The potential role of eutrophication, tidal and climatic on the rise of algal bloom phenomenon in Jakarta Bay

T Sidabutar¹, E S Srimariana² and S Wouthuyzen¹
¹ Research Centre for Oceanography LIPI. Jl. Pasir Putih 1, Ancol Timur Jakarta Utara.
² Faculty of Fisheries, IPB University. Campus Dramaga, Bogor

Abstract. Over the past several years, a number of algal bloom incidents has been increasingly observed in Jakarta Bay. The increasing frequency of algal bloom incidents, and subsequent environmental impacts are a rising threat to the coastal resources, economy and public health. Eutrophication, tidal and climatic are the three processes that suspected to have a potential role with algal bloom incidences in this bay. To understand the role of these three processes, a monitoring program had been conducted from 2008 until 2015. The study reveals that algal bloom occurrences have a strong relationship with major nutrients ratio. Besides that, the bloom incident occurred particularly after the rainy season to dry season. The tides have a potential role in the spread of bloom formation and stratification. During the study the concentration of phosphate in these waters ranging from 0.01-2.5 μg/L and nitrate 0.01-15.89 μg/L. The ratio of major nutrient (N/P ratio) in this waters ranging from 0.2 - 45.4. The N/P ratio tends to be higher in 2010, where the abundance of phytoplankton raising conspicuously. The N/P ratio may controlling the occurrences of algal bloom, while tidal responsible in bloom distribution, and climatic particularly precipitation, effecting nutrients availability.

1. Introduction
Algal blooms are defined as a significant increase in abundance, biomass or the population size of micro-algae, and harm human health, fisheries, aquaculture, and tourism [1][2][3]. The frequency and distribution of algal bloom have been increased recently, and now become a major problem for the environment and economic activities in Jakarta Bay. Algal bloom events need to be evaluated, due to the increasing frequency, scale and impact on human health and fisheries in this bay. During the bloom episode, water discoloration appears in the surface waters, and sometimes harmful to fish and other living organisms.

Phytoplankton bloom may cause fish kills, disruptions to microbial ecosystems, and seafood contamination. Although algal blooms occur naturally, they are also attributed to anthropogenic activities [4]. Nutrient enrichment, mainly nitrogen and phosphorus, was considered to be the stimulating factor of phytoplankton growth in Jakarta Bay. Nutrient enrichment as a result of anthropogenic activity occurs in this bay and the bloom as one of the effects of such an accelerated process of nutrient enrichment. Jakarta bay receives a lot of nutrients input from various sources such as agriculture, industries, domestic waste, urban waste, and consequently, results in eutrophication. The availability of nitrate and phosphate in the waters continuously, may result in the waters became nutrients rich as it is known as eutrophication [1][5][6].
Eutrophication due to nutrient influx by either natural events such as; riverine plumes, mixing, circulation and upwelling, or anthropogenic activities such as; coastal urban run-off and sewage, has been viewed as the cause of algal bloom outbreaks [7][8]. The blooms are closely linked to coastal human activities, such as; aquaculture, marine pollution, industry, transportation and tourism [9]. It has been predicted that bloom as a result of global climate change, eutrophication, and man-made activities in the coastal areas [8]. The blooms are generally attributed to two primary factors such as natural processes, and anthropogenic loadings leading to eutrophication. The latter is assumed to be the primary cause of all blooms in many coastal. The formation of algal blooms occurs when micro-algae, in response to favorable conditions in their environment, proliferate to form dense concentrations of cells [1][3][8]. Some algal blooms cause mass mortality of fish, disruptions to microbial ecosystems, and seafood contamination because they may produce certain toxins [2][10]. This type of bloom is known as a toxic or harmful algal bloom.

