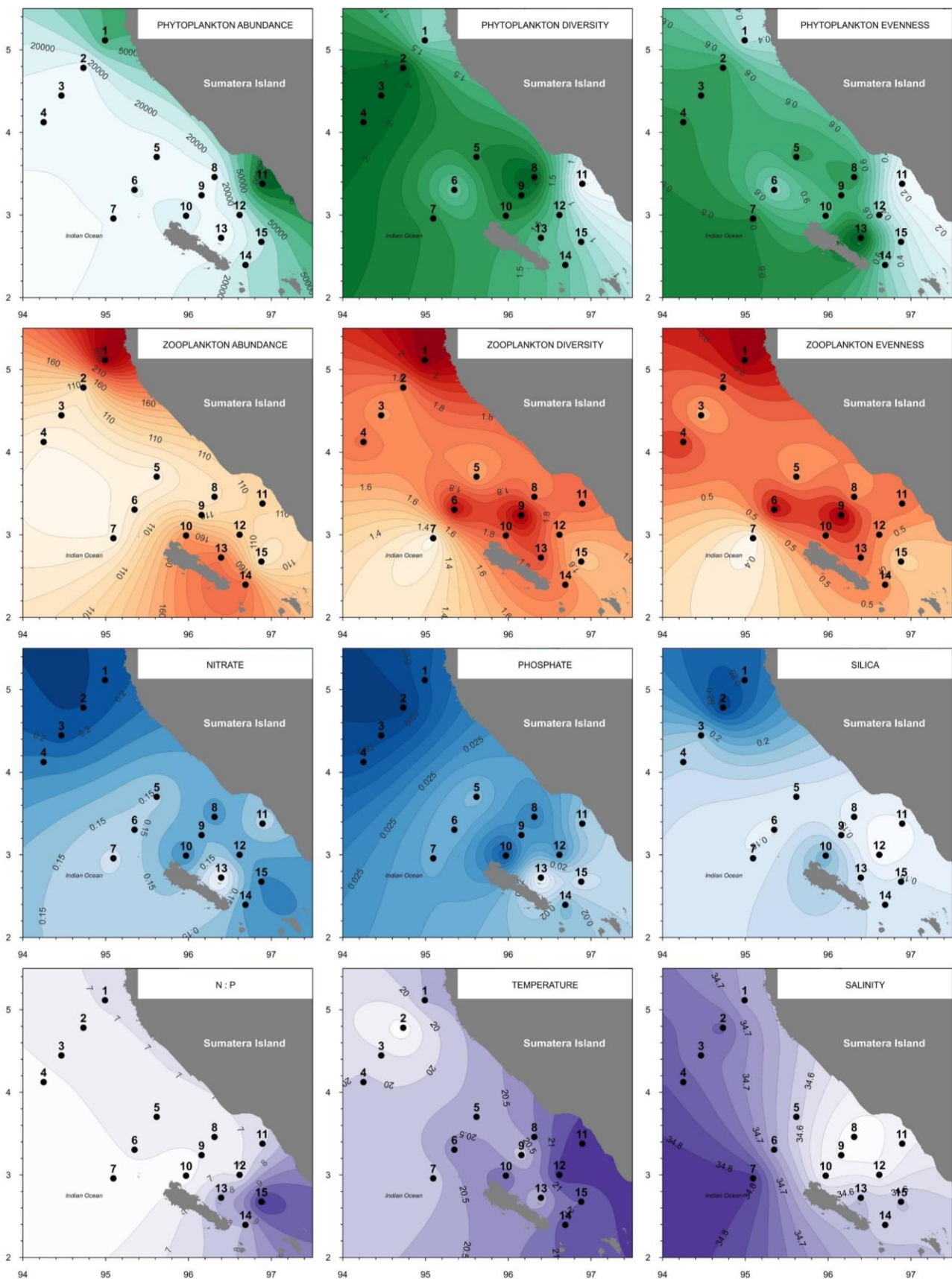


Figure 8. Spatial distribution of plankton community, nutrients, temperature, and salinity

fix N from the air (Domingues *et al.*, 2005; Yurkovskis *et al.*, 1999). The dominance of a particular type of phytoplankton can hamper the other types to obtain food resources. Therefore, diversity is often relatively low in aquatic ecosystem with high population of phytoplankton.

