Algae bloom phenomenon in Jakarta Bay as symptoms of severe eutrophication: Monitoring results of 2014-2016

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Abstract: Algae bloom is one of the symptoms of eutrophication process in an estuary, causing in some ecological and societal problems for the aquatic environments and human activities. Algae blooms observation was conducted in the dry season period between 2014 to 2016, in an eutrophic embayment of Jakarta Bay, Indonesia. Observations were made by conducting transect-boat survey and plankton sampling once the bloom was observed. Samples of chlorophyll-a and net plankton were taken and measured in the laboratory for phytoplankton biomass analysis, cell counting, and identification of bloom-forming species. In the 3 consecutive years of observation, the most frequent bloom-forming species observed were Skeletonema costatum, Pseudonitzschia Spp., and Noctiluca scintillans. The most frequent location of the blooms observed was in the inner part of the bay, in the area in front of Marunda, Ancol and Angke. Phytoplankton biomass during the bloom events were ranged between 126.3 to 232.3 µg Chl-a L⁻¹, with the highest was in 2015 of during the Skeletonema costatum bloom. Blooms were also observed but in low frequency and low biomass at the middle part of the bay off Marunda coastline area. Cell phytoplankton counting were ranged from 1.1₃9 × 10⁶ cell L⁻¹ to 7.893 × 10⁸ cell L⁻¹. During period of surveys, there was no mass mortality of fishes were detected.

Keywords: algae bloom; eutrophication; nutrient enrichment; phytoplankton; tropical bay

1. Introduction
Algae Bloom is one of the symptoms of the eutrophication process, where there is an increase in nutrients content in the midst of sunlight [1, 2]. Algae bloom phenomena will only occur if it is supported by other factors such as availability of underwater light and physical condition of the water. Bloom formation is usually formed during the period of calm water with minimum current and turbulence. When the water is in a stagnant condition, in general, blooming will begin [3, 4].

Jakarta Bay is one of tropical estuarine waters that get an extraordinary supply of organic materials from 13 river estuary that facilitates organic domestic liquid waste from the Jakarta metropolitan area [5,6]. Loads of DIN and phosphate entering the bay of about 21,000 tons DIN year⁻¹ and 6,700 tons phosphate year⁻¹[7]. Lack of communal domestic wastewater treatment is one of the main-concern
related to its high load of nutrients into the bay [6]. Calculation of eutrophication level of Jakarta Bay resulted three main levels of eutrophication namely hypereutrophic level, eutrophic level, and mesotrophic level [5]. There has been an increase in the area of hypereutrophic and eutrophic levels in this bay, elevated from 75.1 km² in 2001 to 114 km² in 2019, and from 186.2 km² in 2001 to 211.7 km² in 2019, for hypereutrophic and eutrophic levels, respectively [5]. The increase of eutrophication levels in Jakarta Bay indicates the increase of ecological pressure towards an environmental condition of this tropical bay.

The high eutrophication state of Jakarta Bay has been causing various consequences such as hypoxia of its near-bottom water and massive algae bloom [8, 5]. One of the most frequent events which is the result of the high organic material in the Jakarta Bay Area is the creation of blooming phytoplankton [9, 10, 11]. Blooming population causes a variety of ecological and economical disorders for the region, such as the mass deaths of water biota and aesthetic disorders [12].

Eutrophication in Jakarta Bay is a chronic result of the continuous supply of nutrient and organic materials from the mainland through the incoming rivers. One of the effects of eutrophication is the rapid increase of algae population or well known as algae bloom [13, 14]. Algae Bloom is a routine phenomenon observed in Jakarta Bay and this is the result of increasing the nutritional system in the estuary waters [15, 8, 9]. However, Smayda [1] and Huisman and Sommeijer [3] stated that algae bloom is not only caused by an increase in nutrient alone. Studies about eutrophication revealed that bloom phenomena are triggered not only by excessive nutrients but also due to some other factors, such as the ratio between the nutrient (especially the ratio between N and P), the availability of underwater light, and physical water movements. The optimum combination of the 4 factors above will lead to the occurrence of blooming algae [3].

This paper is aimed to describe distribution of algae bloom in the period of dry season of 2014 to 2016, which can be used as scientific information about the algae bloom frequency and magnitude as well as its forming species in the tropical embayment of Jakarta Bay. The results of this study can be used for inputs for further management action of Jakarta Bay in the future.