There are some major sources of pollution in Jakarta Bay such as man-made activities, domestic and industrial activities which discharging waste through 13 rivers flowing to the bay. Hence, pollution from land-based sources, including industrial effluent, sewage, and agricultural discharges, has become a major problem. Aquatic ecosystems experience problems due to increasing input load of organic material through some rivers which flowing to this bay, urban drainage and also run-off from land during rainfall [11][12][13][14]. Any material discharged into the bay may cause some changing, may be great or small, long-lasting or transient, widespread or extremely localized. Nutrients enrichment can lead to community changes or succession between populations or species. The availability of nutrients sufficiently will result in total biomass to increase, on the contrary, changes in the nutrient composition may result in changes in species composition. Phosphate and nitrate are nutritional components that play an important role in supporting phytoplankton growth, but excessive nutrients concentration can cause an abnormal explosion of the phytoplankton population. Aquatic disasters such as mass mortality of fish and other living organisms also often occur during the events of algal bloom in these waters [12][15][16].

The contributing factors to the problem may be directly or indirectly anthropogenic, such as through the introduction of non-indigenous species via the transport of ballast water, and local and regional environmental changes caused by eutrophication [17]. The relationship between eutrophication and expansion of algal bloom is still unknown widely, even though in general the eutrophication can affect an explosion of microalgae populations. As in some places, the frequency of algal bloom increases due to increase nutrient levels, especially phosphate and nitrate [18]. How the eutrophication may stimulate the occurrence of toxic phytoplankton species, is still widely unknown and is still under debate until now [19]. However, it is thought that eutrophication as the most likely cause of those algal blooms. Also, the increasing occurrence of algal blooms is most likely as a result of a combination of natural factors and anthropogenic activities. The other factor such as tidal and climatic has a potential role in controlling bloom’s appearance. The purpose of this research is to study the possible link of nutrient enrichment (N/P), tidal and climatic parameters on the rise of algal blooms in Jakarta Bay and their impacts to fisheries.

2. Materials and methods

2.1 Description of location
The research has been conducted in Jakarta Bay (Latitude: 5°53'23.3” - 6°07'46.9” and Longitude: 106°37'10.9” - 107°01'40.8”). It is shallow water with an average depth of 15 meters and a shoreline of about 149 km long, which covers an area of approximately 595 km². The map of Jakarta bay and the sampling stations as shown in Figure 1.
Figure 1. Map of Indonesia, Jakarta Bay, and sampling stations of the study.

2.2 Research period
The research was carried out and focused in the east season or dry seasons from 2008 until 2015 (Table 1). The study was conducted in the dry season by considering the algal bloom events in the waters usually appeared in the east season [13][14]. Generally, the season in this region is classified into the west/rainy season. Between the two seasons, there are transitional seasons I and II. The rainy season occurs from October to March and dry season from April to September. In the rainy season, a lot of organic material enters the waters through sewage discharge, freshwater run-off, rivers flowing into the bay. Therefore, in the rainy season usually the nutrients level increased in the waters, mainly phosphate and nitrate, and fertilizing the waters and triggering the growth of phytoplankton population.

Table 1. Periods, sampling time, and the number of stations.

| Years | Period | Sampling Time          | Number of Stations |
|-------|--------|------------------------|--------------------|
| 2008  | I      | 25, 26, 27, 28 March   | 19 St.             |
|       | II     | 13, 14, 15, 16 May     | 19 St.             |
| 2009  | I      | 26, 27, 28 March       | 26 St.             |
|       | II     | 23, 24, 25 June        | 28 St.             |
| 2010  | I      | 20, 22, 24, 26 March   | 33 St.             |
|       | II     | 24, 26, 28 May - 1, 3 June | 50 St.           |
| 2011  | I      | 21, 22, 24, 26, 27 March | 50 St.         |
|       | II     | 5, 6, 7, 10, 11 July   | 50 St.             |
| 2013  | I      | 4, 6, 8 March          | 30 St.             |
|       | II     | 20, 21, 22 May         | 30 St.             |
| 2015  | I      | 28, 29, 30, 31 July    | 30 St.             |
2.3 Phytoplankton sampling

It was selected around 10 sampling stations around the Jakarta Bay. The fixed position of each sampling station was determined by using GPS. The collection of the sample was conducted in the period of the dry season every year from 2008-2015. It is also monitored the bloom phenomena visually, which is usually seen after rainy season from March-June and transition season from September-December. During that period the discoloration in the surface water appeared due to the phytoplankton outbreak.

