Harmful algal blooms and their impact on fish mortalities in Lampung Bay: an overview

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Abstract. The first disaster caused by harmful algal blooms in Lampung Bay was reported in 1991, where mass mortality of cultivated shrimp occurred in the brackish water ponds due to a Trichodesmium bloom. After this incident, the phenomenon reoccurred in the following years continuously. Around nine species bloom makers in this bay are namely Pyrodinium sp., Noctiluca sp., Phaeocystis sp., Dinophysis sp., Trichodesmium sp., Ceratium sp., Prorocentrum sp., Pseudonitzschia sp., and Cochlodinium sp. The most frequent causative species, such as green Noctiluca and Trichodesmium, co-occurring during blooms and causing fish mortalities in the fish farming floating nets (KJA). Two species are known as the most potentially harmful species, namely Pyrodinium sp. and Cochlodinium sp. Cochlodinium blooms happened at the end of 2012, and since then, this species has continuously reappeared in the following years. The outbreak of Cochlodinium sp. still appeared in 2017 and 2018, but no fish-killing occurred. Phytoplankton bloom events occur at specific locations, mainly at fish farming floating nets on the west side of the bay, next to Hurun Cove. This paper discusses the occurrence of algal blooms in Lampung Bay and the triggering factors for increasing phytoplankton populations that cause harmful algal blooms.

Keywords: algal blooms, causative species, discoloration, driving factor, fish-killing

1. Introduction

Harmful algal blooms (HAB) are natural phenomena caused by the proliferation of one or two, or even more, phytoplankton species. They drive significant negative impacts on human and environmental health, economies, tourism, aquacultures, and fisheries [1]. Most algal blooms are not harmful to marine organisms or humans, but some are poisonous because they produce toxins during the bloom, and bloom events typically last a few days or weeks [2]. The high abundance of phytoplankton species occurs with different colors, resulting in the dominant species such as red, brownish, or green. Several species produce toxins (phycotoxin) that may affect or even kill organisms at higher trophic levels throughout the food web. The phycotoxin infected humans, primarily after consuming contaminated shellfish or seafood [3]. Some HABs species are not toxic, but they may kill fish due to oxygen shortage during a dense algal bloom that occurs in the waters [4].

Lampung Bay is multi-functional, providing numerous livelihood opportunities to most people surrounding the bay. However, recently a problem arose due to an increased human population living
within the surrounding coastline and industrialization around the coastal areas of Lampung Bay [5]. These coastal waters receive nutrients discharging from municipal and nonpoint sources, leading to an increased incidence of harmful algal blooms (HABs) in the recent decade. Lampung bay has now been experiencing anthropogenic stress, resulting in eutrophication, leading to ecological perturbations such as harmful algal blooms and hypoxia [5]. Anthropogenic processes associated with eutrophication can cause the ecosystem to be more susceptible to environmental concerns, including harmful algal blooms [6]. Meanwhile, those harmful algal blooms have increased in frequency of occurrence since the 2000s, and extent over recent decades continue reoccuring until a decade [7-9].

Generally, several abiotic and biotic factors can stimulate harmful algal blooms, but nutrient availability is the most limiting factor [10, 11]. The general view is that increasing nutrient anthropogenic discharging from land-based sources is a significant cause of the global increase in harmful algal blooms [10, 11]. The causal relationship and the nutrient source are usually varied and somewhat different to each location, season, and causative species. The reoccurrence of harmful algal bloom in this bay is due to increased nutrients, mainly N and P, which discharges from the surrounding areas, such as agriculture, industry, harbor, domestic waste, and increased fish farming in the floating nets, on the west side of the bay. Nutrient enrichment leading to eutrophication of the bay is predicted as the main triggering factor for the explosion of the phytoplankton population. The rapid growth of phytoplankton depends not only on increasing nutrient concentration; however, changes in the N and P play an essential role.

There are three types of harmful algal blooms (HABs); the first one is a harmless phytoplankton bloom associated with discoloration of the surface water. It usually belongs to non-toxic species, and no fish kills occurred. The second is a harmful algal bloom associated with the mass mortality of marine organisms. It also belongs to non-toxic HABs and is associated with water discoloration and fish-killing primarily due to oxygen depletion. The third type is a toxic algal bloom causing shellfish contamination, either PSP (paralytic shellfish poisoning) or DSP (diarrhetic shellfish poisoning). It may occur associated with a color change and also without discoloration in the waters [3, 4]. The toxic phytoplankton without a color change still potentially harms humans eating shellfish harvested from the blooming area. Usually, shellfish as filter feeders are not dying by the toxic phytoplankton, even though they accumulate toxins, and the toxin concentration will increase in their bodies without harming their life. So those infected shellfish harm the human consumer.