2. Materials and Method

The study was conducted in the period between 2014 to 2016 in Jakarta Bay, by conducting boat-surveys in every of the dry period of July to October of 2014, 2015, and 2016. Each year of observation was done in four times frequency, which was in the months of August to October (2014), July to September (2015 and 2016) (table 1). The selection of the period was based on previous studies and information presented by Thoha [12], Yuliana [10] and Ladwig, Hesse, van der Wulp, Damar, and Koch [9], which stated that dry period is the period where algae bloom usually occurred in Jakarta Bay. During this period, physical water movement was minimum as result of calmer wind of the east monsoon. The survey of bloom observation was conducted by applying boat-transects survey started from Muara Angke in the west going off north and then to the east direction with zig-zag formation to the center of Jakarta Bay and end up at Marunda coastal waters. During the trip, visual observation was performed, seeking the bloom formation (figure 1). Once the bloom was observed, delineation of the bloom area were made, by using Global Positioning System. In the bloom area, surface water was taken to take chlorophyll-a samples for then analyzed in the laboratory according to the spectrophotometric method of Lorenzen [16]. Samples of phytoplankton were also collected at the bloom sites by means of a 40 μm mesh size for species identification and cell counting.

| The surveys | 2014       | 2015       | 2016       |
|-------------|------------|------------|------------|
| 1st         | 12 August 2014 | 16 July 2015 | 11 July 2016 |
| 2nd         | 29 August 2014 | 3 August 2015 | 6 August 2016 |
| 3rd         | 16 September 2014 | 29 August 2015 | 22 August 2016 |
| 4th         | 5 October 2014 | 11 September 2015 | 8 September 2016 |
Figure 1. Sampling observation transects during algae bloom surveys in Jakarta Bay 2014 – 2016. Arrows showboat sampling survey trip direction. The base map was taken and got permission from Damar, Colijn, Hesse, Adrianto, Yonvitner, Fahrudin, Kurniawan, Prismayanti, Rahayu, Rudianto, and Ramli [5].

Figure 2. Projection of algae blooms spatial distribution during measurement 2014: 12 August 2014 (upper left); 29 August 2014 (upper right); 16 September 2014 (lower left) and 5 October 2014 (lower right). 1: Skeletonema costatum ; 2: Pseudonitzschia sp.
3. Results

During 2014 monitoring campaign, where was done during the middle of the dry season, several locations of algae bloom were observed. The species bloom-forming on that period was *Skeletonema costatum* in the inner waters of the western and central of the bay, and *Pseudonitzschia* in the inner-east of the bay (figure 2). Phytoplankton biomass measurements of the blooms were 232.3 µg Chl-a L\(^{-1}\), 216.2 µg Chl-a L\(^{-1}\), 211.3 µg Chl-a L\(^{-1}\) and 167.3 µg Chl-a L\(^{-1}\) for *Skeletonema costatum* in 12 August 2014, 29 August 2014, 16 September 2014, and 5 October 2014, respectively. The approximate area during the *Skeletonema* bloom events were 15.72 km\(^2\), 24.4 km\(^2\), 17.92 km\(^2\), and 11.96 km\(^2\) (table 2). Cell counting of the bloom-forming species of *Skeletonema costatum* were 7.785 × 10\(^6\) cell L\(^{-1}\), 7.479 × 10\(^6\) cell L\(^{-1}\), 7.382 × 10\(^6\) cell L\(^{-1}\), and 6.285 × 10\(^6\) cell L\(^{-1}\), for the first, second, third, and fourth monitoring campaign. During the three first monitoring, the bloom species was *Skeletonema costatum* alone, but at the fourth monitoring, *Pseudonitzschia* was also detected co-exist with *Skeletonema costatum*. The occurrence of *Pseudonitzschia* was detected in a smaller area, occupying an area of about 6.05 km\(^2\) in the eastern part of the bay close to Marunda coastline. The bloom of *Pseudonitzschia* was having a density of around 3.345 × 10\(^6\) cells L\(^{-1}\) and biomass of around 132.7 µg L\(^{-1}\).