Phytoplankton sampling was carried out using a cone-shaped phytoplankton net which at the end was installed with a pinch to collect concentrates of phytoplankton samples. The pore size or mesh size was 20 μm, and the net length was around 125 cm with the opening diameter of the net mouth was 25 cm. At the end of the net, the ballast was installed so that it can be lowered vertically. The sampling technique was carried out by lowering the phytoplankton net vertically up to a depth of 7-10 m and then being drawn slowly with a constant from a certain depth to the surface. Phytoplankton samples collected in the bucket were then put into a sample bottle and given preservative. Samples were preserved immediately using acidic Lugol’s solution [20]. The preserved phytoplankton samples brought to the laboratory for further quantitative and qualitative analysis under an Olympus inverted microscope (Model IX50-S8F2). Phytoplankton removal was done by Sedgwick-Rafter Counting Cell [19][21]. Quantitatively, the abundance of phytoplankton cells from each phytoplankton genus was calculated. Phytoplankton's identification was done based on several taxonomic references [22][23][24]. The abundance of phytoplankton cells was calculated according to the procedure in phytoplankton manual [20]. The total number of cells of individual species collected at each depth of each station was quantified and the phytoplankton abundance was expressed as the number of cells per cubic volume.

2.4 Nutrient analysis

Water samples for nutrient analysis were also collected from each station. The samples for nutrient analysis were collected from surface water with a depth of 1.0 m using a Kemmerer sampler. Each sample was immediately decanted into an acid-washed bottle and was acidified with 1% v/v HNO3. The method of nutrients (phosphate, nitrate) analysis was determined based on the colorimetric method [25] using a spectrophotometer with wavelengths for phosphate (690 nm) and nitrate (543 nm).

The nutrients in this study were mainly dissolved inorganic nitrogen (DIN), including ammonium nitrogen (NH4-N), nitrate-nitrogen (NO-N) and nitrite-nitrogen (NO-N), and dissolved inorganic phosphorus (DIP), including phosphate-phosphorus (PO4-P). The method for analysis of nutrients used in this study was based on the transformation, through a chemical reaction of the substance to be analyzed, to another compound that can be measured calorimetrically within the wavelength range of the visible spectrum. The water sample was filtered with Millipore filter paper pore size 0.45 μm. The steps followed the manual of chemical and biological methods for analysis [25]. The spectrophotometer employed in this study was a Philips Pye Unicam (Model PU8600). As a general rule, all samples were analyzed as soon as possible after collection and especially when the concentration was expected to below.

2.5 Parameters of oceanography

Oceanographic parameters such as water depth, water temperature, dissolved oxygen, and salinity were measured in situ. The readings of water temperature and dissolved oxygen were taken directly from a YSI Dissolved Oxygen Meter (Model 59) and salinity (in parts per thousand) was measured using an ATAGO Hand Refractometer. The degree of acidity (pH) of seawater is measured by the pH meter of the TOA model of the HM-IK model by dipping the electrode into it. Data analysis was done with the 2010 version of the Excel program which was equipped with XL Statistical analysis.

3 Results and discussion

3.1 Oceanographic characteristics

The annual average water temperature during the study period was 29.97 °C with its range from 29.72-30.48 °C. The lowest monthly water temperatures during the study period were 29.37 °C, recorded in May 2008 and the highest was 30.48 °C recorded in March 2013. The annual average salinity was 28.98
psu with its range from 27.72 – 30.88 psu. The lowest monthly salinity during the study was 26.41 psu, occurred in March 2009 and the highest salinity was 30.88 occurred in May 2010. The salinity range was relatively stable with the exception in May 2008 and March 2009 and June 2009. The annual average dissolved oxygen (DO) ranged from 2.96 – 4.12 ppm. The lowest monthly DO was 2.96 ppm and the highest was in May 2013. The lowest and values during the study period were 2.96 in March and June 2009. The annual average pH was 8.03 ppm, where its range from 7.68-8.30. The lowest monthly pH was 7.68 occur in July 2015 and the highest monthly pH was 8.19 in May 2015. The averages of oceanographic parameters in Jakarta Bay during the study were summarized as seen in Table 2.

There were no extreme values of the oceanographic parameters during the study periods, except the lowest oxygen value recorded in March 2009. Because of the relatively shallow water depth (6–15 meters), as well as flushing by tides and currents, no distinct stratification occurred in Jakarta Bay.