The plankton (both phytoplankton and zooplankton) community in the western waters of North-Sumatera generally divided into two main groups. The first group mostly distributed in the open sea region (the north part of the study area), and the second group mostly

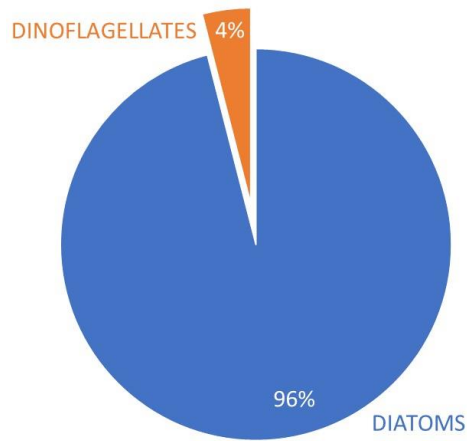


Figure 9. Diatom and dinoflagellate proportions

distributed in the area between Sumatera and Simeuleu island (the south part of the study area). The similarity index of the zooplankton community between the first and the second groups was 57%. Even the similarity index of the phytoplankton community between the first (open sea) and second (Sumatera-Simeuleu) group was only 6.8%. The disparity in the plankton community structure between the two regions was in agreement with the spatial distribution of nutrients. The spatial distribution of nutrients showed that the north parts of the area study was relatively higher than in the south (Figure 8). Presumably, this disparity of the plankton community was mainly influenced by the combination of terrestrial nutrient input from Sumatera and Simeuleu Island. However, the spatial distribution of nutrients showed that the south parts of the study area were relatively lower than in the north. Therefore, further analysis was conducted involving other factors that may have a stronger influence on the disparity of the plankton community in the two regions. The Principal Component Analysis (PCA) showed that temperature and salinity have a stronger influence on the abundance of the phytoplankton and zooplankton than N, P, and Si (Figure

10). In the biplot, the temperature variable located relatively closer to the variables of phytoplankton and zooplankton abundance (same quadrant), while the salinity located in the opposite position (opposite quadrant). It means that the temperature has a positive influence on the abundance of plankton, while salinity was negative.

The *in-situ* measurement of environmental parameters using CTD (Conductivity, Temperature, and Depth) sensors showed that the northern and southern parts of the study area have different temperature and salinity characteristics. Emery (2003) stated that there are five types of water masses in the upper layer (0-500) of the Indian Ocean, namely Bengal Bay Water (BBW), Arabian Sea Water (ASW), Indian Equatorial Water (IEW), Indonesian Upper Water (IUW), and South Indian Central Water (SICW). These water masses have different characteristics of temperature, salinity, and density. Spatial distribution of temperature and salinity, in the upper waters (0 to 500 m) of study area, showed that the north parts of area study have lower temperatures than the south (Figure 8). The diagram of temperature and salinity (T-S diagram) showed there are two main types of water mass in the area study, namely Bengal Bay Water (BBW) and Indian Equatorial Water (IEW) (Figure 11). The BBW has characteristic of temperature of 25-29 °C, salinity 28 - 35 PSU, and density of 21-23 σ_θ (Emery, 2003; Makarim *et al.*, 2019). The IEW has characteristic of temperature of 8 to 23 °C, salinity of 34.6 - 35 PSU, and density of 23.5 - 27 σ_θ . During the transition period of monsoon, the equatorial jet current divided into three directions when reached the western water of Sumatera. One of them flows northerly along the western water of Sumatera toward Bengal Bay and meets the Andaman Sea current at the western waters of North-Sumatera (Mardiansyah *et al.*, 2014). Sugianto *et al.*, (2007) stated that the western waters of Sumatra are the encounter area of the Andaman Sea waters from the North and Indian Ocean waters from the equator. Bengal Bay and the Andaman Sea have oceanographic connections due to their close proximity, and they are influenced by branches

