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Original article

Phytoplankton community structure during monsoon transition period in the Lembeh strait of north Sulawesi, Indonesia

Youyin Ye, Baohong Chen, Qianqian Zhou, Yu Wang, Yanghang Chen, Mao Lin

Third Institute of Oceanography, Ministry of Natural Resources, Xiamen 361005, China

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ABSTRACT

Phytoplankton community structure based on photosynthetic pigments in the Lembeh strait was studied in April 2017, during the period of monsoon transition. With data of the spatial distribution of phytoplankton community structures and environmental factors, the main factors leading to the changes in phytoplankton community structure and distribution of phytoplankton abundance were discussed. Our results show that the phosphate concentration in the north of the strait was higher than that in the south, while the distribution of nitrogen concentration was just the opposite. The silicate concentration had a significance high concentration in the bottom water of the northern strait, indicating that there was a sinking ocean current from the north. Different from previous surveys, the N/P ratio of water ranges from 2.6 to 4.56, proving that nitrogen is the nutrient limiting factor in this survey, which was due to increased phosphorus concentrations due to continuous heavy rains. The main pigments were Chl *b*, 19-hex-fucoxanthin and fucoxanthin during the period of monsoon transition. Chl *a* concentration was significantly higher in the north of the strait than in the south, and Chl *a* concentration at surface was higher than that at bottom. This is because the thrive of cyanobacteria in the northern strait, which were the main group in the Lembeh strait during monsoon transition. They can grow and reproduce in the nutrient-poor sea water, since they can use phosphonates as a source of phosphorus during metabolic processes. Compared with surveys conducted during SE monsoonal period, the abundance of phytoplankton in monsoon transition period was significantly lower. Because the upwelling brought sufficient nutrients to the water, which meet the require of phytoplankton growth, allowing phytoplankton to grow well in SE monsoon. On the whole, the results show that the changes in phytoplankton community structure and distribution of phytoplankton abundance during the monsoon transition period in the Lembeh strait is mainly affected by nutrients.

1. Introduction

Phytoplankton are the most important primary producers in the marine ecosystem. They only account for 0.2% of the biomass of the primary producers, but provide nearly 50% of the primary productivity of the earth, playing a crucial role in the material cycle and energy flow of the ecosystem (Horne et al., 1994; Jun 2011; Song et al., 2004; Yulin et al., 2004). Certain phytoplankton can also be indicators of water masses, ocean currents, or causes of harmful algal blooms. Some phytoplankton also have the ability to enrich pollutants and can be used as indicators of pollution. The abundance and species of phytoplankton change rapidly when the marine environment changes (Feiyan, 2009; Maria et al., 2007; Wong et al., 1995), so the species composition of phytoplankton is considered as a biological indicator of the marine ecosystem (Ghinaglia et al., 2004). At the same time, blooms of phytoplankton can be deadly for ecosystems, such as blooms can cause coral reefs to suffocate and die. For example, the observation of coral reef community in north of Florida showed a significant decrease in coral coverage, which studies showed was related to the blooms outbreak in spring of that year (Hu, 2003). In August 2008, a rare bloom broke out in the Persian Gulf for 10 months, which led to the mass death of corals in the region (Namin et al., 2010).

North Sulawesi has a typical equatorial climate, and the average sea level temperature changes little throughout the year (Aldrian

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and Susanto, 2003). Lembeh strait, in northeast coast of Northeast Sulawesi and situated alongside the Bitung coast, is a long, narrow strait. The strait is strongly influenced by two monsoons, the wet northwest (NW) monsoon from November to March and the dry southeast (SE) monsoon from May to September (Aldrian and Susanto, 2003). The period between the monsoons is called the inter-seasonal period (Abdul-Hadi et al., 2013). Lembeh strait is rich in marine biodiversity, which makes it one of the most popular diving sites. It is said that the Lembeh strait is home to a vast amount of plankton that supports life in the surrounding sea (Rumengan et al., 2011).