Table 2. The averages of oceanographic parameters during the study.

| Oceanographic Parameters | Ranges     | Averages |
|--------------------------|------------|----------|
| Temperature (°C)         | 29.72-30.48| 29.97    |
| Salinity (psu)           | 27.72-30.88| 28.98    |
| pH                       | 7.68-8.30  | 8.03     |
| Dissolved Oxygen (ppm)   | 2.96-5.17  | 4.12     |

3.2. The Abundance of phytoplankton
The results showed that the abundance of phytoplankton ranging from 20.20 x10^6 cells.m^-3 up to 20.61 x10^6 cells.m^-3. The highest abundance was observed in the dry season of 2010, ranging from 44.89 x10^6 up to 20.61 x10^6 cells.m^-3 (Figure 2). There are several peaks of the phytoplankton population in the period of the study. The peaks of the population reached the abundance up to more than one million per cubic meter. It indicates that the bloom was occurring in Jakarta Bay. Usually, the bloom can be seen through discoloration in the surface water due to the increased number of one or more species of the phytoplankton population. Discoloration usually visible when the abundance of phytoplankton reaches the amount of more than one million cells per cubic meter [14][16]. During this study it was often seen that discoloration in the surface water dispersed unevenly in the waters, showing that the phytoplankton bloom phenomenon was reoccurring in the bay.

The graph showed a very conspicuous increased in phytoplankton population in 2010. Generally, there is a correlation of the increasing amount of cell phytoplankton with the availability of nutrients in the waters [26][27]. A high amount of phytoplankton abundance may indicate that the waters was being eutrophication or enriched by anthropogenic nutrients discharging to the bay [28]. The increased anthropogenic activities in the surrounding bay has consequences for nutrients enrichment in the water environment. The increase in the population of the surrounding area and urban development can contribute to the increasing intensity of algal blooms in Jakarta Bay. There were much evidence reported related to increasing in frequency and magnitude of algal bloom events world-wide was linked to cultural eutrophication [29].

During the rainy season, nutrients concentration tends to increase due to high precipitation which brought a lot of organic materials discharged to the bay through the rivers and run-off. Normally, the highest total precipitation occurred during the rainy season from October to March, and drier conditions occur from April to September. There was a strong correlation between precipitation and nutrients concentration in the waters [30], where an increase in nutrients will be followed by an increase in phytoplankton populations in the dry season. The high nutrients ratio will trigger the growth of phytoplankton cells leading to an outbreak of population or bloom episode occurring in this waters [31].
3.3. Algal bloom occurrences

Figure 3 showing the surface water discoloration due to phytoplankton bloom events in Jakarta Bay during the dry season from March to July and during the rainy season from September to November. The discoloration mostly spread unevenly in the surface water produced by phytoplankton such as greenish, brownish and yellowish or a combination of them. The discoloration in the waters that occurred due to the rapid growth of phytoplankton resulted in high abundance [32], which produced by one or several predominant species [27]. The algal bloom phenomenon in the waters is usually identified based on the chlorophyll-a concentration, cell diversity, and discoloration in the surface water. Water discoloration will appear if the chlorophyll-a concentration reaches more than 10 mg.L$^{-3}$ and cover the area more than the fourth part of the bay area. The percentage of the covered areas of bloom events can be determined accurately using satellite images [14].

In Jakarta Bay, most of the algal bloom events reoccur in the dry season, precisely beginning a few weeks after the rainy season is over [16]. In this study, the highest frequency of bloom incidence was observed from March to June and during the rainy season from September to November. Algal bloom events appeared during the dry season which is started from March to June and then reappeared mostly from September to November. The dry season is usually characterized by less precipitation, high nitrate and phosphate concentration, higher air temperature and available sunlight intensity. This condition will trigger the growth of phytoplankton to grow faster and reach a high density of cells during that season. So far, the incidence of algal blooms in Jakarta Bay has been increasing both in frequency and distribution [14].