**Table 2.** Bloom area delineation, density, and biomass during the bloom-surveys in Jakarta Bay 2014 to 2016.

| No. | The surveys | Species | Density (Cell L\(^{-1}\)) | Chl-a (µg L\(^{-1}\)) | Area (km\(^2\)) | Geographic coordinates (center point) |
|-----|-------------|---------|--------------------------|----------------------|----------------|-------------------------------------|
|     |             |         |                          |                      |                | South (°)  East (°)                   |
| 2014| 1           | 12 Aug. | *Skeletonema costatum*   | 7.785 × 10\(^6\)     | 232.3          | 15.72                               | 6.04  106.79                           |
|     | 2           | 29 Aug. | *Skeletonema costatum*   | 7.479 × 10\(^6\)     | 216.2          | 24.44                               | 6.05  106.84                           |
|     | 3           | 16 Sep. | *Skeletonema costatum*   | 7.382 × 10\(^6\)     | 211.3          | 17.92                               | 6.05  106.84                           |
|     | 4           | 5 Oct.  | *Skeletonema costatum*   | 6.285 × 10\(^6\)     | 167.3          | 11.96                               | 6.05  106.85                           |
|     |             |         | *Pseudonitzschia*        | 3.345 × 10\(^6\)     | 132.7          | 6.05                                | 6.02  106.94                           |
| 2015| 1           | 16 Jul. | *Skeletonema costatum*   | 6.322 × 10\(^6\)     | 187.3          | 16.93                               | 6.03  106.90                           |
|     | 2           | 3 Aug.  | *Skeletonema costatum*   | 6.462 × 10\(^6\)     | 192.4          | 14.55                               | 6.04  106.87                           |
|     |             | *Noctiluca scintillans* | 2.128 × 10\(^6\)     | 126.3          | 8.39                           | 6.04  106.76                           |
|     | 3           | 29 Aug. | *Skeletonema costatum*   | 5.785 × 10\(^6\)     | 132.4          | 12.78                               | 6.05  106.86                           |
|     |             | *Noctiluca scintillans* | 3.117 × 10\(^6\)     | -              | 4.9                           | 6.05  106.79                           |
|     | 4           | 11 Sep. | *Skeletonema costatum*   | 5.576 × 10\(^6\)     | 176.4          | 7.65                                | 6.02  106.92                           |
|     |             | *Noctiluca scintillans* | 1.139 × 10\(^6\)     | -              | 10.81                         | 6.04  106.87                           |
| 2016| 1           | 11 Jul. | *Skeletonema costatum*   | 6.997 × 10\(^6\)     | 201.4          | 15.94                               | 6.03  106.77                           |
|     |             | *Trichodesmium Spp.*   | 3.335 × 10\(^6\)     | 144.2          | 7.94                           | 6.03  106.93                           |
|     | 2           | 6 Aug.  | *Skeletonema costatum*   | 7.893 × 10\(^6\)     | 211.3          | 18.88                               | 6.03  106.83                           |
|     | 3           | 22 Aug. | *Skeletonema costatum*   | 6.663 × 10\(^6\)     | 209.3          | 12.9                                | 6.04  106.83                           |
|     | 4           | 8 Sep.  | *Skeletonema costatum*   | 5.771 × 10\(^6\)     | 196.4          | 13.32                               | 6.04  106.88                           |

In the monitoring of 2015, which was done also during the dry season, the blooms were observed in the inner waters of the bay as presented in figure 3. Some species composing of the bloom were *Skeletonema costatum* in the inner waters of the east part of the bay and *Noctiluca scintillans* was detected in the inner-west and middle part of the bay. The duration bloom of those 2 species is about 14 to 15 days for then shifted or diminished. In subsequent monitoring, bloom of *Skeletonema* was accompanied by *Noctiluca scintillans* in the middle and eastern of the bay (in front of the water of Tanjung Priok and Marunda). The species of *Skeletonema costatum* persisted co-exist with *Noctiluca scintillans* (dinoflagellates) in the inner-western part of the bay. *Skeletonema costatum* belongs to the group of diatoms while *Noctiluca scintillans* belong to dinoflagellates. Both species continued to dominate the population community until the monitoring period ends in September 2015. The density, area of the blooms, and biomass of the bloom species are listed in table 2.
Figure 3. Projection of algae bloom spatial distribution during measurement 2015: 16 July 2015 (upper left); 3 August 2015 (upper right); 29 August 2015 (lower left) and 11 September 2015 (lower right). 1: Skeletonema costatum; 2: Pseudonitzschia Sp.; 3: Green Noctiluca scintillans.