Several algal blooms occurring in this bay have caused fish mortalities, mainly those cultivated in floating nets. Interestingly, most water discoloration due to algal bloom occurs in the fish farming areas along the western coast of Lampung Bay. Still unknown if there is any relationship between algal bloom occurrences and fish culture in this bay. However, most fish farming activities with floating nets may contribute to nutrient enrichment from the remaining fish pellets that are wasted and deposited on the bottom of the water. And after a while, there will be a decay of the remaining food. These organic matters will decompose through the process of decomposition by bacteria so that nutrient elements such as nitrogen (N) and phosphor (P) tend to increase in the water column [1]. The study observes the linkage of phytoplankton abundance with nutrient concentration, such as macronutrients nitrate and phosphate. This paper provides an overview of harmful algal bloom episodes, including historical accounts of HABs and their causative phytoplankton species and factors that lead to their proliferation. This information can be a basis for managing coastal water quality and eliminating HAB consequences in Lampung Bay.

2. Methodology
These surveys were conducted in Lampung Bay in 2005-2008, 2009, 2013, 2014, and 2018. The sampling stations were focused primarily on the west side of the bay for a specific reason: algal blooms often occur at this location where fish farming is located. The data of the surveys have been documented officially, and a few articles have been published [12-15]. Therefore, information in this paper is the combination of primary and secondary data such as published articles and other data reported by other related institutions [16-22]. Lampung Bay is a large bay located on the southern tip of Sumatra Island in the Sunda Strait. The Bay of Lampung, which covers 1,888 square km, is a shallow water area with an average depth of 20 meters.
The map of Lampung is shown in Figure 1. Two rivers discharge into the Bay divide Bandar Lampung City. There are many industries along the east coast and an international harbor, while fish farming and pearl oysters culture are located on the west side of the bay. The fish culture in floating nets mainly belongs to local people and also private companies. Also, the Center for Marine Aquaculture of Lampung belongs to the Directorate General of Aquaculture, which monitors the bay's water quality.

Phytoplankton samples were collected using a phytoplankton net with a pore size of 20 µm, a length of 125 cm, and a mouth diameter of 25 cm. A bucket was installed at the end to collect concentrates of phytoplankton. The net also installs heavy material as ballast. The plankton net was operated by drop-down vertically with a rope to 10 m depth, and then, the net was hauled to the surface slowly and constantly. The filtered volume of seawater was calculated by multiplying the depth of the net lowered (H =10 m) with the net mouth area ($\pi r^2$). The formula $V_f = \pi r^2 \times h$, where $V_f$: volume filtered water, $\pi$:3.14, $r$: circle finger (12.5 m), and $h$: net depth lowered (10 m). The collected samples were stored in bottles, and a few drops of Lugol preservative were added until the tea color was visible [42]. The samples were taken to the laboratory for further analysis under an inverted microscope as soon as possible. The enumeration of cells abundance and identification of the species by using Sedgwick-Rafter Counting Cell [42]. Phytoplankton identification was performed by using the following references [43-45]. The counting of cells according to the procedure was described in [42]. The total cells number of phytoplankton was the number per cubic meter volume.

The analysis of nutrients in the laboratory was performed using standard procedures. Therefore first, nitrite was reduced to nitrate by the cadmium-copper column reduction method and estimated with modifications by the sulphanilamide method [46]. While the analysis of phosphate using the ascorbic acid method. The nutrient analysis is based on the transformation of the chemical reaction, spectrophotometrically within the wavelength range of the spectrum. We used a millipore filter paper with a pore size of 0.45 µm for filtering water samples—the steps following the methods according to [46].

**Figure 1.** Map of Indonesia and the sites of monitoring (colored dots) in Lampung Bay. The circle shows the area of fisheries farming where blooms usually occur.

**3. Results and Discussion**

3.1. The abundance of phytoplankton in Lampung Bay

Figure 2 shows a graphic abundance of phytoplankton in Lampung Bay during the study in 2005-2009, 2013, 2014, and 2018. In July 2005, water discoloration occurred due to the bloom of dinoflagellate species *Pyrodinium* sp. as the dominating species. The abundance of total phytoplankton reached the highest at 26.7 x 10^5 cells.m^-3. At that time, slight red-brown discoloration occurred in the surface water
due to the bloom of this causative species, primarily appearing in a specific location at a fish farming area of Hurun Cove. In October 2005, a discoloration reoccurred due to the bloom of Noctiluca sp. and cyanobacteria Trichodesmium sp. These two species dominated the phytoplankton population resulting in a green slightly reddish discoloration along the west coast of the bay. Fish mortality happened in some floating net cages due to a shortage of dissolved oxygen [8, 13].