According to the 2010 census, approximately 188,000 people live along the Lembeh strait. With the rapid development of industry, agriculture and tourism activities from the Bitung city, the strait is facing the problem of environment deteriorations. Considering the environmental problems faced by the mangroves, coral reefs and seagrasses that live around the strait, and the economic benefits they represent, it is necessary to assess the marine biodiversity of the Lembeh strait in order to create a general awareness of the importance of protecting biodiversity, natural habitats and controlling pollution.

In this paper, we summarized the relationship between phytoplankton community structure and environmental factors by analyzing the data of phytoplankton groups and abundance distribution in the monsoon transition period of Lembeh strait in 2017, with aims to obtain the background of phytoplankton, understand the relationship between phytoplankton community structure and monsoon changes, and the impact of human activities on local ecology.

2. Materials and methods

The authors set out in transition season, a transition from Northeast monsoon to Southwest monsoon in 2017. Seawater samples were collected from 9 sites in the Lembeh strait (Fig. 1). When the depth of the station is less than 15 m, the surface water is taken; when the depth of the station is greater than 15 m, take the water both at the surface and 15 m.

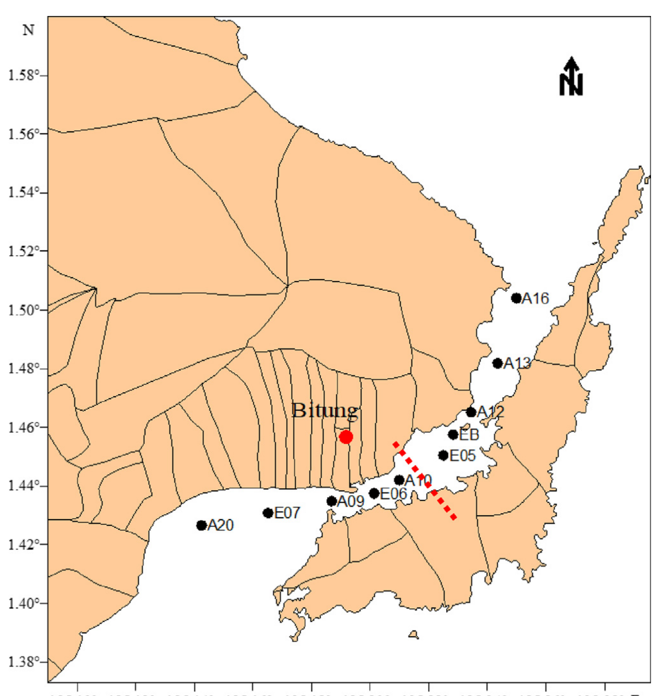

Fig. 1. Location of sampling stations.

To study the distribution of water chemical and phytoplankton groups, the survey area is divided into north and south, the northern part from site A10 to site A16, while the southern part from site A10 to site A20 (Fig. 1).

Photosynthetic pigment samples were collected and placed in a low temperature, dark place and brought back to the laboratory for filtration. 2 ~ 3 L water samples were collected by 0.7 μ GF/F filtration membrane with aperture, and the filtration negative pressure was less than 0.6 atm (1 atm = 101325 Pa). The membrane is folded in half and placed in an aluminum foil bag, then store in liquid nitrogen. Defrost the filter film in the filter paper to absorb excess water; 2 mL N and N-dimethyl formamide (DMF) were used as extraction agents. Place it in the dark at −20 °C for 2 h to fully extract the pigment. After fully mixing, centrifuge (5 min, 4 kg, −4°C), take supernatant, filter GF/F membrane with Millipore (13 mm), and collect filtrate (2 mL) in brown chromatographic vial. The whole process was carried out under low light intensity and low temperature to reduce the degradation of photosynthetic pigment.