Figure 4. Projection of algae blooms spatial distribution during measurement 2016: 11 July 2016 (upper left); 6 August 2016 (upper right); 22 August 2016 (lower left) and 8 September 2016 (lower right). 1: Skeletonema costatum; 2: Pseudonitzschia Sp.; 3: Green Noctiluca scintillans; 4: Trichodesmium Spp.
In monitoring 2016, algae bloom was again observed along the inner waters of the bay. Somewhat different from the previous ones, in the beginning of early and late of July 2016, the bloom of the Cyanobacteria from the species of *Trichodesmium erythreum* was detected in the western part of the bay co-exist with *Skeletonema* in the inner-middle part of the bay. The occurrence of *Trichodesmium erythreum* was detected during the period of about 2 weeks with a density of about $3.335 \times 10^8$ cells L$^{-1}$, occupying an area of around 7.94 km$^2$. At the same time, the bloom of *Skeletonema costatum* was also observed in the inner-middle waters of the bay occupying an area of about 15.94 km$^2$ (table 2). The bloom of *Trichodesmium* was disappeared and has never been found during the period of our monitoring. *Skeletonema costatum* blooms have lasted longer with a slight move into east direction with its density ranged from $5.771 \times 10^6$ to $7.893 \times 10^6$ cells L$^{-1}$ (table 2 and figure 4).

4. Discussion

Algae Bloom is one of the severe symptoms of the eutrophication process in Jakarta Bay that has lasted decades. Long-term monitoring conducted by Damar et al. [5] stated that there has been an increase levels of eutrophication in Jakarta Bay. It is also reported that there has been an increase in the frequency and magnitude of algae bloom in this tropical embayment as have been reported previously [10-12].

From three consecutive years of our observation, blooms were always detected in the early time of the dry season (east monsoon) and the transitional period between east and west monsoon. During this period, the physical movement of the water e.g. turbulence current and current are minimum, while the nutrient content is stable throughout the year [17]. Bloom of phytoplankton as results of biomass accumulation in water column and functions of various factors such as high nutrients, sufficient of underwater light and minimal water current [18, 19]. The combination of those three main factors is main trigger for the occurrence of bloom phenomenon [3]. Nutrients are never been a limiting factor for phytoplankton growth in Jakarta Bay as having been always in high concentration [8, 5], especially in the area close to the shoreline. Nutrients concentration in Jakarta Bay was always above the minimum level for both DIN and phosphate requirements for phytoplankton growth, i.e. $K_N$ which are $1.5$ µM and $0.5$ µM for DIN and phosphate respectively [5]. Continuous supply of nutrients from the incoming rivers in this site maintain high nutrient levels available, as have been calculated, amounted to 22,000 ton of DIN year$^{-1}$ and 6700 phosphates year$^{-1}$ loads from the river into the bay [7].

Another decisive factor for the development of bloom is underwater light. Jakarta Bay system has two main types of situations related to underwater light availability that is high turbidity during west monsoon and low turbidity during east monsoon [7]. It is related to a load of sediments from the incoming rivers which increased during west monsoon and decreased during east monsoon. In the area close to the shoreline where the most frequent algae bloom was observed, underwater light into this shallow waters area is always available in sufficient amount, despite its higher turbidity, but due to its shallows water, light is able to penetrate deeper into the near-bottom water, allowing phytoplankton cell grows [5]. Underwater light availability can be indicated by ratio between $Z_{mix}$:$Z_{oa}$, as being shown by Colijn and Cadee [20] and Damar, Colijn, Hesse and Wardiatno [7]. In this high nutrient site, the ratio is approaching 1, indicating an optimum level of underwater light availability [7].

Third factor and determining the bloom occurrence is the physical condition of the water, which is the current velocity, turbulence current (vertical current), and horizontal current. Water with minimal physical movements gives phytoplankton time and opportunity to develop and accumulate its biomass. The longer time of the stagnant condition will create higher probability to accumulate biomass or known as bloom. This was conveyed by Smayda [1] and Huisman and Sommeijer [3] in their research mentioning that physical water movement factor is a determining factor of the bloom. Physical factor of water movement then becomes the only factor triggering the bloom event, and during the dry period, with low physical movement of water current, resulting in accumulation of phytoplankton biomass formed as bloom [17].