In 2006 and 2007, there was no discoloration or fish mortality due to the phytoplankton outbreak. In 2006, the highest abundance of phytoplankton was recorded in March reached 2.6 x 10^5 cells.m^-3, and in 2007, the highest abundance was recorded in April reached 3.9 x 10^5 cells.m^-3. The predominant species during these periods were Noctiluca sp. and Trichodesmium sp. In 2008, water discoloration occurred due to the bloom of Noctiluca sp and Trichodesmium sp., and fish mortalities happened, mainly fishes culturing in the floating net cages. The highest abundance of phytoplankton during that time reached 40.7 x 10^5 cells.m^-3. In March 2009, greenish discoloration on the surface water appeared due to the bloom of Noctiluca sp., and only a few dead fish occurred in some fish cages. In 2010, 2011, and 2012, according to [7] that phytoplankton bloom occurred, and a few dead fish were also found in fish farming locations. A high number of dead fish happened in 2012 due to the outbreak of dinoflagellate species Cochlodinium sp. It was the first record of this species appearing and blooming in Lampung Bay. The highest abundance was recorded in October 2012, reaching 3.07 x 10^7 cells per liter [7]. Mass mortality is caused by a lack of dissolved oxygen and clogging of the gills due to the high density of cells and mucus (Figure 3). The bloom of this species reoccurred in June 2013 and caused fish mortalities. The high number of phytoplankton during the tragedy was 538,8 x 10^5 cells.m^-3.

Lampung Bay has been experiencing at least two distinct types and detrimental impacts of HABs since 1991. They are toxic microalgae causing various illnesses in humans due to the consumption of contaminated shellfish and a mono-species bloom or fish-killer directly causing economic fishery losses due to massive fish-killing from aquaculture farms in the natural environment [47, 49, 50]. So far, there are three types of harmful algal blooms (HABs); the first one is a harmless phytoplankton bloom associated with discoloration of the surface water. It usually belongs to non-toxic species, and no fish kills occurred. The second is a harmful algal bloom associated with the mass mortality of marine organisms. It also belongs to non-toxic HABs and is associated with water discoloration and fish-killing primarily due to oxygen depletion. The third type is a toxic algal bloom causing shellfish contamination, either paralytic shellfish poisoning (PSP) or diarrhetic shellfish poisoning (DSP). It may occur associated with a color change without discoloration in the waters [47, 48]. The toxic phytoplankton without a color change still potentially harms humans eating shellfish harvested from the blooming area [48]. Usually, shellfish as filter feeders are not dying by the phytoplankton toxin, even though they accumulate toxins. The toxin concentration will increase in their bodies without harming their life; on the contrary, infected shellfish harm the human consumer.

Figure 4 shows the frequency of discoloration and fish-killing events in Lampung. The occurrence of harmful algal blooms tended to increase from 2004 until 2014. The first disaster of fish-killing occurred in 2005 due to harmful algal blooms, primarily fish cultivated in the floating net cages. Although discoloration occurs in the bay, it is not always followed by the death of the fish in the farming area. Massive fish mortality occurred in 2008 due to the combination outbreaks of Trichodesmium sp. and Noctiluca sp. Since this tragedy, the phytoplankton bloom frequency increased until 2012, where at this period, a substantial fish-killing occurred due to the blooming of Cochlodinium sp [7, 8]. This fish-killing incident was recorded as the most significant disaster ever happened in this bay. Since the tragedy in 2012, fish-killing still recurring due to the same causative species in 2013.

Discoloration of surface waters during bloom events depends on the causative species. The color change in the surface water of Lampung Bay was caused by combining one or more predominant species. The color change of surface water due to phytoplankton bloom is mainly greenish, brownish, reddish, and possible combinations. Formerly, the discoloration due to the phytoplankton bloom was known as red tide, brown tide, or green tide [49]. This term is now misleading since a non-toxic species can bloom without discoloration appearing in the water; conversely, adverse effects occur where shellfish are contaminated by phycotoxin. [47]. The scientists agree to use the term harmful algal bloom (HAB) to all discoloration phenomena due to phytoplankton blooms. So far, there are two species already known as potentially dangerous species in this bay, such as Pyrodinium sp. and Cochlodinium...
sp. The most toxic one, *Pyrodinium* sp., has been known as toxin-producing and appeared in a high number unexpectedly in 2012. *Cochlodinium* sp. is the most harmful one that occurred for the first time in October 2012, and since then, the bloom has reappeared unpredictable in the following year, 2013. During the first incident, the abundance of the genus *Cochlodinium* sp. reached $10^7$ cells L$^{-1}$ [7]. The bloom of *Cochlodinium* sp. still reappeared in 2013 and decreased after that, but no fish-killing has occurred since then, although the species still exist.