The separation of pigments by HPLC and the use of chromatographic column and mobile phase were carried out according to references (Jixin et al., 2003, 2006). Contributions of each phytoplankton group to Chl *a* were obtained by transforming data of 13 characteristic pigments by CHEMTAX program factor analysis method (Jixin et al., 2006; Furuya, 1998; Van Heukelem and Thomas, 2001), which was expressed as Chl *a* concentration (ng/L). The initial value of characteristic pigment and chlorophyll ratio was obtained by Mackey (1998).

The collection and determination methods of dissolved inorganic nitrogen (DIN), silicate, phosphate and the others were conducted in accordance with *Marine monitoring code* (GB17378.4-2007).

3. Results

3.1. Environmental factors

Water is essential for life due to its unique chemical properties. The presence or absence of some constituents in water determines water quality that may create favorable or unfavorable condition to life form. Thus, water chemistry plays an important role in the health, abundance and diversity of the aquatic life.

The concentrations of DIN, phosphate and silicate in this survey are shown in Fig. 2. The DIN concentration in the monsoon transition period in the Lembeh strait was low. There was little difference between the surfer water and the bottom water, but varies

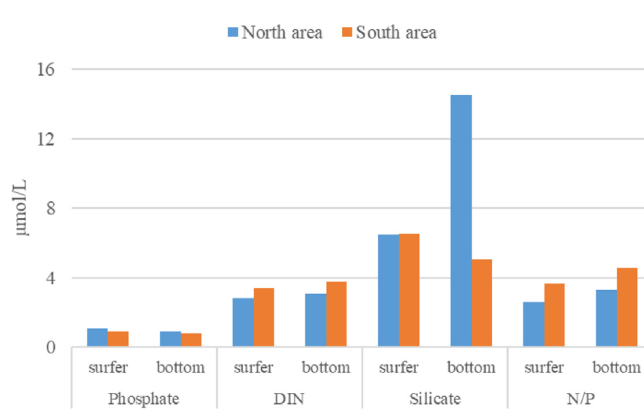

Fig. 2. Nutrient concentrations in different areas.

greatly between the south and the north, which the DIN concentration of southern strait was higher than the northern strait.

The mean value of phosphate concentration during monsoon transition period was less than 1.00 μmol/L. Contrary to DIN, the phosphate concentration in northern strait was higher than that in southern strait.

It is worth noting that the silicate concentration changes dramatically at bottom, that the silicate concentration in northern strait was as high as 3 times that in southern strait. However, the distribution of silicate concentration at surface was uniform, and there was no significant difference vary with regions.

In this survey, the N/P ratio of water ranges from 2.6 to 4.56, the mean value of N/P ratio in the bottom water was higher than the surfer water, and the southern part was higher than the northern part. Our result shows that nitrogen was a limiting factor, that was different from previous survey (Baohong et al., 2016).

3.2. Composition and distribution of photosynthetic pigments

The distribution of Chl *a* concentration in the Lembeh water is shown in Fig. 3. In the period of monsoonal alternation, the mean value of Chl *a* concentration was 273.85 ng/L. It was said that the Chl *a* concentration at surface was higher than that at bottom, and the northern water was higher than the southern water. The highest Chl *a* concentration at surface appeared at site A16 of northern part of strait, and the second was found at site A20 and A13, which at both ends of strait. The Chl *a* concentration at bottom was evenly distributed, and the highest concentration was found at site A16. The second highest Chl *a* concentration was in the middle-north part of strait, while the south of the strait had a lower Chl *a* concentration.

