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Phytoplankton changes during SE monsoonal period in the Lembeh Strait of North Sulawesi, Indonesia, from 2012 to 2015

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Abstract
Phytoplankton species composition and abundance in the Lembeh Strait waters was studied in four cruises of April 2013, May 2014, June 2012 and October 2015, during the period of monsoon transition time of SE monsoon. With data obtained the seasonal alternations of phytoplankton community structures and its driving factors were discussed. A total of 416 taxa belonging to 5 classes of phytoplankton were recorded in the four month surveys. Phytoplankton density was averaged 2 348 cell/L and diatoms and dinoflagellates had the most diversified species. Cyanobacterium was characterized by its low species numbers but high abundance in the waters of Lembeh Strait. Total phytoplankton abundance occurred low in April and October in the monsoon transition period and it raised high in May and June during the SE monsoon. Frequently occurred species were pelagic diatoms in addition to cyanobacterium *Trichodesmium*. Abundance and diversity of phytoplankton significantly differed seasonally. The diatoms *Thalassionema* and *Pseudo-nitzschia*, and cyanobacterium *Trichodesmium* contributed most to the community dissimilarities. Due to potentially higher nutrient supply in the south of Lembeh Strait, diatoms and dinoflagellates showed higher densities in the south than in the north of the strait. Though, cyanobacterium preferred distributing much evenly in all waters, it had higher density in the southern Lembeh Strait. Total phytoplankton abundance is quite low compared with the Jakarta Bay and some bays in China. Analysis showed that nutrients from upwelling forced by SE monsoon are the key factor varying the monthly phytoplankton abundances. Due to its primitive nature state, Lembeh water can be an ideal location for the study of pelagic ecosystem under merely the influence of macro environment changes with lower background noise from human activities.

Key words: Lembeh Strait, phytoplankton diversity, community alternation, *Trichodesmium*, monsoon

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1 Introduction

Indonesia, consisting of approximately 17 506 islands of estimated 81 000 km coastline which span a distance of 5 200 km and an area of 2 000 000 km^2, because of the nature of the archipelago's complex, geological origins, many of its islands support unique flora and fauna found nowhere else in the world (Ross and Wall, 1999). Locating on the equator has made Indonesia as a country that is very rich in natural resources with extraordinary diversified species included in the group of mega-biodiversity countries. Thus, Indonesia's coastal and marine resources are important to the world.

North Sulawesi has a typical equatorial climate, and the mean temperature at sea level is uniform, varying by only a few degrees throughout the region and throughout the year, from 20°C to 28°C (Aldrian and Susanto, 2003). Tides in this area are mixed and mainly semi-diurnal, and fluctuated slightly with an annual tidal range of 2.4 m. The area have one peak and one trough of and experiences strong influences of two monsoons, namely the wet northwest (NW) monsoon from November to March and the dry southeast (SE) monsoon from May to September (Aldrian and Susanto, 2003). The transition period between the monsoons is known as the inter-seasonal period (Abdul-Hadi et al., 2013). The wind condition is moderate with changing directions (Germi, 2015). The rainfall decreased from May to October and reached lowest value in July (Yulihastin and Kodama, 2010).

The total rainfall in Bitung City varies with months. Bitung Meteorology Station (2012) records that the highest rainfall in 2011 occurred in February, when it reached 296.8 mm. The lowest rainfall, only 13.7 mm, occurred in July. April was also colored with the highest rate of rainy day, with 25 d (interior report). Generally, the monthly average temperature that measured at Meteorology Station of Bitung in 2011 was 27.5°C to 29.3°C. The lowest temperature (27.5°C) occurred in February and June. The highest temperature (29.3°C) occurred in April. The tropical area of Bitung has a high relative humidity with monthly average about 75% to 81% in 2011.

The Lembeh Strait is situated alongside the Bitung coast (Fig. 1) in the east of North Sulawesi. The strait is a long, narrow and

