Spatial and temporal dynamics of diatoms (bacillariophyceae) in Jakarta Bay

SM Rahayu¹, A Damar²,³ and M Krisanti²

¹ Graduate student from Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Bogor 16680, Indonesia
² Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Bogor Agricultural University, Indonesia
³ Center for Coastal and Marine Resource Studies, Bogor Agricultural University, Indonesia

Corresponding author: smirarahayu@gmail.com (S M Rahayu)

Abstract. The condition of Jakarta Bay which receives a high load of nutrients causes the bay to experience phytoplankton blooms. One of the phytoplankton groups that often experience the blooms are diatoms (Bacillariophyceae) in addition to its existence which are naturally abundant. This study aims to analyze the dynamics of diatom distributions in Jakarta Bay. Samples were taken in July to October 2017 at 15 sampling stations. The distribution of diatoms seems to be high in the central part of the bay (September and October) due to the higher Secchi depth than that in the river estuary; and higher nutrients level than that in the offshore area. Meanwhile, the distribution in the other months seem to be more influenced by nutrients (July) and seasonal variables such as water current, and wind (August).

1. Introduction
Organic and inorganic pollutant loads received by semi-closed coastal water, Jakarta Bay, tend to increase over time [1]. Damar et al. [2] stated Jakarta Bay is the most polluted embayment in Indonesia with the highest anthropogenic pressure in Asia. Continuous input of organic material into Jakarta Bay causes an increase in nutrient levels in the bay. High levels of nutrients trigger phytoplankton to rapidly develop and multiply in a relatively short time so that they experience a population explosion or bloom.

Bloom phenomenon causes a lot of negative impacts on ecological, economic, biodiversity, and public health aspects. These phenomena have occurred several times in Jakarta Bay [3, 4, 5]. Phytoplankton groups that often experience population blooms in Jakarta Bay are diatoms (Bacillariophyceae). The bloom of Skeletonema costatum population in the Jakarta Bay is known as a common phenomenon that occurs regularly [6, 7].

Diatoms have many important roles due to their position of the food chain. Diatom population, which is naturally abundant in Jakarta Bay, causes the algae to contribute a great deal in primary productivity in the embayment. Diatoms are also known to contain high levels of omega-3 which are good for the growth of various biota at higher trophic levels (zooplankton, mollusks, crustaceans, and fish), with the result that changes in diatom populations are closely related to changes in other biotic communities [8]. Additionally, diatoms can respond quickly to changes in various ecological characteristics so as they can be used as indicators of water quality [8, 9, 10]. Therefore, the analysis of the spatial and temporal dynamics of diatoms and their relationship to environmental physical-chemical factors in Jakarta Bay
needs to be analyzed which then can be used as one of the bases in the management of pollution and phytoplankton blooms in Jakarta Bay.

2. Material and Methods
Diatom samples were taken in July-October 2017. There were 15 sampling stations spread from river mouths, near shore, to offshore waters (Fig. 1). Three of them were located in the river mouths discharge to Jakarta Bay, they are Muara Angke, Sunter, and Marunda River, respectively, representing the western, central, and eastern part of Jakarta. Sample analysis was conducted at Micro-Biology Laboratory 1, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University.

Data of nutrient distribution (NH4-N, NO3-N, NO2-N, PO4-P, SiO2-Si) and water quality (in situ) were obtained from Damar et al. (in prep) [11] (analyzis based on APHA, 2012). In situ parameters included Secchi depth, temperature, salinity, DO, and pH.

Diatom samples were taken by 30 µm plankton net and preserved by Lugol's solution. Cell counting was performed by a 50 × 20 × 1 mm³ (1 mL) Sedgwick-Rafter Counting Cell (SRC). Sample identification was done based on Yamaji [12], Davis [13], Hasle and Syvertsen [14]. Phytoplankton abundance was calculated based on APHA [15].

Two-way analysis of variance (ANOVA) was conducted spatially and temporally (α = 0.05) for each variable. Euclidean distance analysis with complete linkage method [16] was carried out based on physical-chemical variables. Distribution of diatoms and the other variables were analyzed by ArcGIS 10.2.2 software with IDW-contour method. Correlation coefficients (Pearson r) were calculated to determine the closeness relationship between variables.