Discaloration due to algal blooms phenomena in Jakarta Bay, reoccurring mainly in March until June and occasionally in September to November. During the rainy season from December to February, there was no appear discoloration of surface waters due to algal bloom. It is apparently, that the algal bloom episode in Jakarta Bay is associated with the dry season (precisely after rainy season) when the N/P ratio increased in the waters from March and April [14].

Figure 2. Phytoplankton abundance (million cells/m$^3$) along with the observations.
3.4. Eutrophication and algal bloom

Table 3 show the concentration of nitrate and phosphate during the study period in Jakarta Bay. The average concentration of nitrate during the study period ranged from 0.01 – 15.89 μg.A.L⁻¹, while the mean concentration of phosphate range from 0.01-2.5 μg.A.L⁻¹. The highest concentration of phosphate was observed in the dry season of 2009, while the highest nitrate was observed in the period dry season of 2015. Phosphate concentration tends to decrease, on the contrary, the nitrate concentration tends to increase during the study. The results showed that there has been rising in nitrate concentration and decreasing phosphate concentration in the waters from 2008 until 2015. An increasing inorganic matter has been observed in Jakarta Bay, resulting in an increased incidence of algal blooms since the 1970s [15]. Starting in the 70s to the 80s algal blooms were rarely seen, but in the 90’s the algal bloom seemed to increase in connection with the increasing amount of anthropogenic nutrients in the bay. A relationship between the increased of eutrophication with the expansion of algal bloom in the bay is still not proven although in general eutrophication may result in an explosion in the community of phytoplankton [28]. The rise in parallel to the increasing incidence of blooms due to the enrichment of nutrients, such as incidents in the South China Sea and Hong Kong [18][27].

The average of the N/P ratio during this study is ranged from 0.3 - 22.1. It was recorded that a higher N/P ratio was observed from 2010 until 2013. In the period of dry season 2010, the highest concentration of nitrate was recorded in May with a value of 10.61 μg/L and phosphate 0.58 μg/L. During this period, the N/P ratio reaches the value to 18, which means that N plays a role as a triggering factor and P as a limiting factor for the growth of phytoplankton. It is apparent, that there is a strong linkage between nitrate concentration and the abundance of phytoplankton. There was a connection between high ratios of N/P with the algal bloom abundance. However, this relationship does not indicate that the bloom of phytoplankton would experience following the increase in the N/P ratio. The ratio of N/P describes that N plays as the main factor that can stimulate the growth of phytoplankton. However, the concentration of P is the limiting factor, meaning that at least, there should be a certain amount of P in the waters. Both of these nutrients N and P is seemed to be complementary to each other and together controlling the growth of phytoplankton.

Figure 4 showing the trend of the N/P ratio during the study period. The ratio of phosphate (P) and nitrate (N) during the study ranging from 0.2 to 45.4. The highest N/P ratio ever recorded during the study was 45.4, which occurs in 2010. The N/P ratio decreased from 2008 until 2009, while the N/P ratio was increased from 2010 until 2013. The N/P ratio in 2010 seemed to be conspicuous compared to
the others. This showing that nitrate concentration higher than phosphate in the waters during that time. It seemed that nutrient enrichment of N and P in this bay was occurring since 2010, onwards.

The ratio of N:P is good for the growth of phytoplankton in the range 15-30, where the N/P ratio is high indicating that nitrate as a triggering factor and phosphate as limiting factor [33]. It is also said that when the atomic ratio of N/P is greater than 16 (example 25-30), showing that P as a limiting factor (P-limited) for phytoplankton growth [28]. It means that if there is a deficiency of phosphorus in the water, would prevent further growth of phytoplankton. On the other side, it is said that if the N/P ratio is less than 10 indicates that N as limiting growth or N-limited [26][33]. The rise in this ratio indicates that there is an increase in organic matter in the water that causes enrichment of nutrients or eutrophication [34][35][36]. Eutrophication will result in the outbreaks of the phytoplankton population or algal bloom incident. The incident of phytoplankton blooms may indicate that organic nutrients that required for the growth are already available in high concentration in the waters [31][37][38].