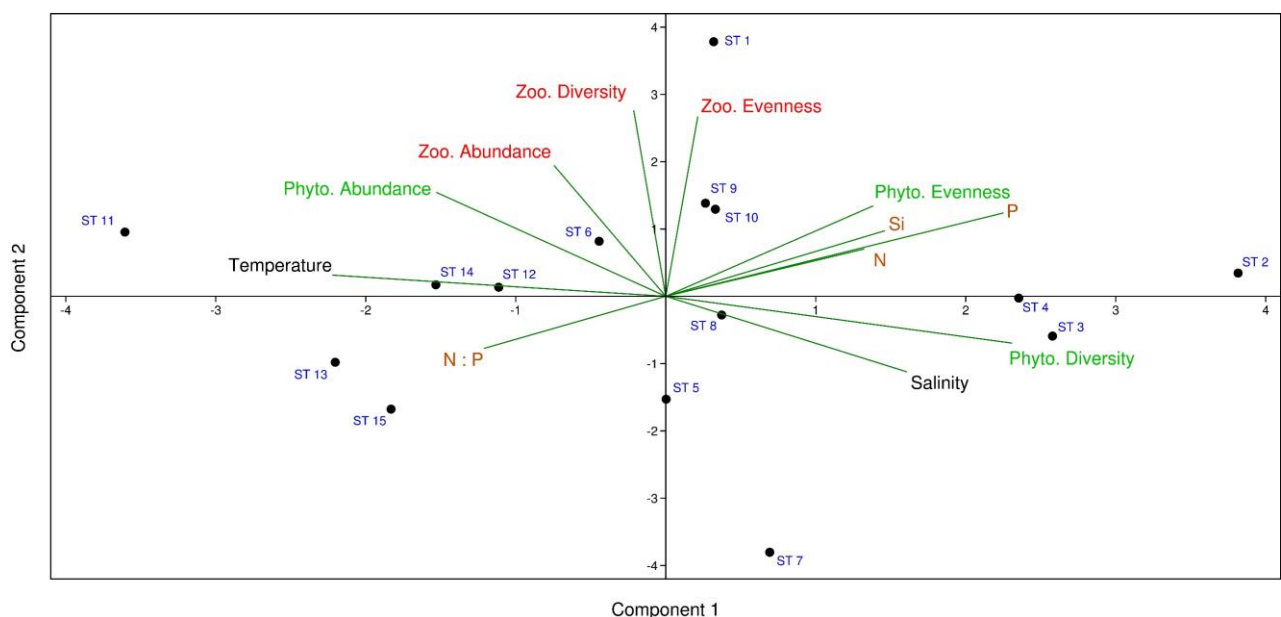


Figure 10. Principal Component Analysis (PCA)

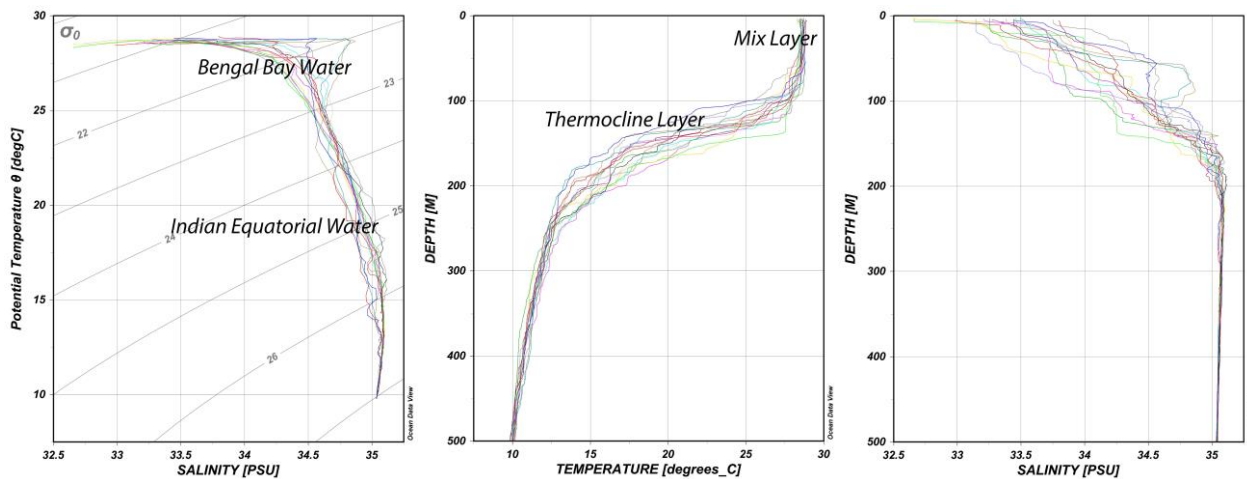


Figure 11. The T-S diagram and the profile of temperature and salinity in the study area

of the Equatorial Current system (Varkey *et al.*, 1996). We assumed that water mass characteristics in the northern parts of the study area reflect the characteristic of Bengal Bay Water. Meanwhile, in the south part reflect the characteristics of the Indian Equatorial Water that flows along West Sumatra. The confluence of the two currents causes changes of various water characteristics in the western waters of Sumatra, including temperature, salinity, and nutrients between the north and the south parts of area study. The changes in water characteristics will subsequently generate different plankton communities between the north and the south parts of the study area.