3. Results and Discussion
3.1. Spatial and temporal cluster
The variables tested for station clustering are the physical-chemical variables which are spatially differed based on analysis of variance (p<0.05). There are five groups of stations formed (minimum similarity level of 75%). Five groups are generally located in three areas of the bay. Group 1 is stations 1, 4, 5 and 7 located in the outer side of the bay (offshore); group 2 consists of stations 2, 6, 8, 3, 9, 11, 12, 10 located in the central part of the bay (nearshore); and group 3, group 4, group 5 which are respectively station 13, station 14, and station 15 which are located at the river mouth (estuary) namely
Marunda River, Angke River, and Sunter River (respectively). Meanwhile, the variables tested for temporal clustering were the physical-chemical variables which were temporally differed based on analysis of variance (p<0.05). Temporally, the analysis shows that the four months form a different group for each month (minimum similarity level of 75%).

3.2. DIN (Dissolved Inorganic Nitrogen)

DIN is calculated by summing the concentration of nitrate, nitrite, and ammonium. The relative concentration of ammonium at river stations (station 14 and 15) was dominating with proportion about 80% (Fig. 2). While the proportion of ammonium compared to the proportion of nitrate and nitrite in the nearshore and offshore areas tends to be low.

There were significant differences of DIN between stations and time (ANOVA, p<0.001, p<0.05, respectively). DIN concentration was high at the river stations (0.618-1.976 mg L-1) and decreased towards offshore area (0.159-0.309 mg L-1) (Fig. 3). This indicates the influence of river discharge containing anthropogenic waste from Jakarta. This is supported by the negative correlation value between DIN and salinity (r Pearson -0.85). Temporally, the highest mean DIN concentration was observed in September (0.584 mg L-1), while the lowest was observed in August (0.330 mg L-1).

Figure 2. The relative mean concentration of ammonium, nitrate, and nitrite concentration at each sampling station (Damar et al. (in prep) [11]).
3.3. Phosphate

There was a significant difference between stations in phosphate concentration (ANOVA, p < 0.001). Phosphate distribution tends to decrease towards offshore (Fig. 4). The high phosphate concentrations at stations 13, 14, and 15, which are the mouth of Marunda, Angke, and Sunter River, indicate the high influence of freshwater input from rivers which commonly contain high nutrient concentrations [7]. This is supported by a negative relationship between phosphate and salinity (r Pearson -0.66). The highest phosphate concentration was observed at the mouth of the Sunter River (0.101-0.267 mg L-1), while the lower concentrations were observed at nearshore to offshore stations (stations 1 to 8) ranged 0.002-0.009 mg L-1. The low concentration was suspected to be caused by dilution and utilization activities by phytoplankton [7], considering the Secchi depth value at the stations tends to be higher.
Figure 4. Phosphate distribution (mg L$^{-1}$) in Jakarta Bay in July (A), August (B), September (C), and October (D) (Damar et al. (in prep) [11]).

3.4. Silica
Aside from nitrogen and phosphorus, silica is the main nutrient for diatoms. In contrast to nitrogen and phosphorus, silica is not related to anthropogenic activity. Silica distribution in Jakarta Bay is strongly influenced by river runoff. This is indicated by the high concentration of silica in the estuary area, especially station 14 (Angke River) which is always high in every observation (mean value is 4.879 mg L$^{-1}$), and decrease along nearshore to offshore (mean range is between 0.782-1.212 mg L$^{-1}$) (Fig. 5), as well as a negative correlation between silica and salinity ($r_{Pearson}$ -0.88). Temporally, observations in October had a low mean concentration of silica (0.857 mg L$^{-1}$) compared to observations in the other three months (1.444-1.836 mg L$^{-1}$). Silica distribution in Jakarta Bay during observation differed spatially and temporally (ANOVA, p<0.001).
Figure 5. Silica distribution (mg L⁻¹) in Jakarta Bay in July (A), August (B), September (C), and October (D) (Damar et al. (in prep) [11]).