The composition and concentration of pigments in the Lembeh strait were dramatically spatial variation. The major pigments at surface were Chl *b*, 19-hex-fucoxanthin, fucoxanthin, β-carotene and zeaxanthin, while at bottom were Chl *a*, 19-hex-fucoxanthin, Chl *b* and Chl c_2. Fig. 4 shows the spatial distribution of pigment concentration in the Lembeh strait. Chl *b* was the main pigment during the monsoon transition period. The Chl *b* concentration in southern part of surface water was higher than that in northern part and reaches its peak at site A20. The Chl *b* concentration was evenly distributed at bottom, and the mean values of Chl *b* concentration in the north and south water were the same. The 19-hex-fucoxanthin was the major pigment as well, and its distribution in surfer water was close to Chl *b*, and the highest concentration also found in the southern water. The 19-hex-fucoxanthin concentration at bottom was evenly distributed, and the concentration in the central of the strait was slightly higher than that at both ends. The distribution of fucoxanthin concentration was

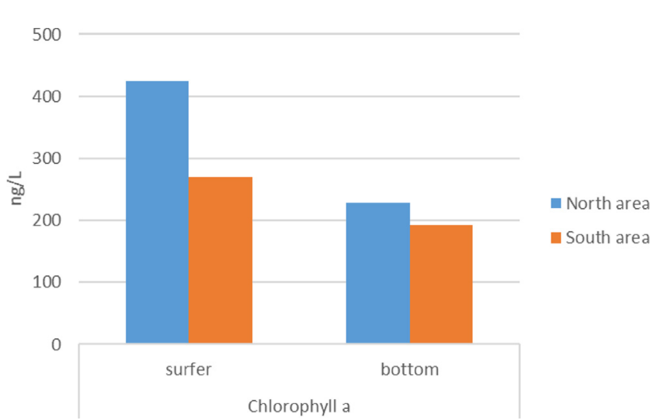

Fig. 3. Distribution of Chl *a* concentration.

higher in the surface of the southern strait. The peak of β-carotene and zeaxanthin concentrations were mainly concentrated in the northern water, and the concentration at surface was significantly higher than that at bottom. The Chl *a* and Chl c_2 concentrations were significantly higher in the southern water and the bottom water.

3.3. The abundance and spatial distribution of phytoplankton groups

As results of the CHEMTAX, cyanobacteria were the most important group in the monsoon transition period of the Lembeh strait, followed by crysophytes, prasinophytes, cryptophytes, diatoms and dinoflagellates, and the abundance of chlorophytes was the lowest (Fig. 5).

Cyanobacteria was the main group during the period of monsoon transition in the Lembeh strait, and the spatial distribution vary with regions. The cyanobacteria abundance at surface was significantly higher than that at bottom, and the northern strait was higher than the southern strait.

Crysophytes was the second group of Lembeh strait, but its abundance was only 10% of cyanobacteria. The crysophytes abundance was evenly distributed, its abundance at surface was slightly higher than that at bottom, and the southern water was slightly higher than the northern water.

The mean value of prasinophytes abundance was same with crysophytes. But different from other groups, its abundance in the bottom water was higher than that in the surface water, and the distribution of abundance was more uniform.

There was little difference in cryptophytes abundance between the surface water and the bottom water. The abundance at surfer shows an obvious decreasing trend from south to north, while it was just opposite at bottom. Among them, the cryptophytes abundance at site A20, which in the southernmost strait, was less than 5.00 ng/L.

The other phytoplankton groups abundance was very low, theirs sum of abundance of diatoms, dinoflagellates and chlorophytes was less than 50 ng/L.

3.4. Composition and distribution of phytoplankton community

Cyanobacteria was the main group in the Lembeh strait during monsoon transition period, which was the largest dominant group in whole area and contributes 75% to the total abundance (Fig. 6). Its proportion was decreasing from the northernmost to the central and then increasing to the southernmost. The proportion of crysophytes at surface was larger than that at bottom, and the proportion of crysophytes in the strait increases from northernmost to southernmost, which was especially obvious in the surface water. Prasinophytes were detected more at bottom, and accounting for less than 10.00% of all sites. At surface, the cryptophytes abundance was lowest in the northernmost of strait, and the distribution trend of abundance proportion was increasing from the northernmost to the middle of strait, until the central reached a high value. However, the cryptophytes at bottom had a relatively high and uniform distribution. The abundance of diatoms, dinoflagellates and chlorophytes in the monsoon transition period of Lembeh strait was low, and the contribution proportion to phytoplankton abundance was less than 5.00%.