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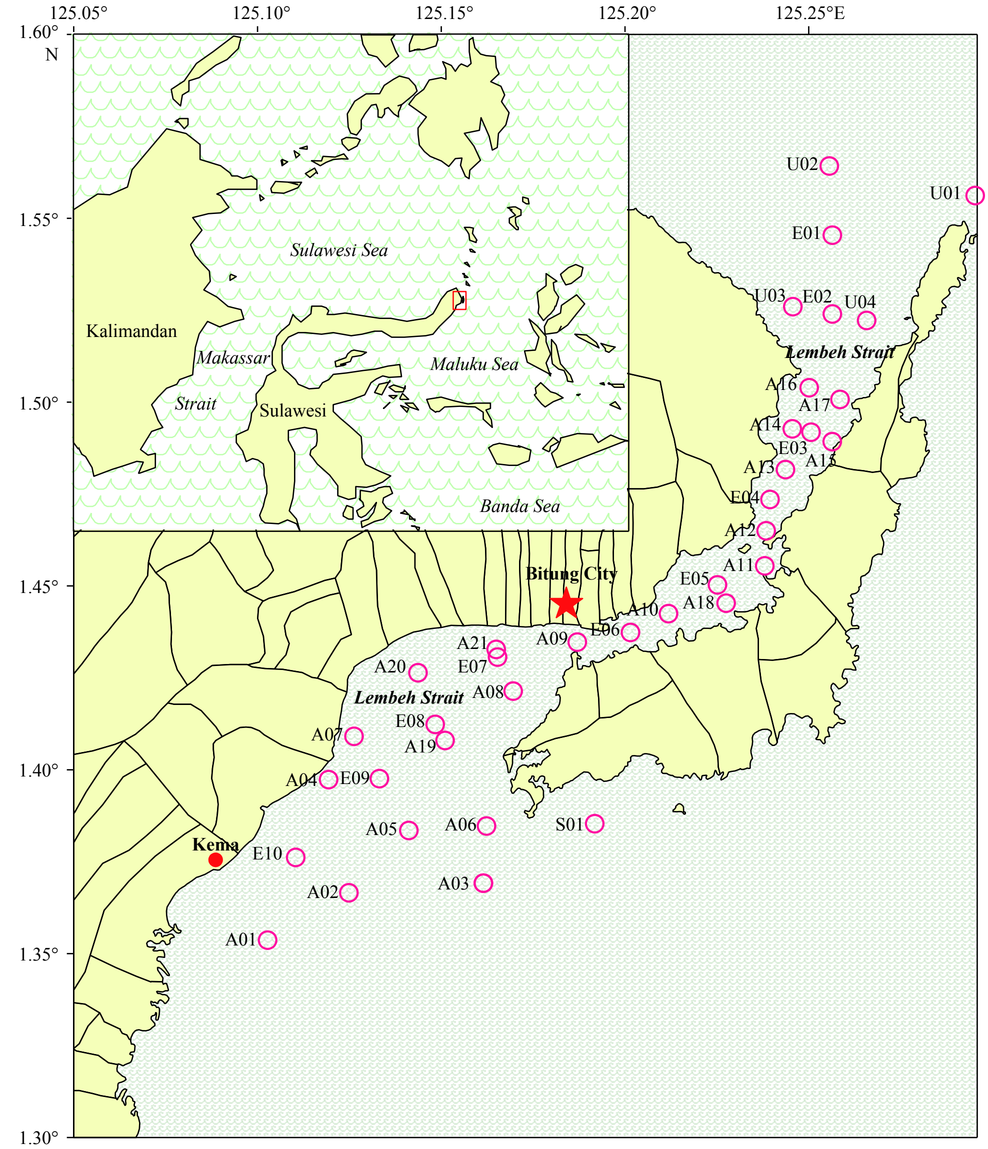


Fig. 1. Sites sampled in the Lambeh Strait for phytoplankton study in 2012–2015.

channel in the top of Northeast Sulawesi coast and sheltered by the small Lembeh Island. It is in length of 15 km and width of 1–2 km, only about 800 m at its narrowest point. It has water depth of 5–30 m with transparency as high as 25 m generally. Protected by the Lembeh Island and due to its primitive, the strait is calm, clean and charming. Many coral reefs and other marine organisms, along with exotic species (Erdmann and Vagelli, 2001), can be found in the strait, and it is a famous resort for coral reef ecotourism.

With populations of 187 652 living in the boundary of Lembeh Strait by census of 2010, coast sea waters of Bitung City and "world class" diving destinations in these areas are facing with environment deteriorations by increasing pollution burdens from transportation, aquaculture farming, fisheries, manufactory and touristic activities from the city. Considering the critical level of degradation of the coral reefs, mangroves and sea grasses and the socioeconomic interest that they represent, it is necessary to assess tropical marine biodiversity for the general awareness of the conservation of biodiversity and natural habitats. The principal goals of the investigation should acquire data on various groups of organisms, the species composition and distribution and their relations to the environments in areas of the Lembeh Strait.

To understand the potential impacts of anthropogenic activities on the biodiversity in this protect waters, it is necessary to understand the baseline and present situation of the phytoplankton in this area. As phytoplankton stand at the bottom level of the food chain, they bear a significant importance in respect of their roles in aquatic ecosystems and their relations with other living organisms at upper levels. At the same time, phytoplankton is one of the top living groups, which react fast to pollution in aquatic environment, and their species carry the information that may tell the habitat environment or the surrounding water qualities (Taylor, 2002). Thus, the composition of phytoplankton can be utilized to identify the trophic state, diversity, water quality and pollution of the areas.

Under the project of joint venture for marine diversity study by scientists from both Research Center for Oceanography, Indonesian Institute of Sciences and State Oceanic Administration (SOA) of China, we used the data of four cruises of marine biodiversity studies in the Lembeh Strait and its nearby waters from 2012 to 2015. Here, we summarize the results of phytoplankton species composition and abundance changes in months from 2012 to 2015, with aims to acquire the background of pelagic ecosystem in the areas and demonstrate the responds of phytoplankton community to monsoonal alternations and factors that may have impacted on the local ecosystem due to human activities.