An interesting phenomenon occurred at station 11 where the phytoplankton was abundant while nutrients as its nourishment were relatively low (Figure 8). This phenomenon may indicate that nutrients were used up by *Thalassionema*. In addition, the growth phase of the *Thalassionema* population had reached the peak phase or it was in transition from the stationary phase to the death phase. This indication underpinned by the data of the phytoplankton abundance that reached 87,815 cells / m³, which is two times higher than it was at Station 1. Such conditions have an impact on the high utilization of nutrients, especially silica by *Thalassionema*. It was evidenced by spatial distribution of nutrients showing that silica content at station 11 was relatively lower among other stations. Previous study which was conducted by Saito *et al.* (2006) also found the fact that diatom bloom was in the stationary phase when silicate content was very low. As a diatom, *Thalassionema* requires silica as the main element in the formation of cell walls (Noll *et al.*, 2002). Phytoplankton growth peak occurs when phytoplankton has passed the stationary phase where the availability of nutrients is no longer sufficient to meet the needs. At this stage, phytoplankton population begins to enter the death phase (death/declining phase) (Saito *et al.*, 2006).

5. Conclusion

The study showed that the microphytoplankton community in the western waters of North-Sumatera, during the onset monsoon of Asian winter, was dominated by *Thalassionema* (diatom) while the zooplankton was dominated by Copepoda. The plankton community

formed two main groups. The first group was concentrated in the open sea region (north part of the study area), and the second group was concentrated in the waters between the Sumatera and the Simeuleu island (south part of area study). The disparity between those two groups of plankton communities was mainly influenced by the temperature and salinity of water mass. The diagram of temperature and salinity (T-S diagram) showed there are two main types of water mass in the area study, namely Bengal Bay Water (BBW) and Indian Equatorial Water (IEW). We assumed these water characteristics subsequently generate different plankton communities between the north and the south parts of the study area. For future study, we recommend using a plankton net with mesh size below 80 mm to get the smaller phytoplankton (nanoplankton) which has higher contributions to global ocean primary production. Furthermore, the in-situ analysis of chlorophyll is also recommended to conduct in future studies. It is important to get a comprehensive understanding of the effect of the monsoon dynamic on primary production in the western water of North-Sumatera. Especially, under the issues of fisheries, biodiversity, and climate change.

Acknowledgement

We thank the team of Cruise Ekspedisi Widya Nusantara 2017 for the cooperation. We thank also the Research Center for Oceanography, Indonesian Institute of Sciences, as an organizer of the cruise.

References

- Ara, K. and Hiromi, J. (2009). Seasonal variability in plankton food web structure and trophodynamics in the neritic area of Sagami Bay, Japan. *Journal of Oceanography*, Vol. 65. 757-779.
- Behrenfeld, M. J. and Falkowski, P. G. (1996). Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnol. Oceanogr.* Vol. 42, 1-20.
- Berdalet, E., Marrase, C., Estrada, M., Arin, L. and Maclean, M. (1996). Microbial Community Responses to Nitrogen and Phosphorus Deficient Nutrient Inputs: Microplankton Dynamics And Biochemical Characterization. *J. Plankton Res.*, 18(9): 1627-1641.
- Betsill, R. K. and Van Den Avyle, M. J. (1997). Effect of Temperature and Zooplankton Abundance on Growth and Survival of