4. Discussion

4.1. Environmental factors effects

Due to the sensitivity of marine ecosystem to environmental changes, the factors leading to change of phytoplankton com-

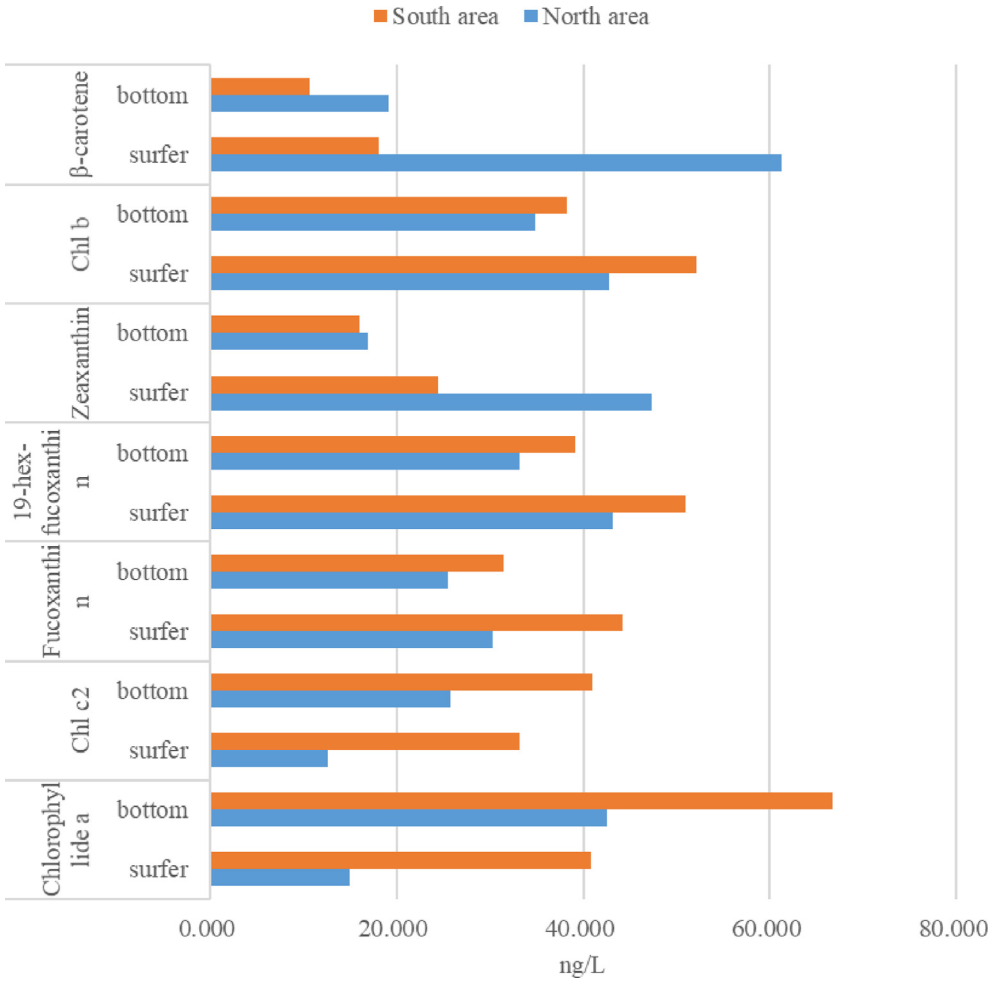

Fig. 4. Distribution of major pigments concentration in the Lembeh strait in the monsoon transition period.