2 Materials and methods

Four cruises of phytoplankton surveys conducted in Indonesia by China-Indonesia cooperation was finished in June 2012, April 2013, May 2014 and October 2015. The sites and date for the surveys are listed in Table 1. In convenience of analysis on the seasonal changes of phytoplankton abundance, the date in this report is rearranged in sequence of the months instead of years. Thus we can look into the development of phytoplankton with environmental factors.

Table 1. Date and sites for phytoplankton surveyed in the Lembeh Strait

Cruise	Date	Month	Year	Site
1	11–13	Jun.	2012	24
2	27–28	Apr.	2013	26
3	24–25	May	2014	15
4	27	Oct.	2015	12

A maximum of 36 sites were set up in the strait and they were mostly sampled in months of 2012–2015 (Fig. 1). To simplify the results, only the samples from surface water are analyzed in this report.

Phytoplankton samples were collected with bottle sampler. It is a cylinder PMMA which can take the water sample from 15 m below the water surface with capacity of 2–5 L seawater per sampling. Here, surface water samples were taken at 0.3 m below the water surface. In the surveys, 1 L water was taken, prepared and concentrated for counting.

Water sample is fixed with 5% Lugol's solution before settled and concentrated. Settlement finished after 24 h and the supernatant is siphoned. Then, the remains of the water sample were collected carefully and put finally into a 50 mL screw vial. All samples were stored in dark before carried to the laboratory of Third Institute of Oceanography, Ministry of Natural Resources, in Xiamen of China.

A special Stempel pipette in given volume of 1–5 mL, depending on the cell density, is used for the subsample. Before subsampling the vial is gently reversed several times to mix fully the phytoplankton cells. Subsample of concentrated sea water in the vial is moved to a glass chamber that is covered with slide for observation. Sample examination and cell counting are done under the inverted microscope Olympus CKX41. Generally, a minimum of 400 cells were counted per chamber (Venrick, 1978 with reference to Lund et al., 1958).

The abundance of phytoplankton is expressed as cell numbers per liter water and for cyanobacteria *Trichodesmium*, which is counted as trichome as the unit equivalent to the cell count of unicellular species. Species identification is performed following the literatures of Tomas (1997), Jin (1964), Cheng (1996) and Guo (2004) and so on.

To figure out the most important species contributing the communities in the four months, SIMPER analyses was carried out using PRIMER 5 software (PRIMER-E Ltd, Plymouth, UK). Cell density data was square rooted before process. With result of SIMPER analysis only the first three species with the highest contribution to the community abundance of each cruise are extracted. At last, the cruise data is reorganized in sequence of the months instead of the years to highlight the seasonal changes. Besides, CLUSTER analysis was done after the dissimilarity analysis and the relations between the communities of monthly investigations were probed.

Again, to examine the distribution patterns of important species, the study areas are arbitrarily divided into two areas, the north and the south parts. The water in the south of Lembeh Strait begins from Site A10 to the south, including the coastal water of Bitung City and the south opening of Lembeh Strait. The north assigned to the water to the north of Site A10.

3 Results

3.1 *Species composition*

A total of 416 taxa belonging to 5 classes of phytoplankton were recorded in the surveys of four months in four years, of which 108 genera, 295 diatoms, 104 Dinoflagellates, 9 Cyanobacteria, 6 Chrysophyta and 2 Euglenophyta were identified.

Among these taxa from the surface water of the Lembeh Strait, diatom accounts for more than 70%, dinoflagellate around 25% and Cyanobacteria, Chrysophyta and Euglenophyta about 4% of the total (Fig. 2). The composition of planktonic had high species richness at a few sites of the four month surveys. The species of *Thalassionema*, *Pseudo-nitzschia*, *Rizhosolenia*, *Trichodesmium*, etc. are common and extensively appeared in samples from the four month investigations.

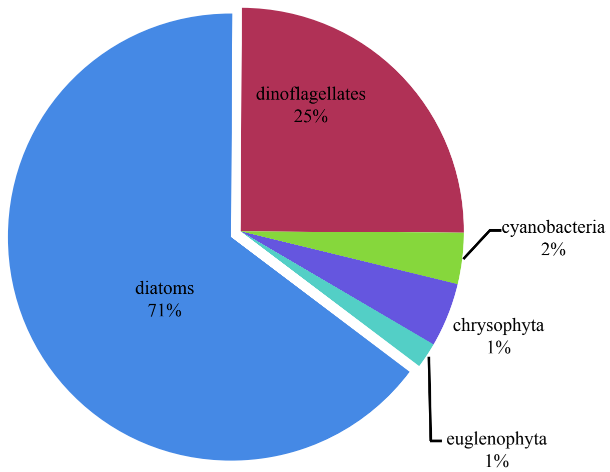


Fig. 2. Total species composition of phytoplankton from four month surveys in the Lembeh Strait.

