An overview of harmful algal blooms and eutrophication in Jakarta Bay, Indonesia

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Abstract. Algal blooms have been occurring in Jakarta Bay for twenty years. However, recently the occurrence of algal blooms, their harmful effects, and their duration have been intensified. Algal blooms have devastated the marine environment, caused fish mortality, and been detrimental to local tourism, local fishing, and other industries along the coast. It comes to speculation that the increase of anthropogenic activity from surrounding areas is taking a toll on the environment. So, this research aimed to study the recent rise of algal blooms in Jakarta Bay and the possible anthropogenic links, mainly through cultural eutrophication, to the increasing occurrence of red tides and their impact. Observation has been conducted to study the dynamic of algal blooms concerning eutrophication and the existing seasons. Collecting samples were performed using a canonical plankton net from 2008 until 2015. The results showed that the abundance of phytoplankton ranged from 40.90 x 10^6 up to 1699.10 x 10^6 cells.m^-3. The highest quantity of cells was observed in May 2010 between rainy to dry seasons. There is evidence that the reported increase in frequency and magnitude of algal bloom events in Jakarta Bay is linked to cultural eutrophication. The recent exponential growth of the city may be a contributing factor in the increasing intensity of algal blooms. The cultural eutrophication of coastal waters increased, leading to the intensity and frequency of algal bloom.

1. Introduction

Recently, the incidents of harmful algal blooms in Jakarta Bay increased more than 20 years ago. They caused fish-killing, leading to economic losses in local fisheries, affect environmental quality, and even threatening those who consumed fish harvested from the bay. It is now a significant challenge for the local government in this bay because of harm to human health, fisheries, mariculture, and esthetic scenery [1]. An algal bloom is a substantial development of biomass and often leads to discoloration of sea surface [2-4]. Many studies showed that nutrient enrichment due to anthropogenic activities is the most likely cause of those algal blooms.

Other pressures, such as climate change, can also influence bloom events [5, 6]. The combination of natural factors and anthropogenic nutrient enrichment is most likely the driving factor of increasing phytoplankton blooms [7, 8]. Nutrient enrichment resulting from anthropogenic activity occurs in Jakarta Bay, and the blooms phenomena are the effects of such an accelerated process. Nutrients are input from various sources such as agriculture, industries, domestic waste, urban waste, consequently causing eutrophication [9]. Those materials enter the bay through river flow and also drainage [10-12].
Eutrophication is the primary cause of bloom outbreaks linked to human activities in the coastal area [14, 15, 16] and global climate change [8]. The formation of algal blooms occurs as they respond to favorable conditions and increase to form dense concentrations of cells [11, 13, 14]. Increased nutrients such as nitrogen (N) and phosphorus (P) by rivers to coastal waters, as a part of global environmental changes, have been triggered by human activities on land, including in particular agricultural and industrial sectors [15]. Surplus of N and P in aquatic systems and shifting N/P ratios in marine systems have resulted in eutrophication followed by several negative impacts such as oxygen depletion, hypoxia, fish kill [16, 17]. Nowadays, coastal eutrophication is become a rising problem and is often the leading cause of bloom occurrences [9].

In connection with this significant condition in Jakarta Bay, we researched harmful algal blooms from 2004 until 2015, although not sequentially every year. The research aims are to study the recent increase of phytoplankton blooms in Jakarta Bay and the possible links between cultural eutrophication and algal bloom increases. This paper is part of the main study conducting in Jakarta Bay.

2. Materials and methods

2.1. Location
The study took place in Jakarta Bay (Figure 1). At least 13 rivers and canals flow through Jakarta and its hinterland cities with nearly 30 million inhabitants [18]. Most of the rivers dispose of the polluted wastes from human activities into this bay. The bay experienced a load of organic material through some rivers flowing to this bay, leading to phytoplankton bloom caused fish killings [17].

2.2. Research Period
We researched from 2007-2011, 2013, and 2015 at 12 fixed sampling stations selected. The sampling took place in the dry or east season, considering that the phytoplankton bloom often occurs after the rainy season leading to dry seasons (April-September). In the rainy season, the nutrients increase in the bay, mainly N and P, as essential for phytoplankton growth. Collecting samples were conducted primarily in the transition season from the rainy to the dry seasons (Mar-Apr-May) and in the middle month of the dry season (Jun-Jul-Aug). No sampling was conducted in transition from dry to rainy seasons (Sep-Nov) and rainy seasons (Dec-Feb).