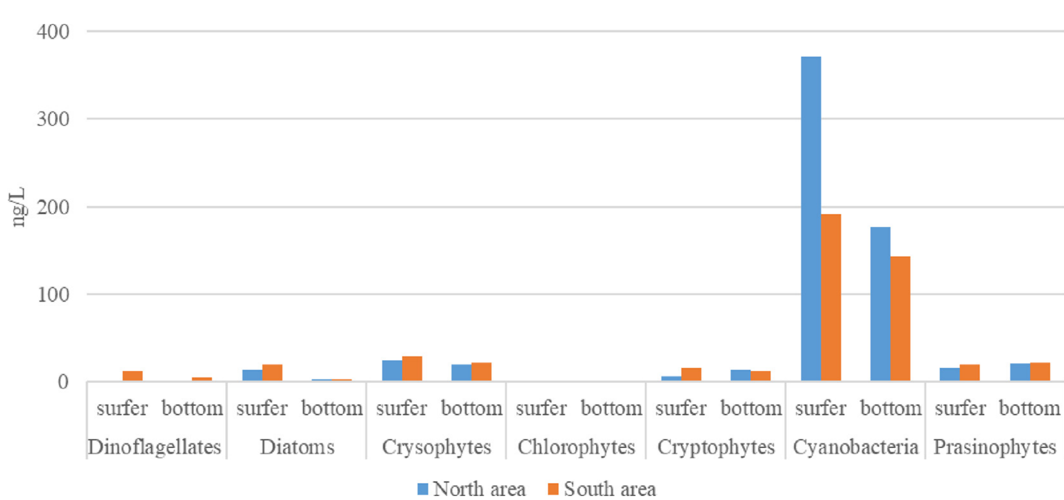

Fig. 5. Distribution of phytoplankton groups abundance.

munity structure and abundance distribution are complex (Wirtz and Wiltshire, 2005). Phytoplankton in low-nutrient tropical seas are mainly affected by nutrients and light, while nutrients supply are mainly affected by monsoons (Kämpf and Chapman, 2016; Tang et al., 2004). Thus, understanding nutrient supplies during monsoon transition period in the Lembeh strait is essential.

It is reported that, there are different water masses in the north and south of the Lembeh strait, indicate that less water exchange between the north and south of strait. (Weibo et al., 2018). In addition, North Sulawesi, located west of the equatorial Pacific Ocean, has a deep and sharp thermocline, where the water column is obviously stratified, making it difficult for rising nitrogen to maintain new primary productivity (Sophie et al., 2009). Thus, high silicate

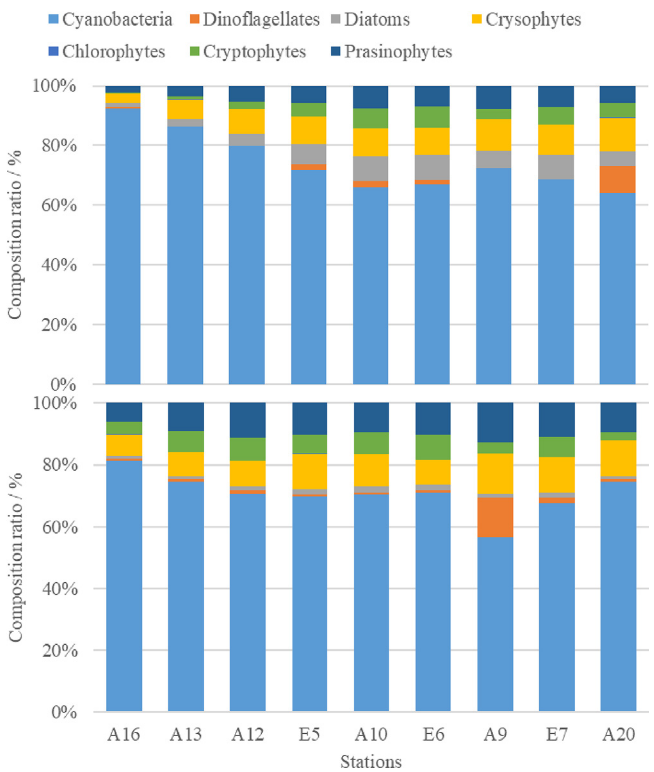

Fig. 6. Contribution of different phytoplankton groups to phytoplankton abundance in the Lembeh strait in the monsoon transition period.