Among the five phytoplankton groups recorded, diatoms have the most diversified species (295 species) in the surface water of Lembeh Strait and they occurred at all sites where the samples were taken. The diatom density reaches 2 348 cell/L in average in the four surveyed months. However, in terms of species composition, as one of minor group cyanobacteria is the most dominant species by abundance in Lembeh water where its density reached 436 trichome/L. The species of Cyanobacteria includes *T. eurythraeum* and *T. tiebautii*, besides occasional occurred *T. contortum*. High diversified species of dinoflagellates were also found frequently in water samples. The group of dinoflagellates is characterized by high species diversity (104 species,

Fig. 2) and lower density (110 cell/L in average) compared with diatoms and cyanobacteria (Fig. 3).

Characterized by high diversity and wide distribution in time and space, diatoms account to the highest occurring rate (31%) in the Lembeh Strait. The next, cyanobacteria occurred much frequently and dinoflagellates rank the third in its occurring rate (Fig. 4). Three of these important groups are composed of the diversities characterized by differences of abundance, species composition and occurrence. That is high abundance for diatoms and cyanobacteria, low species numbers and high occurrence of Cyanobacteria and low diversity and low abundance dinoflagellates.

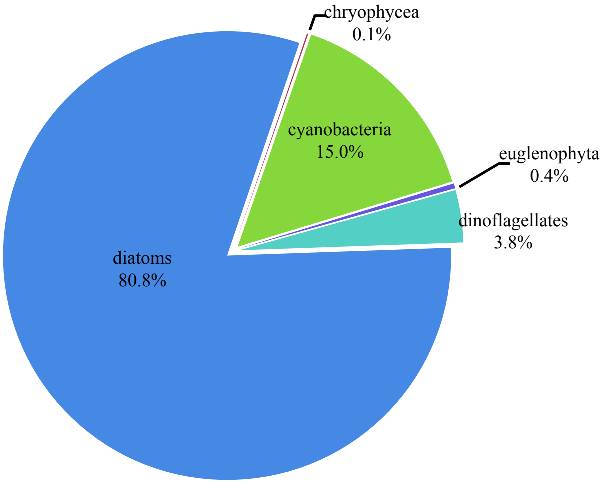


Fig. 3. Abundance composition of phytoplankton from four month surveys in the Lembeh Strait.

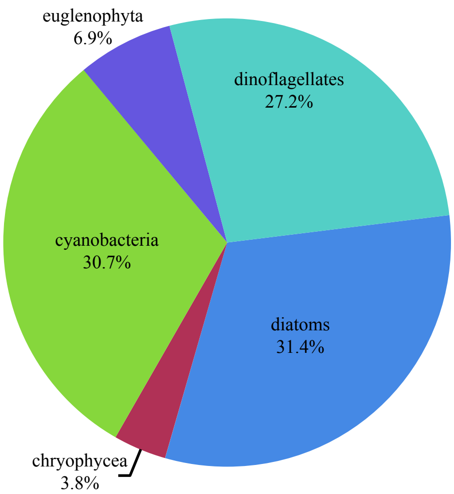


Fig. 4. Occurring rate in the surface water of the Lembeh Strait in four month surveys.

Besides, Euglenophyta is also a minor class of low occurrence, composed of *Eutreptiella* spp. and *Euglena* sp., and it had higher occurring rate in April than in other months surveyed and it covered around half sites in the Lembeh Strait where the average density reached 29 cell/L. The species occasionally found in May and June, and it did not occurred in May. It is no much difference in occurring rate among the groups of diatoms, dinoflagellates and cyanobacteria (Fig. 4) though they are quite different in their species compositions.

3.2 *Dominant species*

Dominant species changes in different months. Table 2 lists the first three species that makes the most contribution to their community densities during the time of investigations. It shows that the species of cyanobateria *Trichodesmium* has major contribution to the communities of April and October while diatoms has greater contribution to the communities of May and June. SIMPER analysis shows that the density of the first three species not only contribute the major cumulative percentage (21%–37%) to their community but also support the most dissimlarity among the monthly communities.

Though six species had made up 50% cumulative abundance to the community in April, more species, i.e., 12, 9 and 9, made up the same contribution to the communities of May, June and October, respectively (Table 2). In other word, the dominated species of the community in April was less diversified than the following months. However, *Trichodesmium* dominated much in community of April than June and October except for May. Thus, *Trichodesmium* is a common species for all four months.

Higher numbers of dominant diatom species appeared in May, June and October except for April (Table 2). Though the numbers of diatom species of Jane and October are the same included in the 50% contribution species, the diatom species has taken down the position in October community, where cyanobacteria and dinoflagellates flags their importance in the species composition.

Most of species identified are centric diatoms. They were *L. danicus*, *Skeletonema*, *Rhizosolenia*, *Thalassionema* among others. High species diversity and high abundant diatoms constituted the main community characterizing the species composition in the time of SE monsoonal period.