2.3. Phytoplankton Samples
Phytoplankton sampling was collected using a phytoplankton net with a mesh size of 20 µm, a net length of 125 cm, and a mouth diameter of 25 cm. It was equipped with ballast at the end of the net to make it easy to pull down vertically. The phytoplankton net pulls down to a certain depth around 7-10 m and, after that, slowly hauling up the surface. We poured samples into bottles mixed with preservatives. We preserved using Lugol [19]. The samples were taken to the laboratory for further analysis under an Olympus inverted microscope (Model IX50-S8F2). The calculation of cells abundance and identification of phytoplankton using Sedgwick-Rafter Counting Cell [19]. References for phytoplankton identification by using [20-22]. The cells abundance counted using the formula as follow:

\[ N = n \times (V_t/V_s) \times (1/V) \]
\[ V = \pi \times r^2 \times d \]

where: N = all species of phytoplankton abundance (cells/L); V = volume of filtered water; Vt = the initial sample volume; Vs = sub-sample volume (fraction), n = number of phytoplankton in sub-sample, \( \pi \times r^2 \) - the area of net opening, and d = the water depth at each station.

2.4. Measurement of Nutrient (N and P)
We collected water samples for nutrients analysis (N and P) from surface water using a Kemmerer sampler. The water samples were decanted into an acid-washed bottle and acidified with HNO3. Nutrients concentration was measured using a spectrophotometer (Philips Pye Unicam, Model PU8600),
with 690 nm wavelength for phosphate and 543 nm for nitrate. We used millipore filter paper, pore size 0.45 µm following [23] methods.

![Figure 1](image_url)

**Figure 1.** The map of Indonesia (upper) and Jakarta Bay (bottom). (Number in red color (1-10) indicating the stations of sampling)

### 3. Results and Discussions

#### 3.1. Phytoplankton abundance

The results showed that most phytoplankton blooms occurred from April to May (dry season) and from September to October (transition season). The blooms events rise from 2004 until 2015, indicating that the frequency of reoccurring increases mainly in April-May and September to October. The color change in the surface water varies depending on the predominant species, e.g., reddish, brownish, yellowish, or combination. The color change occurred due to the rapid growth of phytoplankton by one or several dominant species [4, 5].

Figure 2 shows the highest abundance of phytoplankton reaches $20.61 \times 10^8$ cells.m$^{-3}$ occurred in 2010. During the study periods, several peaks of the phytoplankton population reached more than one million per cubic meter. Discoloration in the surface water is generally visible by the naked eye when the phytoplankton density is at least around one million cells per cubic meter or the concentration of chlorophyll-a higher than 7.5 mg/L [1].

The events of harmful algal blooms in this bay increased in frequency and distribution [12, 17, 18], mainly in the dry season characterized by less rainfall, higher nitrate and phosphate availability, and sunlight intensity. All this condition triggers phytoplankton's development and reaches a high density of cells during that season [12]. A high phytoplankton abundance may indicate that the bay is experiencing eutrophication due to discharging of anthropogenic nutrients released from surrounding areas [24]. Many studies show that the increase of harmful algal bloom events is due to cultural eutrophication [5, 14, 25]. The harmful algal blooms reoccur when they respond to favorable environmental conditions and form high biomass concentrations, resulting in color change. The driving factor in increasing phytoplankton bloom in Jakarta Bay is mainly the nutrient enrichment that rivers discharge into the bay. Most of the anthropogenic nutrient comes from the domestic released from the city and its surroundings and becomes the leading cause of water disturbance [1, 11].
3.2. Phytoplankton and nutrients

Figure 3 showing the graphic concentration of nitrate and phosphate during the study in Jakarta Bay. It shows that the nitrate concentration ranges from 0.01 – 15.89 ug/l, and the phosphate concentration ranges from 0.01-2.5 ug/l. It also shows the higher phosphate concentration was in Jun 2009 and May 2013; however, overall, the phosphate concentration tends to decrease along with this study. Meanwhile, the concentration of nitrate tends to increase in fluctuation along with this research. It means a rise in nitrate concentration and a decrease in phosphate concentration along with the study. A previous study shows that nutrient increase in this bay led to increased phytoplankton blooms since the 80s [1, 7, 17]. The first occurrence of harmful algal bloom appeared in the 90s, and they tend to increase coinciding with the increase of nutrients in this bay. It may be indicating that the relationship between eutrophication and harmful algal bloom development [15].