- Larval Threadfin Shad. *Transactions of the American Fisheries Society*, Vol 126 (6). 999-1011.
- Bray, J. R., & Curtis, J. T. (1957). An Ordination of the Upland Forest Communities of Southern Wisconsin. *Ecological Monographs*, 27 (4), 325-349.
- Carter, C. M., Ross, A. H. Schiel, D. R. Howard-Williams, C. and Hayden, B. (2005). In Situ Microcosm Experiment on The Influence of Nitrate and Light on Phytoplankton Community Composition. *J. Exp. Mar. Biol. Ecol.*, Vol. 326. 1-13.
- Chang C.P., Wang Z., Hendon H. (2006) The Asian winter monsoon. In: The Asian Monsoon. Springer Praxis Books. Springer, Berlin, Heidelberg.
- Chen, M., Fan, M., Liu, R., Wang, X., Yuan, X., & Zhu, H. (2015). The dynamics of temperature and light on the growth of phytoplankton. *Journal of Theoretical Biology*, 385, 8-19.
- Cox, G.W. (1976). *Laboratory Manual of General Ecology*. 3rd edition. Iowa: W. C. Brown Company Publishing.
- D'Elia, C. F., Sanders, J. G. and Boynton., W. R. (2011). Nutrient Enrichment Studies in a Coastal Plain Estuary: Phytoplankton Growth in Large-Scale, Continuous Cultures. *Canadian Journal of Fisheries and Aquatic Sciences.*, 1986, 43(2): 397-406.
- Domingues, R. B., Barbosa, A. and Galvao, H. (2005). Nutrients, Light, And Phytoplankton Succession in A Temperate Estuary (the guadiana, southwestern Siberia). *Estuarine, Coastal, and Shelf Science*, Vol. 64. 249-260.
- Duan, Y., Liu, L., Han, G., Liu, H., Yu, W., Yang, G., Wang, H., Wang, H., Liu, Y., Zahid, and Waheed, H. (2016). Anomalous behaviors of Wyrтки Jets in the equatorial Indian Ocean during 2013. *Scientific Report*, Vol. 6 (29688), 1-7.
- Emery, W. J. (2001). *Water Types and Water Masses*. Encyclopedia of Ocean Sciences, 3179-3187.
- Falkowski, P., Scholes, R. J., Boyle, E., Canadell, J. Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S., Mackenzie, F. T., Iii, B.M., Pedersen, T., Rosenthal, Y., Seitzinger, S., Smetacek, V. and Steffen, W. (2000). The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System. *Science, New Series*, Vol. 290 (5490). 291-296.
- Gordon, A., Shroyer, E., Mahadevan, A., Sengupta, D., and Freilich, M. (2016). Bay of Bengal: 2013 Northeast Monsoon Upper-Ocean Circulation. *Oceanography*, 29(2), 82-91.
- Grasshoff, K., Kremling, K. and M. Ehrhardt. (1999). Methods of seawater analysis, 3rd Edn., WileyVCH, Weinheim, 600 pp.
- Heip, C. H. R., Peter M. J. and Soetaert, K. (1998). Indices of diversity and evenness. *Oceanis*, Vol. 24 (4). 61-67.
- Hirai, J., Yasuike, M., Fujiwara, A., Nakamura, Y., Hamaoka, S., Katakura, S., Takano, Y. and Nagai, S. (2015). Effects of plankton net characteristics on metagenetic community analysis of metazoan zooplankton in a coastal marine ecosystem. *Journal of Experimental Marine Biology and Ecology*, Vol. 469, 36-43.
- Kadim, M. K., Pasingi, N. and Kasim, F. (2018). Spatial and temporal distribution of phytoplankton in the Gorontalo Bay, Indonesia. *AAFL Bioflux*, Vol 11 (3). 833-845.
- Khasanah, R., Sartimbul, A. and Herawati, E. (2013). Kelimpahan dan Keanekaragaman Plankton di Perairan Selat Bali. *ILMU KELAUTAN: Indonesian Journal of Marine Sciences*, Vol. 18, No. 4, pp. 193-202.
- Krebs, C. J. (1989). *Ecological Methodology*. Harper and Row Publisher. New York.
- Litchman E., Klausmeier C. A., Miller J. R., O. Schofield M., Falkowski P. G. (2006). Multi-nutrient, multigroup model of present and future oceanic phytoplankton communities. *Biogeosciences, European Geosciences Union.*, Vol. 3 (4). 585-606.