3.3 *Community successions*

The results of clustering analysis show that communities ap-

Table 2. Monthly dominant species with highest contribution to the community smilarities by SIMPER analysis (unit: cell/L or trichome/L for *Trichodesmium*)

Rank	April 2013	May 2014	June 2012	October 2015
1	*Trichodesmium erythraeum* 683.96	*Pseudo-nitzschia* sp. 1 374.50	*Thalassionema nitzschioides* 375.15	*Trichodesmium thiebautii* 87.39
2	*Thalassionema nitzschioides* 307.39	*Thalassionema nitzschioides* 811.83	*Thalassionema erythraeum* 198.08	*Prorocentrum micans* 201.68
3	*Trichodesmium* spp. 111.30	*Leptocylindra danicus* 623.46	*Nitzschia* sp. 1 197.18	*Thalassionema erythraeum* 151.60
Cum.%	37.67	21.36	24.59	24.41
>50%	6	12	9	9
Diatoms	3	10	8	3
Monsoon	transition	SE monsoon	SE monsoon	transition

Note: Cum.% means cumulative contributions of percentage.

peared in the sequent month are much associated except for a few sites (Fig. 5). The communities in May and June shared the dissimilarity of 71.6, which is much closer in contrast to the other two communities of October and April. Community of April is much closer with communities of May and June with dissimilarity less than 74.6. As a result, the community of October is far from the communities of the other months. The dissimilarities between the sequent months are lower than the other combinations. Thus, it shows that communities from the monthly investigation changed regularly with time. The community of October is quite different from that of May and June for that October has three month interval from the June with the changes of environmental conditions.

3.4 *Distribution patterns*

Compared with phytoplankton abundances from 4 months, the highest density (4.82×10³ cell/L) was found in May and the next, June (3.69×10³ cell/L). The lowest densities (around 1.73×10³ cell/L) occurred in April and October, less than half of the abundance in May and June (Fig. 6).

The cell numbers of diatoms contributes the most portions of the total phytoplankton densities in view of monthly distribution and thus it has a similar pattern like the monthly total phytoplankton cell distributions. However, the diatom density was much lower in April when cyanobacterium was dominating. Cyanobacteria densities dropped half in May and June and stayed the lowest in June. In contrast, dinoflagellate density developed

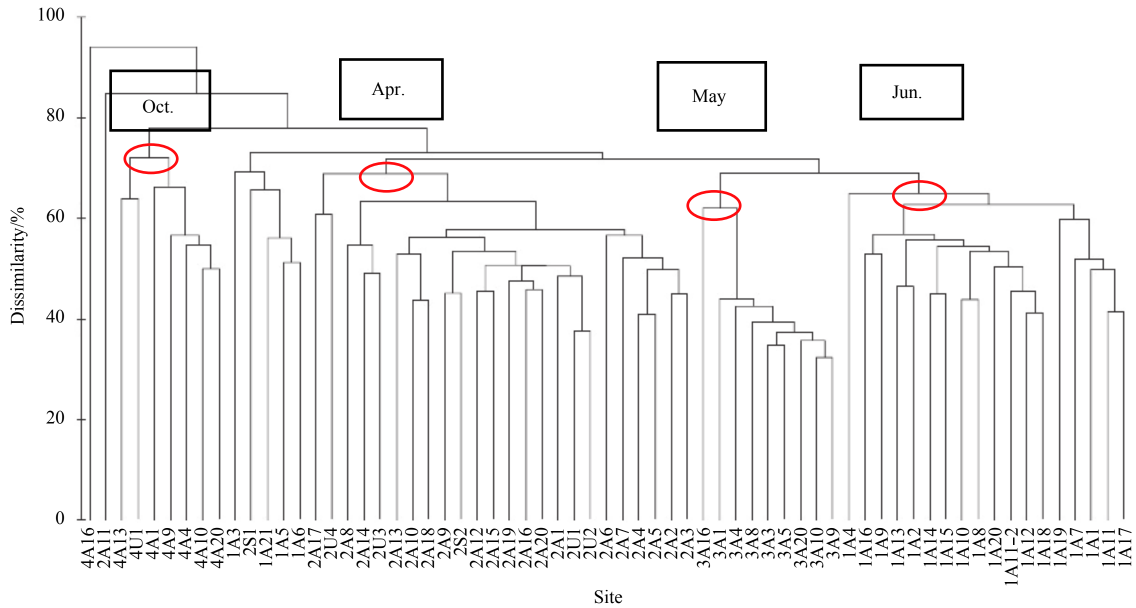


Fig. 5. Results of clustering analysis by the monthly species composition at sites of different surveys, where the first Arabic characters 1, 2, 3 and 4 stands for cruises of June, April, May and October, respectively.