3.5. Ratio of DIN to phosphate (N/P) and to silica (N/Si)

The composition of N, P, and Si can affect the composition and dominance of phytoplankton [17, 18, 7]. Ratios of N/P in the observation sites were significantly different (ANOVA, p<0.001). Stations at the river mouth especially station 13 and 15, have low ratios (less than 16, the Redfield ratio) (Fig. 6 A). A higher ratio indicates that phytoplankton growth will be limited by phosphorus, while a lower ratio will be limited by nitrogen [19, 11]. Nevertheless, according to Damar et al. [11] the low ratio was caused more by the high phosphate at the sites, rather than the low nitrogen concentration, and partly due to nitrogen uptake by phytoplankton.

The N/Si ratio can indicate N or Si limitation for phytoplankton growth. The strong predominance of diatoms generally indicates the low ratio of N/Si [11]. In general, the ratio of N/Si at almost all of stations and observations were worth less than 1 (Redfield ratio) (Fig. 6 B), indicating that Si was not a limiting factor for the growth of phytoplankton.
Figure 6. Ratio of N/P (A) and N/Si (B) (Damar et al. (in prep) [11]). The horizontal line shows the value of Redfield ratio, 16 for N/P ratio and 1 for N/Si ratio.

3.6. Secchi depth
In general, all observations show that Secchi depth in nearshore and offshore stations had higher value than those around river mouth (Fig. 7). Stations 13, 14 and 15 which are the mouth of Marunda, Angke, and Sunter River pronounced to have low Secchi depth with a mean value of 0.323; 0.230; and 0.293 m, respectively. This reflected the high influence of river water input which carried dissolved or non-dissolved organic matter that can reduce the level of light penetration in the water column. This can be seen from the positive correlation between Secchi depth and salinity (r Pearson 0.44). Salinity can describe the effect of freshwater input from the river [7].

3.7. Physical-chemical parameters
Salinity tends to increase towards offshore (Fig. 8 A). Low salinity observed at station 14 with a mean value of 19.00‰, while the stations in the central and the outer side of the bay have mean salinity reached 32.25‰. This reflects the influence of river input in the estuary to the nearshore area; and then the influence decreased towards offshore, with the result that the offshore area was only influenced by the Java Sea.

Temperatures at the study site ranged 29-34 °C which reflected the temperature of tropical waters. The estuary area (river mouth) tends to have higher temperatures than nearshore and offshore areas (Fig. 8 B).
Figure 7. Secchi depth distribution (m) in Jakarta Bay in July (A), August (B), September (C), and October (D) (Damar et al. (in prep) [11]).

Generally, DO at station 13, 14, and 15 were lower than the stations located offshore (Fig. 8 C), with a mean value of 4.7; 4.3; and 1.1 mg L\(^{-1}\), respectively. This difference due to high oxygen consumption by microbes in the decomposing organic matter in the river mouth area. The pH value at the study location ranged from 6.83 to 8.56. The differences were observed at station 13 and 15 which is the estuary of the Marunda and Sunter River (Fig. 8 D). The stations tend to have low pH value (7.54 and 7.44, respectively).

3.8. Composition of diatom population
Diatom populations in the sampling sites were made up by 35 genera, which 20 of them are centric diatoms (order Biddulphiales) and the rest 15 are pennate diatoms (order Bacillariales). The genera of centric diatom that frequently found were Chaetoceros sp., Skeletonema sp., Thalassiosira sp., Rhizosolenia sp., Leptocylindrus sp., Hemiaulus sp., Lauderia sp., Bacteriastrum sp., and Melosira sp.. Meanwhile, the genera of pennate diatom that frequently found were Nitzschia sp., Navicula sp., and Thalassiothrix sp.. Centric diatoms were dominating the diatom abundance with a relative abundance of more than 80% both spatially and temporally (Fig. 9).
Based on the abundance of the predominant genera, there were significant differences (ANOVA, p<0.05) in estuaries, nearshore, and offshore area (Fig. 10). Chaetoceros sp. which is oceanic species tends to dominate the offshore area. Nearshore part tends to be dominated by Chaetoceros sp. and Skeletonema sp.. Meanwhile, river estuaries tend to be dominated by Skeletonema sp. and Thalassiosira sp.. Apparently, the predominance of Skeletonema sp. pronounced in the nearshore area and river estuary due to a polluted condition in the areas [20], while Thalassiosira sp. colonies are good indicators of the high-level nutrient area [21].