Not all phytoplankton blooms caused discoloration; likewise, not all bloom events caused fish-killing. In 2004, there were twice the blooms phenomena that caused fish mortality in April and November. The same thing fish-killing in 2005 occurred in November and December. In 2006-2009, only a few dead fish appeared in April and December and appeared only in specific locations. In 2010 fish-killing occurred more widely, covering a more extensive area in April and May. And in the next year, from 2011, few fish-killing happened, distributed in specific areas. However, most fish-killing occurred after the extensive algal bloom covering the bay, where the comprehensive bloom events reoccurred after the rainy seasons. There was a linkage of the reoccurrence of algal bloom with rainfall and rain days, leading to nutrient enrichment and eutrophication in the waters.

According to [2, 3, 9], nutrient enrichment is the primary driver of phytoplankton development. The other essential driving factors include stratification and current as of the critical role of scum formation and its consequences on living organisms. The disaster of fish-killing occurs when harmful algal bloom primarily due to oxygen shortage in the water column. Oxygen depletion can be due to high rates of respiration by the algae (at night or in dim light conditions) but is more likely by bacterial respiration during the decay of the dead plankton biomass. Fortunately, there were no toxic species during bloom in Jakarta Bay, so fish death was not caused by poisonous species. Previous observation showed that dissolved oxygen concentration in the surface waters reached less than 2.0 ppm and nearly zero in the bottom during the bloom tragedy [26].

![Phytoplankton Abundance](image-url)
Phytoplankton population tends to develop mainly after the rainy season and the second transition from dry to rainy, where nutrients are available and favorable conditions. The connection between nutrient enrichment and the harmful algal bloom is complex because HABs are not new. Although phytoplankton bloom may occur preceded by coastal enrichment, and of course, it is not the only prerequisite for their presence. The other factor, such as climate change, can also drive harmful algal bloom [27, 28].

Figure 3. The concentration of nitrate and phosphate during the study period in Jakarta Bay

3.3. Algal bloom and nutrient ratio
An important issue regarding harmful algal blooms is the role of nutrient ratios in governing the development of the phytoplankton population. The nutrient ratio is usually a decisive factor concerning phytoplankton development. It is known as the Redfield ratio showing the chemical composition requirement for phytoplankton growth where the ratio C: N: P: Si is 106:16:1:1. The nutrient in the minor condition for the development is considered the limiting nutrient [27,28]; however, if both nutrient concentrations are high concerning the need for phytoplankton, the ratio will have little or no effect. The nutrient ratio based on the Redfield ratio is used concerning ambient nitrogen and phosphate concentrations to predict which nutrient is likely to limit development. The percentage of N and P is higher than 16 (N:P >16), indicating N as triggering and P as a limiting factor.

The concentration of nutrients in Jakarta Bay tends to increase coinciding with high rainfall, causing many organic materials to enter the bay through the rivers and canals [29-31]. Nutrient concentration increased after the rainy season and leading to increasing phytoplankton development in the dry season. Figure 4 shows the nutrient ratio of N: P: Si and phytoplankton abundance during this study. The nutrient ratio N: P ranging from 1.9 - 39.30 with an average of 17.07. The Si: N ratio was ranging from 0.15 - 9.48 with an average of 4.20. The N: P ratio tends to increase and reached its peaks in 2010 and 2011. In 2010, the N/P ratio was higher in May, with an average of 27.33. In 2011 the N/P ratio was higher in July, with an average of 39.30. The N: P ratio averages 17.07, indicating that N is a triggering factor and P limits phytoplankton development. The high concentration of nitrogen (N) drives the phytoplankton to grow faster. In contrast, phosphate (P) is limited where a certain amount of phosphate must be available complementary to nitrogen. Phosphate is a limiting factor, meaning that deficiency of phosphate would prevent the further growth of phytoplankton.