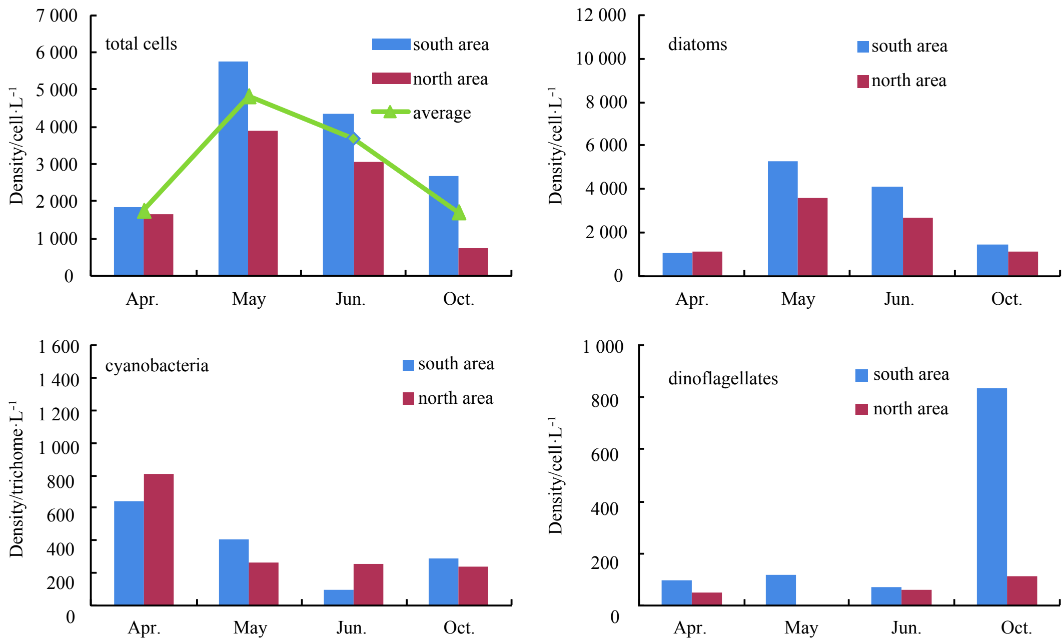
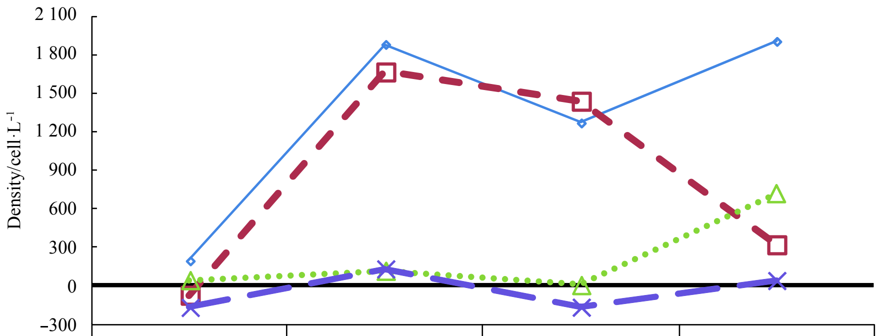


Fig. 6. Monthly distributions of phytoplankton densities in the north and south waters of the Lembeh Strait.

comparatively high in October than they were in the previous months (Fig. 6).

In view of abundant distribution both diatoms and dinoflagellates have higher densities in the south water than in the north waters of Lembeh Strait in the most time (Fig. 6). The distributions of total abundance are similar to the pattern of diatoms. In contrast to diatoms, distribution of cyanobacteria *Trichodesmium* abundance was higher in the north than in the south in April and June while in May and October it was unnoticeably higher in the south than in the north (Fig. 6). Higher cyanobacterium density in the north area was resulted from that higher *Trichodesmium* densities (>1 000 trichome/L) appeared much often in northern water than it was in the south, where cyanobacterium densities occurred in some lower densities. Thus, diatom and dinoflagellate tends to have higher abundance in the south water of Lembeh Strait than in the north while cyanobacteria *Trichodesmium* behaved reversely showing some higher density in the north water though the difference is not significant (Fig. 7).



	Apr.	May	Jun.	Oct.
total	199	1 889	1 276	1 913
diatoms	–70	1 674	1 446	324
dinoflagellates	48	121	10	725
cyanobacteria	–165	136	–163	45

Fig. 7. Density difference (cell/L) between the south and north waters of the Lembeh Strait.

4 Discussion

4.1 *Monsoonal effects*

The reason for the different in abundance distribution depends on many factors, such as hydrodynamics (including stratification), solar energy input and temperature, as marine ecosystems are sensitive to a variety of physical variables (Wirtz and Wiltshire, 2005). In water of tropical and subtropical oligotrophic seas, phytoplankton production in the ocean is usually limited by nutrient availability and solar radiation (Tang et al., 2004). It is reported the phytoplankton abundance and productivity are changed with monsoonal alternations in Indonesia waters (Kinkade et al., 1997; Gieskes et al., 1988). This is because of close relations of monsoon with nutrient supply (Kämpf and Chapman, 2016). Since types of monsoonal alternations vary with regions, the nutrient availability is complicated in Indonesia seas (Aldrian and Susanto, 2003). It is necessary to confirm the nutrient supplies during SE monsoonal period in the Lembeh Strait.