The algal bloom outbreaks are closely linked to coastal human activities, such as aquaculture, marine pollution, the seafood industry, transportation (ship’s ballast water) and tourism [39]. The occurrences of harmful algal bloom (HAB) were predicted as a result of global climate change, eutrophication, and man-made (industrial and domestic) activities in the coastal areas [40][41]. Algal blooms are attributed to two primary factors such as natural processes and anthropogenic loadings leading to eutrophication. The latter is generally assumed to be the primary cause of all blooms. The formation of algal blooms occurs when algae, in response to favorable conditions in their environment, proliferate to form dense concentrations of cells or blooms.

In Jakarta Bay, the nutrient pollution was mainly discharged from 13 rivers flowing through the city and from land-based sources including industrial effluent, sewage, and agricultural discharges. All these had become a major problem in Jakarta Bay. The increased frequency and magnitude of algal bloom events and related fish mortality in Jakarta Bay is linked to cultural eutrophication. Due to the high population and development around Jakarta and its hinterland cities, many rivers discharge their loads into the bay and are becoming the main threat to the water quality [12]. The previous study in 2001 showed that the temporal variations in nitrate concentrations were significantly lower during the dry season compared to the rainy season [11], while phosphate concentrations showed insignificant differences. During the wet/rainy season the levels of phosphate and nitrate were consistently shown to be higher close to the seashore.

![Figure 4](image-url)  
**Figure 4.** Trend of N/P ratio during the study period in the dry season from 2008-2015.
Table 3. Mean concentration of nitrate and phosphate and N/P ratio.

| Observation Periods | Mean Nutrients and N/P Ratio |
|---------------------|-----------------------------|
| Year                | Months | PO$_4$ (µg./l) | NO$_3$ (µg./l) | Mean N/P Ratio |
| 2008                | March  | 0.82           | 1.98           | 2.4            |
|                     | May    | 0.77           | 1.96           | 2.6            |
| 2009                | March  | 0.01           | 0.01           | 0.9            |
|                     | June   | 2.5            | 0.87           | 0.3            |
| 2010                | March  | 0.62           | 2.28           | 3.7            |
|                     | May    | 0.58           | 10.61          | 18.4           |
|                     | June   | 0.73           | 4.6            | 6.3            |
| 2011                | March  | 0.71           | 5.67           | 8              |
|                     | July   | 0.27           | 5.96           | 22.1           |
| 2013                | March  | 0.27           | 5.03           | 18.5           |
|                     | May    | 1.37           | 15.89          | 11.6           |
| 2015                | July   | 0.05           | 0.08           | 1.7            |
| Minimum             |        | 0.01           | 0.01           | 0.3            |
| Maximum             |        | 2.5            | 15.89          | 22.1           |

3.5. The species of algal bloom

During the study, it was observed the causative species of blooms events which is responsible for the discoloration of surface water in the dry season in Jakarta Bay. Most of them belong to diatoms such as *Skeletonema*, *Chaetoceros* and *Thalassiosira*. The color that appeared in the surface water during bloom events in Jakarta Bay is always correlated with that predominant phytoplankton, which resulted in green, brownish and yellowish discoloration. The species of phytoplankton called predominance are those that usually exists in the population with an abundance of more than 10 percent. They are considered important species because they play an important role in the marine life of these waters. Furthermore, these organisms can be used as a biological indicators for the condition of the waters. There is three genera of phytoplankton such as *Skeletonema*, *Chaetoceros*, and *Thalassiosira* which can be categorized as the common species in Jakarta Bay. The incident of algal blooms have occurred more frequently in Jakarta Bay and the harmful effects and duration of the blooms have been intensified lately.

The results of observation on the abundance of predominant phytoplankton in Jakarta Bay is shown in Figure 5. The relative abundance of *Skeletonema* ranges between 30-87 percent (average 49%), and *Chaetoceros* as the second with abundance ranges between 14-57 percent (average 28%) and *Thalassiosira* (9%) and Nitszchia (5 %). The others phytoplankton around 9 % that also make up the community. *Skeletonema*, *Chaetoceros*, and *Thalassiosira* as the predominant genus in the dry season. They are often found together to be predominant in the phytoplankton population. It is also found as many as 10 types of phytoplankton have a relative abundance of at least 1.0 %, but the frequency of its presence is quite high and 20 genera have a relative abundance is below 1.0 % of the total abundance. It seems that the existence of these species is connected with the dry season. However, further research is still needed in relation to their occurrence in the wet season. A previous study in Jakarta bay showed that *Skeletonema* also predominates in the phytoplankton community during the wet season while *Chaetoceros* tend to be predominance in the dry season [16]. The other phytoplankton such as *Thalassiosira* sometime appears predominant during the dry season. It is concluded those three genera
of phytoplankton *Skeletonema*, *Chaetoceros* and *Thalassiosira* can be considered as an important genus which is responsible as bloom maker in Jakarta Bay.