A change in the N:P ratio usually impacts harmful algal bloom occurrences, e.g., in Tolo Harbour, Hong Kong, where the N:P ratio decreased from 20 to 10 from 1982 - 1989. That decrease in the nutrient ratio is significantly due to an increase in the bloom events [32-34]. On the contrary, from 1998 until 2007, the N: P ratio increased to 35: 1; however, the bloom decreased. The crucial thing that needs to
consider is the diatoms also require silicon (Si) to develop their cells wall. The Si limitation may slow down the diatom development and promotes the dinoflagellate to establish. Most field studies confirm that Si limitation promotes dinoflagellates over diatoms [35]. A high ratio of N: Si potentially promotes dinoflagellates development and, on the other side slows down the diatom to develop.

![Figure 4](image)

**Figure 4.** The linkage of the nutrient ratio of N/P and Si/N and phytoplankton abundance (Note: Mar’8 = Mart 2008…etc)

3.4. The species of bloom maker

Most of the harmful algal bloom events perform a discoloration in the surface water. In Jakarta Bay, mainly the bloom maker species belong to the diatoms such as *Skeletonema, Thalassiosira, Chaetoceros,* and *Thalassitrix.* The one belongs to dinoflagellate such as *Noctiluca* and belongs to cyanobacteria such as *Trichodesmium.* However, only three of them are categorized as the most common species responsible for the bloom event: *Skeletonema, Chaetoceros,* and *Thalassiosira,* and they occur in abundance mainly in the dry season. However, previous research showed that they are sometimes predominantly in the rainy season [36]. Therefore, those three phytoplankton species are responsible for harmful algal bloom events leading to fish-killing in Jakarta Bay.

3.5. Harmful algal bloom and fish-killing

Phytoplankton is a naturally good food for most herbivore fishes. However, when the phytoplankton occurs in excess number, it can harm the fish because it adversely impacts the environment, leading to mass mortality of fish. Usually, non-toxic algal blooms can cause mass mortality of fishes in the aquatic ecosystem through oxygen depletion to anoxia conditions.

Primarily, a harmful algal bloom in this bay does not lead to fish-killing caused by toxic phytoplankton or fish killer; however, almost due to the shortage of oxygen caused fishes suffocation. The fish-killing occurred over recent years in specific locations of the bay. Usually, massive mortalities of marine biota are typically due to the high phytoplankton abundance, leading to oxygen shortage in the water column, especially at night. The incident of depleted oxygen occurs mainly during the night and when the ebb tide is in calm conditions. The lack of dissolved oxygen in the water column at night because most phytoplankton needs oxygen for respiration. Besides, when the high abundance of phytoplankton biomass dies, decaying microorganisms will consume more oxygen and deplete oxygen in the affected area [36, 37]. The fish will experience difficulty breathing and then die massively.

Fish-killing happened in Jakarta Bay depends on the coverage area of the high-density phytoplankton population. There were massive fish mortalities due to harmful algal blooms in 2004 and 2005, where
bloom formation appeared almost three-quarters of the bay. Similarly, enormous fish mortality occurred in 2007 due to oxygen shortage (less than two ppm) in the waters. The other fish mortalities also occurred in 2010 and 2015, mainly fish killings due to the lack of oxygen in the water column [1].

4. Conclusion
The occurrences of harmful algal bloom in Jakarta Bay seemingly relate to anthropogenic nutrient enrichment of the bay, leading to the eutrophic state. The eutrophic state of the bay is the primary cause of why harmful algal bloom occurred. The Redfield ratio of nutrient concentration plays an essential role in developing algal blooming, where N:P:Si ratio is 16:1:15 used to predict which nutrient is likely to limit development. When the percentage of N and P is higher than 16 (N:P >16), indicating N as triggering and P as a limiting factor. However, if the ratio of N: Si is higher than 1 (N: Si ≥1), the diatom species will dominate the population and slow down the development of dinoflagellate, even though the N:P ratio is higher than 16 in the waters. Generally, the diatom species as the dominant and primary causative species of harmful algal bloom in this bay, namely Chaetoceros, Skeletonema, and Thalassiosira. The dominant phytoplankton is known as common species, and their occurrences are seasonally dependent. The massive mortalities of fish during algal bloom in Jakarta Bay due to a shortage of dissolved oxygen in the water column and none of the fish-killing due to the toxic one or fish-killer phytoplankton.

Acknowledgments
Many thanks to our college and technicians who assisted in doing research.

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