concentration detected at bottom of the northern water also demonstrate that an influx of sinking current from the north to the strait. On the other hand, different from the Nanliu river (Youyin et al., 2017a,b), there is no large river discharge with high nutrient concentration to the water during the non-SE monsoon period, and low wind speed cannot form upwells (Koagouw et al., 2013). In addition, compared with other sea areas, the aquaculture in Bitung city receives limited nutrients into the seawater (Youyin et al., 2017a,b, 2018). As a result, compared with the SE monsoon period, when nutrients are fully supplied by upwelling, the monsoon transition period is nutrient-poor and difficult to the meet the require of phytoplankton growth in the Lembeh strait.

4.2. The significance of cyanobacteria in monsoon transition period

Our results show that the phytoplankton abundance was low during monsoon transition period in the Lembeh strait. Higher phytoplankton abundance in southern strait because of cyanobacteria thrive in the water. Cyanobacteria were the main group during the monsoonal alternation season, accounting for more than 75% of the total phytoplankton abundance, which was consistent with the results of microscopic examination (Senming et al., 2018). Microscopic examination shows that *Trichodesmium erythraeum* was the dominant species in the Lembeh strait during the monsoon transition. Cyanobacteria are considered an indicator of nutrient-poor water because they can use phosphonates as a source of phosphorus during metabolic processes and thrive in nutrient-deficient waters (Capone, 1997; Dyhrman et al., 2006). It is suggested that cyanobacterias were dispersed by currents or tides and came from Molukka sea because the group abundance was usually found higher in northern part than in southern part (Bin and Dirhamsyah, 2018). Therefore, the thrive of cyanbacterias indicates that the waters of Lembeh strait is nitrogen limited during this survey period, particularly, in northern strait (Fig. 2). In this survey, the phosphate concentration was relatively high and nitrogen was a limiting factor, which was due to the continuous rainstorm in the days before the survey (Bin and Dirhamsyah, 2018). This result is different from the previous survey, in which phosphorus is the main limiting factor. (Baohong et al., 2016; Senming et al., 2018).

Furthermore, the thrive of cyanobacterias may be have significance to the ecosystem of Lembeh strait. In oligotrophic seas water, characterized by low levels of inorganic nitrogen, cyanobacteria provide nutrients to the euphotic zone through nitrogen fixation and upward nutrient pumping to supplement the lack of nutrient regeneration by heterotrophic grazers to sustain phytoplankton productivity (Xu et al., 2009). Thus, we assumption that the increased levels of nitrogen fixation by *Trichodesmium* sp. have important contribution to the high biodiversity in the Lembeh strait.

4.3. Comparison of different periods

In the period of SE monsoon, the upwelling of Lembeh strait brings enough nutrients to meet the require of phytoplankton, which promotes the rapid growth of phytoplankton. During the SE monsoon period in 2015, we set 4 monitoring station in the surface water for investigation (Bin and Dirhamsyah, 2018), and compared with the same stations in this survey. Our results show that the pigment composition, major groups and phytoplankton abundance between these two periods were significantly difference (Table 1). The results indicate that phytoplankton prefer to grow during the SE monsoon, in particular, the abundance value detected at site A9 was up to 13 times higher than that in the transition period (Fig. 7). Besides, the succession of phytoplankton community was obvious during the two periods, and the major groups of phytoplankton in the SE monsoon was diatom, prasinophytes and synechococcus (Table 1).