- Loiterton, B., Sundbom, M. and Tobias, V. (2004). Separating Physical and Physiological Effects of Temperature on Zooplankton Feeding Rate. *Aquatic Sciences*. Vol. 66. 123-129.
- Makarim, S., Sprintal, J., Liu, Z., Yu, W., Santoso, A., Yan, X-H. and Susanto, R. D. (2019). Previously unidentified Indonesian Throughflow pathways and freshening in the Indian Ocean during recent decades. *Scientific Reports*, Vol. 9 (7364), 1-13.
- Mardiansyah, W. and Iskandar, I. (2014). Variasi temporal Arus Wyrтки di Samudera Hindia dan hubungannya dengan fenomena Indian Ocean Dipole. *J. Segara*, Vol. 10 (2), 98-105.
- Newell, G. E. and R. C. Newell. (1963). *Marine Plankton. A Practical Guide*. Hutchinson of London. UK. 244p.
- Noll, F., Sumper, M., and Hampp, N. (2002). Nanostructure of Diatom Silica Surfaces and of Biomimetic Analogues. *Nano Letters*, Vol. 2 (2). 91-95.
- Odum, E.P. (1998). *Dasar-dasar Ekologi*. Diterjemahkan oleh Tj. Samingan. Gajah Mada University Press, Yogyakarta.
- Pielou, E. C. (1966). The Measurement of Diversity Types of Biological Collection. *Journal of Theoretical Biology*, Vol. 13. 131-144.
- Prerna, S., Chatterjee, A., Mukherjee, A., Ravichandran, M., and Shenoi, S. S. C. (2019). Wyrтки Jets: Role of intraseasonal forcing. *Journal of Earth System Science*, Vol. 128 (1). 1-18.
- Rachman, A. (2019). Struktur Komunitas Fitoplankton di Area Tambang Timah dan Perairan Sekitar Kabupaten Bangka Barat. *Jurnal Teknologi Lingkungan*. Vol. 20 (2), 189-204.
- Saito, H., Tsuda, A., Nojiri, Y., Nishioka, J., Takeda, S., Kiyosawa, H., Kudo, I., Noiri, Y., Ono, T., Taira, Y., Suzuki, K., Yoshimura, T. and Boyd, P. W. (2006). Nutrient and phytoplankton dynamics during the stationary and declining phases of a phytoplankton bloom induced by iron-enrichment in the eastern subarctic Pacific. *Deep Sea Research Part II: Topical Studies in Oceanography*, Vol. 53 (20-22). 2168-2181.
- Schalk, P.H. (1987). Monsoon-Related Changes in Zooplankton Biomass in the Eastern Banda Sea and Aru Basin. *Biological Oceanography*, Vol. 5 (1), 1-12.
- Schabhüttel, S., Hingsamer, P., Weigelhofer, G., Hein, T., Weigert, A. and Striebel, M. (2013). Temperature and Species Richness Effects In Phytoplankton Communities. *Oecologia*, Vol. 171 (2). 527-536.
- Schott, F. A. and McCreary, J. P. (2001). The monsoon circulation of the Indian Ocean. *Prog. Oceanogr.* Vol. 51 (1), 1-123.
- Schrader, H. and Sorknes, R. (1990). Spatial and temporal variation of Peruvian coastal upwelling during the last Quaternary. *Proceedings of the Ocean Drilling Program, Scientific Results*, Vol. 112: 391-406.
- Shannon, C. E. (1948). A mathematical theory of communication. *Bell System Technical Journal*, Vol. 27. 379-423.
- Sidabutar, T., Bengen, D., Wouthuyzen, S. and Partono, T. (2016). The Abundance of Phytoplankton and Its Relationship to the N/P Ratio in Jakarta Bay, Indonesia. *Biodiversitas*, Vol. 17 (2). 673678.
- Silubun, D. T., Lumban-Gaol, J., and Naulita Y. (2016). Estimasi Intensitas Upwelling Pantai Dari Satelit Aquamodis Di Perairan Selatan Jawa Dan Barat Sumatera. *Jurnal Teknologi Perikanan dan Kelautan*, Vol. 6 (1). 21-29.
- Spellerberg, I. F. and Fedor, P. J. (2003). A tribute to Claude Shannon (1916-2001) and a plea for more rigorous use of species richness, species diversity and the "Shannon-Wiener" Index. *Global Ecology and Biogeography*, 12 (3), 177-179.
- Sriwijayanti, L. A., Djumanto, D., Setiawan, R. Y., Firdaus, M. R., Fitriya, N. and Sugeha, H. Y. (2019). Community Structure of Phytoplankton in The Surface and Thermocline Layers of