3.9. Distribution of diatoms

Based on the analysis of variance, diatom distribution did not differ significantly between stations. However, it can be slightly seen that the average abundance of diatoms tends to be lower at river estuary stations, that are station 13, 14, 15 (1.51 × 10⁸ - 2.89 × 10⁸ cells m⁻³) and higher at stations located in the central and outer part of the bay (2.96 × 10⁸ - 12.62 × 10⁸ cells m⁻³) (Fig. 9 A). This is supported by a positive correlation, albeit low, between diatom abundance and salinity (Pearson r 0.23). Meanwhile, the distribution of diatoms was significantly different temporally (ANOVA, p <0.05). Average diatom abundance in October was higher than in other months (31.19 × 10⁸ cells m⁻³), while the lowest mean abundance was observed in July (3.83 × 10⁸ cells m⁻³) (Fig. 9 B).
Figure 9. Mean diatom abundance, at each station (A) and observation time (B)

Figure 10. Composition of total abundance of diatoms at each station

Observation in July (Fig. 11 A) generally show that the abundance of diatoms tends to be higher in the estuary and central of the bay, while in the outer side of the bay tends to be lower. It indicates that the distribution of diatom in this month seems to be more depended on the nutrients, particularly DIN (ammonium) and phosphate. This is supported by the positive correlation of diatoms-ammonium and diatoms-phosphate of this month (r Pearson 0.65 and 0.55, respectively). The highest diatom abundance was found at station 11 with total 3.84 × 10^8 cells m^-3 dominated by Chaetoceros sp. (2.42 × 10^8 cells m^-3) and the lowest abundance was found at station 14 with a number of 1.64 × 10^6. Chaetoceros sp. was dominating almost all stations, but stations 6, 12 and 15 which were dominated by Skeletonema sp., and station 14 which was dominated by Thalassionema sp.

In contrast to July, observations in August showed a high diatom abundance in the western outer side of the bay and lower towards the southeast part of the bay (Fig. 11 B). The distribution of diatoms in this month seems to be more controlled by monsoon winds. The winds blew from east to west resulting the surface residual currents to move in the direction of the winds, seeing that August was in the southeast monsoon (SEM) period [22]. The highest abundance was found at station 1 with a number of 2.76 × 10^9 cells m^-3 dominated by Chaetoceros sp. (1.39 × 10^9 m^-3 cells) and the lowest was observed
Diatom distribution in September tends to be high in the central part of the bay and low at the river mouth and the outer side of the bay (Fig. 11 C). The highest abundance was found at station 12 with a number of 2.57 × 10⁹ cells m⁻³ which was dominated by Skeletonema sp. (2.24 × 10⁹ cells m⁻³) and the lowest was observed at station 14 with a number of 1.04 × 10⁶ cells m⁻³. Generally, Skeletonema sp. and Chaetoceros sp. was dominating the survey in the month.

Diatom distribution in October tends to be higher in the central part of the bay (Fig. 11 D). The highest abundance was found at station 11 with an abundance of 3.12 × 10⁹ cells m⁻³ which was dominated by Chaetoceros sp. (2.58 × 10⁹ cells m⁻³), while the lowest was observed at station 13 with an abundance of 3.06 × 10⁶ cells m⁻³. Station 1 to 12 and station 15 was dominated by Chaetoceros sp.

The distribution pattern in September seems to be the same as that in October. In these months, diatoms were abundant in the central part of the bay due to the higher Secchi depth level than that in the river mouth stations. In the river mouth stations, even though nutrient concentrations were high, Secchi depths were low, it could limit the photosynthesis process in these areas. Reversely, the offshore area had high Secchi depth level, but had low nutrient level, made diatoms less abundant in these areas than that in the central part of the bay. This is strengthened by the positive correlation between diatoms and Secchi depth value in these months (r Pearson in September= 0.49 and October= 0.63).
4. Conclusion
The distribution of diatoms in Jakarta Bay controlled by nutrients, Secchi depth, and winds. Diatom distribution in July tends to be proportional with the nutrients distributions. Meanwhile, the distribution in August seemed to be more influenced by seasonal variables such as winds and water currents. Diatom abundance in September and October seem to be more controlled by Secchi depth.

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