![Figure 5](image_url)

**Figure 5.** The composition of predominant phytoplankton during algal bloom.

### 3.6. Bloom events and fish kills.

Mass mortality of fishes and other organisms due to algal bloom events have been observed over recent years in certain parts of Jakarta Bay [13][14][16]. In many cases, massive fish kills happened several days or weeks after the occurrences of algal bloom, however, most of the algal bloom incidence does not always result in mass mortality of fish in this bay. During the study, the tragedy of fish kills occurred in April and November 2008 and in November and December 2015. There must be another factor or certain condition which also play a role in the cases of fish-killing during algal bloom incidence. Phytoplankton is good food for many of fishes, therefore algal bloom occurrences in the bay should be beneficial for marine life. However, the algal bloom is not necessarily beneficial for the fish, otherwise it could adversely impact on the environment which in turn resulted in mass mortality of fish. Eutrophication is the major factor that triggers phytoplankton growth, but the other factors such as water stratification and current movements can influence bloom formation and its effect on fish and other living organisms in the waters [8]. Both of these factors can prevent bloom formation and it’s consequently on living organisms in the waters. The tragedy of fish kills during the bloom incident in Jakarta Bay was due to the decreasing of oxygen concentration (oxygen depletion) in the waters.

The stratification of the water column and current movement may play an important role in the tragedy of dead fish. The distribution of algal blooms in Jakarta Bay is mainly controlled by the current, particularly current movement due to tidal state. The bloom may concentrate on a particular location depending on the current movement, so it may harm the surrounding ecosystem. Usually, algal bloom events which lead to oxygen depletion in the water column during night time. During the dark time, the respiration process and decomposition organic matter take place which consumes a lot of oxygen, consequently dissolved oxygen (O₂) depleted to a low level and vice versa CO₂ increases as results of respiration. And also, when the bloom biomass dies off, more oxygen is consumed to decay, leading to oxygen depletion in the affected area [8][42]. Massive fish kills will occur due to dissolved oxygen deplete drastically and also the water circulation is weak during that nigh.

Fish kills may happen several days after the occurrences of algal bloom. Among the algal bloom events in Jakarta Bay, tragically, a massive fish kill on May 7 2004, was recorded as the biggest incident of an aquatic disaster which is never happened before [14]. The other conditions that were recorded before algal blooms and massive fish kill events were the unusual rain, and unusual calm of seas in the next day after heavy rainfall [43]. The oxygen depletion after an algal bloom is the main factor that caused a massive fish kill on November 16, 2007 [14]. It was concluded that the main cause of massive
fish kills in Jakarta Bay was due to oxygen depletion to the lowest level, less than 2 ppm, in the water column after high biomass of algal bloom incidence.

3.7. Conclusion
The rising frequency and magnitude of algal bloom events in Jakarta Bay are linked to nutrient availability as a result of eutrophication leading to the intensity of algal blooms. Algal bloom incidents are associated with the dry season until the transitional season. Most of the incidence is closely related to nutrients enrichment or eutrophication, particularly, it has a strong linkage with the ratio of N/P in the waters. Rainfall mainly contributes to increasing the number of nutrients into the bay, while tidal plays a role in the distribution of blooms formation on the surface. The nitrogen plays a role as a triggering factor and phosphorus as a limiting factor. Both N and P are complementary to each other and together will control the growth of phytoplankton. There are three important genera of phytoplankton such as Skeletonema, Chaetoceros, and Thalassiosira that play an important role during bloom episodes in Jakarta Bay. These genera of phytoplankton are known as common species in Jakarta Bay and also seasonally dependent.

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