In contrast to the east coast of northern Sulawesi, the southwest coast (Labuan water) of Sabah waters, Malaysia, maintains high concentrations of nutrients due to the effect of the Padas River discharge during the rainy season (Abdul-Hadi et al., 2013). However, we expected limited nutrient supply from the runoff during the NE monsoon in Lembeh waters since geographically there is no large river discharge with substantially high nutrients to the sea during the wet season. Besides, low wind speed (<0.3 m) during the west monsoon in Bitung areas (Koagouw et al., 2013) is suggested helpless for the upwelling formation in nearby coastal waters. It is also real even in wide areas of Sulawesi seas in both monsoonal seasons (Kinkade et al., 1997). Thus, it is believed that only the period of SE monsoon can have the nutrient supply from the upwelling to meet the request of phytoplankton growth.

4.2 *Changes in phytoplankton abundances*

High phytoplankton abundances occurred in May and June is basically contributed by diatoms, which is dominated by *T. nitzschioides*, *Pseudo-nitzschia* sp. and *Leptocylindra danicus* (Fig. 3). *Pseudo-nitzschia* grew well in nutrient-rich water (Liefer et al., 2009) and better adapted to utilizing high NO_3 concentrations during upwelling pulses (Seeyave et al., 2009). Increase in *Pseudo-nitzschia* abundance appears to reflect a response to eutrophication rather than diagenesis and its occurrence provides evidence for a possible link between coastal eutrophication and harmful algal blooms (Parsons et al., 2002). *Thalassionema nitzschioides* is cosmopolitan species except for polar seas. It is commonly found in nutrient-rich upwelling regions or it may either transported from upwelling centers or resulting from less frequent upwelling conditions (Abrantes, 1988).

Our result shows that appearance of high density diatoms in May might be the indication of upwelling water emergence. It is because lower abundances of phytoplankton in April and October have in fact reflected a short of nutrient supply during the monsoon transition months. The nutrients in the Lembeh Strait were low and classified as poor nutrition waters from the April survey (Baohong et al., 2016). The concentration of dissolved inorganic nitrogen (DIN) and PO_4–P in water column to 15 m depth only maximized 0.181 and 0.007 mg/L, respectively, and it was phosphate limited as well (Baohong et al., 2016).

4.3 *Species during monsoon transition period*

Results from our surveys show that the phytoplankton abundance is quite low in April and October, i.e., transitional period of monsoonal alternation delimitated by Wang et al. (2010) and Abdul-Hadi et al. (2013). Low abundant phytoplankton appeared during the periods of monsoonal transition also report by Satpathy et al. (2009), who reported that significant decrease in phytoplankton density and chlorophyll biomass from pre-transition to transition and post-transition periods associated with the drop of number of phytoplankton species in the coast waters of the Bay of Bengal. Increase in nitrogenous nutrients (nitrate and total nitrogen) and decrease in phosphate content were observed, simultaneously (Satpathy et al., 2009).

Responding to the changes in physiochemical variations in water mass, there should be alternations of phytoplankton communities. As shown in this study the species composition during the transitional period is different from the SE monsoonal period (May and June, Table 2). High density cyanobacterium *Trichodesmium* and dinoflagellates occurred in April and October, respectively. It means that, firstly, during the monsoonal transition period much stable hydrodynamic conditions promoted the growth of the nitrogen-fixing cyanobacterium *Trichodesmium* (Kromkamp et al., 1997). Thus, it can be the signature of lull upwelling showed by the extensive *T. erythraeum* blooms (Thomas et al., 2013). Secondly, it also means a nutrient limitation in the water column (Higginson et al., 2004).

The occurrence of dinoflagellates by nature selection in the waters of Lembeh Strait in October also demonstrates the conditions of stratified water column where nutrient supply in the upper water layer was limited (Margalef, 1978; Berdalet, 1997). Besides, the rainfall event in October of the transitional monsoon can help explaining a trigger and a calm stable water column for sustained development of dinoflagellates (Hallegraeff et al., 1995). So, it is interesting to learn that both *Trichodesmium* and dinoflagellates have strategies dominating in nutrient limited waters by nitrogen fixation (Karl, 2002) or by accessing the deep nitrogen rich water in stratified water column (Jephson, 2012), respectively. However, as most sites in the Lembeh Strait are sheltered by the Lembeh Island and there were not much additional nutrients during no upwelling period except for self-sustained biogenic nutrients, the total phytoplankton abundance in both April and October should be comparably low.

The cyanobacteria *Trichodesmium* can be found in four months by the surveys. Since cyanobacteria are nitrogen fixation species able to use phosphonate as a source of phosphorous in metabolic processes (Dyhrman et al., 2006), they thrive in nutrient deficient water and were taken as indicator of the nutrient poor water (Capone et al., 1997). The appearance of the species indicates that most of time the waters of Lembeh Strait is basically nitrogen limited, particularly, in northern water of the strait (Fig. 6). This is much evident from the data of April cruise. It is reported that the phosphate is an overall limiting factor in Lembeh waters and much lower concentrations of nitrogen and phosphate were detected in the northern Lembeh Strait (Baohong et al., 2016). We believed that higher density of *Trichodesmium* in northern waters is the real status of the water quality. At least, the north part of the strait and its coast zone is as primitive as it is compared with the south coast waters in view of the anthropogenic activities.