It is reported that appearance of high diatoms abundance during SE monsoon may have indicated the sign of upwelling water emergence. Because of lower phytoplankton abundances have in fact reflected shortage of nutrient supply during the monsoon transition (Senming et al., 2018). Part of the diatoms, such as *Pseudo-nitzschia* sp. and *Thalassionema nitzschioides* prefer to grow in nutrient-rich water (Liefer et al., 2009). It is said that the increase of *Pseudo-nitzschia* sp. abundance seems to reflect the eutrophication of water, which provides a link between coastal eutrophication and harmful algal blooms (Parsons et al., 2002).

This study provided data on phytoplankton community composition and abundance distribution during monsoon transition in the Lembeh strait on the east coast of Sulawesi, Indonesia. Our results showed that, the phosphate concentration in this survey was higher than that in previous surveys since the continuous rainfall, and nitrogen was the limiting factor. Due to the influence of human activities, the nitrogen concentration was significantly high on the coast of Bitung city. And the concentration of silicate at

Table 1
Major pigments/Chl *a* ratio and phytoplankton abundance/Chl *a* ratio during SE monsoon and monsoon transition period.

Time	Major pigments/Chl *a* ratio (%)	Phytoplankton abundance/Chl *a* ratio (%)
SE monsoon	Chl *b* (0.306–0.333), zeaxanthin (0.081–0.127), fucoxanthin (0.113–0.132)	Prasinophytes (26.48), Synechococcus (25.73), Diatoms (20.49)
Monsoon tranition	β-carotene (0.065–0.165), Zeaxanthin (0.093–0.116), Chl*b* (0.059–0.218), 19-hex-fucoxanthin (0.052–0.184)	Cyanobacteria (0.828)

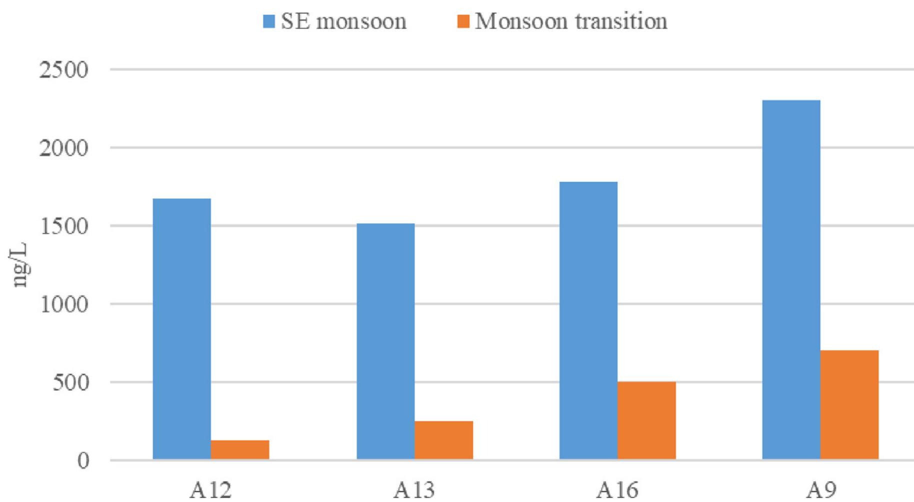

Fig. 7. Phytoplankton abundance during SE monsoon and monsoon transition period.

bottom of strait changes greatly, which may be caused by different water masses around the Lembeh strait.

In this study, cyanobacteria were found to be the dominant group in the monsoon transition period of the Lembeh strait, and prefer to grow in northern strait. This is because the south of the strait is saturated with nutrients, while the north, where nutrient conditions is poor, is more conducive to the growth of *Trichodesmium* sp.

During the period of SE monsoon, phytoplankton thrive because of upwelling to replenish enough nutrients, and the abundance of phytoplankton was significantly higher than that transition period. The phytoplankton community composition was also different from that in the transition period, mainly composed of diatoms and other species that prefer to grow in nutrient-rich waters.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Declaration of Competing Interest

All the authors hereby agreed and confirm that there is no conflict of interest for this research work and publication of this paper.

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