During the observation period, the species detected were *Skeletonema costatum*, *Pseudonitzschia*, and *Noctiluca scintillans*. Two first species belong to diatoms, while the last species belongs to dinoflagellates. The occurrence of *Skeletonema costatum* has been widely informed in the coastal
tropical waters [7, 21, 22]. This species is a chain-forming diatom and able to have rapid growth in very high nutrients water [23] and shallow coastal waters. The appearance of *Skeletonema* bloom in Jakarta Bay has been reported by many studies [7, 9, 10, 12]. In some coastal seas, the bloom of *Skeletonema* is frequently accompanied by blooms of other species of diatoms, such as *Chaetoceros, Nitschia,* and *Pseudonitschia* [24, 25]. On some occasions, the bloom of *Skeletonema* and other species of diatoms are followed by dinoflagellates, which might be related to the shift in N/P ratio or change in physical movement of the water as having been reported previously [26, 27]. The disadvantages of blooming of this type of diatoms are the large biomass that causes various ecological disorders such as lack of oxygen (hypoxia) [28].

Species of *Pseudonitschia* was considered as harmful algae producing neurotoxin of domoic acid [26] and strongly related to high nutrients due to severe eutrophication. This species with its toxicity can cause mass mortality of fish but so far none of the investigation has been conducted in the study area of Jakarta Bay. *Noctiluca scintillans* reported in Jakarta Bay are green *Noctiluca* and very rare the red scintillations have been reported. A study on dinoflagellates bloom showed that besides nutrient ratio, salinity preference was also the main factor triggering dinoflagellates bloom [19] in the south-eastern temperate Australian estuary. This has been also reported [18] on the bloom of dinoflagellates *Heterocapsa* in the shallow tidally mixed Newport River estuary, North Carolina, USA. Shift and duration of algae bloom was varied and driven by various factors involving physico-chemical and biological factors. More eutrophic water then to be characterized by dinoflagellates bloom rather than diatoms [18]. In addition to that, the role of N/P ratios in affecting algae bloom has been becoming long question among scientists. The role of N/P ratio in affecting phytoplankton bloom was also discussed [27] in the East China Sea where they found that changes in the availability of reduced N and the N/P ratios both in the form of inorganic and organic forms were important in the bloom succession. In their study bloom of dinoflagellates of *Karenia mikimotoi* was followed by *Prorocentrum donghaiense*. Other studies about the role of N/P ratio in algae bloom came to the conclusion that relative role of either N or P can be a limiting factor and react differently in more eutrophic waters compared to less eutrophic water [29].

In term of coastal management, the algae bloom has brought some both ecological and societal problems which can lead to a detrimental situation. In Jakarta Bay, algae bloom is always associated with mass mortality of some aquatic biota, including fishes. Mass mortality of aquatic biota have been reported occurred in Jakarta Bay in 2004, 2009, and 2013 [30, 31]. However, environmental aquatic problems in Jakarta Bay are not only about eutrophication but also due to some other types of pollution such as heavy metals and hydrocarbon-related compounds contaminants as having been reported previously [32, 33]. Intense economic activities of the country capital of Jakarta City have been putting some consequences on the nearby coastal aquatic ecosystems. Disturbance on local fisheries products has been reported showing high contents of pollutants in fish and mussel tissues in Jakarta Bay [34]. The economic effects of algae blooms in term of economic valuation seems to be one of the ways in figuring how severe the impacts on society as being conducted by Lu and Hodgkiss [35] in their calculation showing that the Harmful algal blooms (HABs) of *Gymnodinium mikimotoi* and *Gyrodiunium* sp. in Hong Kong’s waters in 1998 killed massive aquaculture estimated economic loss caused was about HK$315 000 000 (equivalent to US $40 000 000).

### 5. Conclusion

Algae blooms have been detected during the dry season period of 2014, 2015 and 2016. The most frequent sites of algae bloom were detected along the nearshore waters of Jakarta Bay, either in the west, center, or eastern part of the bay, in the high nutrient and shallow part of the bay waters. The species responsible for algae bloom during the observation period were *Skeletonema costatum*, *Pseudonitschia*, and *Noctiluca scintillans*. The first two species belong to diatoms while the third species belongs to dinoflagellates. The bloom of diatoms was always accompanied and followed by dinoflagellates which might be related to the shift in N/P ratio. There was no significant change in the area of algae bloom
during the period of observation from 2014 to 2016 and none of them were categorized as harmful algae bloom.

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