4.4 *Background of phytoplankton environment*

Higher abundant of phytoplankton in southern waters of the Lembeh Strait may have indicated the sign of water pollutions from Bitung City, particularly in the west coast of Lembeh Strait. Sewages from the piers, shipyards, shrimp hatchery farms, palm oil factors along the coast of Bitung City are the potential nutrient sources for the strait waters. In fact, higher nutrient concentrations are detected at sites in the west coast of southern Lembeh Strait in April (Baohong et al., 2016). The diatom *S. costatum*, the species being able responding quick to the nutrient input (Hobson et al., 2001; Tas and Okus, 2009), was common at a few localized sites in the south of Bitung coast water in May, June and October. Besides, *Leptocylindra* and *Thalassionema* are also the signal of the high nutrient contents in water. These species often occur as red tide species in nearshore waters of China (Guo, 2004).

Generally the phytoplankton abundances are higher in the inner bay than in nearshore water due to poor water exchange and human activities. For example the density for *T. nitzschioids* was measured over 10×10^3 cell/L and for *S. costatum* were 90×10^3–250×10^3 cell/L in the Quanzhou Bay in 2001 (Tang and Chen, 2006). The later has been found reaching a density of 17.3×10^3 cell/L in the Jiaodong Bay, the west coastal of the Yellow Sea, where it is considered as newly invasive species (Liu et al., 2012). It is noticed that the data provided above is the density occurred in the no red tide periods. When the red tide or alga bloom occurs, the density normally goes to some ten to hundred millions per liter for diatoms①.

In the Jakarta Bay, phytoplankton cells were reported reaching 2.9×10^6 cell/L and at some site accumulated 1.8×10^6 cell/L for *S. costatum* during the red tide (Thoha et al., 2007). Recent survey on the phytoplankton abundances shows the densities range from 40×10^6 cell/m^3 up to 1 699.1×10^6 cell/m^3, the highest data were retained during the east monsoon (Sidabutar et al., 2016). Since the data of Jakarta were from the net samples, the real abundance should be higher when water sample was used. As a result, the phytoplankton abundances in Jakarta are generally several times higher than those in the bays of China under normal conditions even though the abundance is underestimated because of net samples used in Indonesia.

Considered that the maximum density was only 1×10^3 cell/L for *S. costatum* and the total diatom density was 2.35×10^3 cell/L (0.061×10^3–22.62×10^3 cell/L) in the Lembeh Strait during the high production of SE monsoon period, we are certain that the phytoplankton abundances in the waters of Lembeh Strait are relatively low. In fact, it is only some tenths or even hundredths of the abundance compared with some coastal bays of China (Table 3). So, the situation of seawater environment is quite well by its spe-

Table 3. Phytoplankton abundances in the Jakarta Bay, Indonesia, and coastal bays of China

Species	Density/10^3 cell·L^{-1}	Sea areas
Skeletonema costatum	1 800	Jakarta Bay (Thoha et al., 2007)
Diatoms	2 900	Jakarta Bay (Thoha et al., 2007)
Total phytoplankton	40–1 699	Jakarta Bay (Sidabutar et al., 2016)
Total phytoplankton	27.8–1 140	Zhangjiang Estuary, Fujian Province (Chen et al., 2007)
Skeletonema costatum	90–250	Quanzhou Bay, Fujian Province (Tang and Chen, 2006)
Skeletonema costatum	17.3	Jiaodong Bay, Shandong Province (Liu et al., 2012)

① Technical Specification for Red Tide Monitoring. HY-T 069–2005. State Oceanic Administration, China.

cies diversity in the waters of Lembeh Strait. The marine environment of the Lembeh Strait can be taken not only as the idea study sites of global climatic changes and its effects on the pelagic ecosystem but also as the study sites of Marine Protected Areas for marine ecosystem management and biodiversity protection.

5 Summary

This study provides the data of phytoplankton species composition and abundance variations for the first time during the time of monsoonal alternations, particularly, the transitions of pre and post SE monsoon in the waters of Lembeh Strait in the east coast of North Sulawesi, Indonesia. The original data suggest that the presence of high diversified diatom and dinoflagellate species, high numbers of dominant cyanobacterium *Trichodesmium* have characterized the water conditions in dry SE monsoonal seasons.

We also found that distribution of phytoplankton species abundances is different among the classes. Diatom and dinoflagellate species have higher abundance in the south than in the north waters of Lembeh Strait, while the cyanobacteria *Trichodesmium* is prone to distributed in northern waters of Lembeh Strait. This is because the coast water in the south of Lembeh Strait may have slightly higher nutrient input either from terrestrial or upwelling, and comparatively poor nutrient condition in northern water favors the growth of *Trichodesmium.*

The water quality condition is quite clean in term of low phytoplankton abundance even in the season of high productivity. Comparison of diatom abundances among the Lembeh Strait, the Jakarta Bay and the bays in China tells the story. The abundance of given phytoplankton species can be taken as the indicator of water conditions for the amount of nutrient presented.

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