- Sangihe And Talaud Waters, Indonesia. *Bonorowo Wetlands*, 9 (2): 51-58.
- Sugianto, D. N. and Agus, A.D.S. (2007). Studi pola Sirkulasi Arus Laut di Perairan Pantai Provinsi Sumatera Barat. *Ilmu Kelautan*. Vol. 12 (2). 79-92.
- Tang, S., Rachman, A., Fitria, N., and Chen, B. (2018). Phytoplankton changes during SE monsoonal period in the Lembeh Strait of North Sulawesi, Indonesia, from 2012 to 2015. *Acta Oceanol. Sin.* Vol. 37 (12). 9-17.
- Toha, Hikmah. (2004). Kelimpahan Plankton Di Perairan Bangka-Belitung Dan Laut Cina Selatan, Sumatera, Mei - Juni 2002. *MAKARA Sains*, Vol. 8 (3). 96-102.
- Toha, Hikmah. (2007). Kelimpahan Plankton di Ekosistem Perairan Teluk gilimanuk, Taman Nasional, Bali Barat. *MAKARA, Sains*, Vol. 11, No. 1, April 2007: 44-48.
- Toha, H. and Rachman, A. (2013). Kelimpahan Dan Distribusi Spasial Komunitas Plankton Di Perairan Kepulauan Banggai. *Jurnal Ilmu dan Teknologi Kelautan Tropis*. Vol. 5 (1). 145-161.
- Toha, H. Intan, M. D. B., Rachman, A. Senming, T. (2019). Phytoplankton Community in The Lembeh Strait, Bitung and Wori Beach, Manado, North of Sulawesi, Indonesia. *Majalah Ilmiah Biologi Biosfera: A Scientific Journal*, Vol. 36 (3), 118-125.
- Tomczak, M and Godfrey, J. S. (2001). *Regional Oceanography: An Introduction*. Pergamon.
- Trenberth K.E., Hurrell J.W. and Stepaniak D.P. (2006). *The Asian monsoon: Global perspectives*. In: The Asian Monsoon. Springer Praxis Books. Springer, Berlin, Heidelberg.
- Uitz, J., Claustre, H., Gentili, B., and Stramski D. 2010. Phytoplankton class-specific primary production in the world's oceans: Seasonal and interannual variability from satellite observations. *Global Biochemical Cycles. American Geophysical Union*, Vol. 24 (3).
- Valiela, I., Foreman, K., LaMontagne, M. Hersh, D., Costa, J., Peckol, P., DeMeo-Andreson, B., D'Avanzo, C., Babione, M. Sham, C., Brawley, J and Latjha, K. (1992). Couplings of watersheds and coastal waters: Sources and consequences of nutrient enrichment in Waquoit Bay. *Massachusetts*, Vol. 15 (4). 443-457.
- Varkey, M. J., Murty, V. S. N. and Suryanarayana, A. (1996). Physical oceanography of the Bay of Bengal and Andaman Sea. *Oceanography and Marine Biology*.
- Webster P.J. (2006) The coupled monsoon system. In: The Asian Monsoon. Springer Praxis Books. Springer, Berlin, Heidelberg.
- Wickstead, J. H. (1965). *An introduction to the study of tropical plankton*. Hutchinson & Co Publisher. United Kingdom. 160p.
- Wyrtki, K. (1961). *Physical Oceanography of the South East Asian Waters*. Published by the Scripps Institution of Oceanography, University of California, San Diego, C.A. 195 pp.
- Wyrtki, K. (1962). The Upwelling in the Region between Java and Australia during the South-East Monsoon. *Australian Journal of Marine and Freshwater Research*, Vol. 13 (3). 217 - 225.
- Wyrtki, K. (1973). An Equatorial Jet in the Indian Ocean. *Science*, Vol. 181, Issue 4096. 262-264.
- Yamaji, I. (1966). Illustration of the marine plankton of Japan. Hougusho. Japan. 369p.
- Ye, Y., Chen, B., Zhou, Q., Wang, Y., Chen, Y. and Lin, M. (2020). Phytoplankton community structure during monsoon transition period in the Lembeh strait of north Sulawesi, Indonesia. *Journal of King Saud University - Science*, Vol. 32 (1). 1190-1196.
- Yurkovskis, A., Kostrichkina, E. and Ikauniece A. (1999). Seasonal succession and growth in the plankton communities of the Gulf of Riga in relation to long-term nutrient dynamics. In: *Blomqvist E.M., Bonsdorff E., Essink K. (eds) Biological, Physical and Geochemical Features of Enclosed and Semienclosed Marine Systems. Developments in Hydrobiology*, vol 135. Springer, Dordrecht.

Declarations

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors declare no conflict of interest.

Additional information

Reprints and permission information is available at <https://mri.lipi.go.id>

Publisher's Note: Indonesian Institute of Sciences remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.