![Figure 2](image1.png)

**Figure 2.** The trend of fluctuation of phytoplankton abundance in Lampung Bay during the studies [23-28].

![Figure 3](image2.png)

**Figure 3.** Bloom of *Cochlodinium* sp. and fish-killing during the incident in 2012 [16].
3.2. HABs occurrences in Lampung Bay

Algal blooms have been historically present on the western coast of Lampung Bay in 1991, where shrimp mortalities happened mainly in the brackish water ponds of the west coast of Lampung Bay. This disaster was due to cyanobacteria blooming *Trichodesmium* sp. [52], the first-ever record of algal bloom occurrence in this bay. This bloom phenomenon occurred in the brackish pond nearby the gulf area. Afterward, there was no incident of algal bloom reported until the 2000s. In 2002 harmful algal bloom occurred in Hurun Cove of Lampung Bay due to an outbreak of species dinoflagellates *Pyrodinium* sp., following an outbreak population of *Noctiluca* sp. [53, 54]. The species of *Pyrodinium* sp. is known as a toxin-producer that causes paralytic shellfish poisoning (PSP). However, no fish-killing occurred during these blooms. Since these phenomena, *Noctiluca* species reoccurs continuously in Lampung Bay and generate fish killings [54].

Table 1 shows the episodes of HABs in Lampung Bay from 2002 until 2014. Nine species were recorded as the predominant species since 2010-2012, namely, *Pyrodinium* sp., *Noctiluca* sp., *Phaeocystis* sp., *Dinophysis* sp., *Trichodesmium* sp., *Ceratium* sp., *Prorocentrum* sp., *Pseudonitzchia* sp., *Cochlodinium* sp. There was no significant fish-killing happened during bloom events from 2002 until 2004. However, in 2005 massive fish-killing occurred mainly in the floating net-cages (KJA) due to the bloom of *Noctiluca* sp. The substantial fish-killing happened in fish farming in 2008 due to the bloom occurrence of cyanobacteria *Trichodesmium* sp. and continued by *Noctiluca* sp. It is interesting to note that *Noctiluca* sp. is the most frequent causative species of harmful algal blooms in this bay from 2005 until 2014. This species is almost present in all bloom events as the predominant causative species preceded by *Trichodesmium* sp. The outbreak of the *Trichodesmium* sp. population often coincides with the occurrence of *Noctiluca* bloom. They usually cause fish kills due to oxygen depletion and high ammonia in the water column of fish net-cages [8].

The substantial incident of fish-killing occurred in 2012 due to the bloom of *Cochlodinium*. This species is a chain maker that belongs to dinoflagellates. The abundance of this species during the bloom ranges from 10^3 to 10^6 cells/L [7]. The bloom occurrence of this species continues to reappear in the following two years. The phenomenon also coincides with the event of *Noctiluca* sp. It was the first bloom ever known in Indonesian waters due to *Cochlodinium* sp. as the causative species [55]. This species is also known to occur in some waters in other countries and is a fish-killer [56-58].
Prevalent of HABs in Lampung Bay, especially in the areas where fish farming operate. It seemed that there is a connection of algal bloom phenomena with fish farming floating nets. The increase in aquaculture has been blamed for pollution of the ecosystem, especially in Asia [50, 51].

Table 1. The occurrences of predominant species in Lampung Bay from 2004-2014.

| Predominant Species | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 |
|---------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Pyrodinium sp.      | √    | √    | -    | √    | -    | -    | -    | -    | √    | -    | -    | -    | √    |
| Noctiluca sp.*      | √    | -    | √    | √    | √    | √    | √    | √    | √    | √    | √    | -    | -    |
| Phaeocystis sp.     | -    | -    | -    | -    | -    | -    | √    | -    | -    | -    | -    | -    | -    |
| Dinophysis sp.      | -    | -    | -    | -    | -    | -    | -    | -    | √    | -    | -    | -    | -    |
| Trichodesmium sp.*  | -    | -    | √    | √    | √    | √    | √    | -    | √    | √    | √    | -    | -    |
| Ceratium sp.*       | -    | -    | -    | -    | -    | √    | -    | -    | -    | -    | -    | -    | -    |
| Prorocentrum sp.    | -    | -    | -    | -    | -    | -    | √    | -    | -    | -    | -    | -    | -    |
| Pseudo-nitzia sp.   | -    | -    | -    | -    | -    | -    | √    | -    | -    | -    | -    | -    | -    |
| Dinochlymenium sp.* | -    | -    | -    | -    | -    | -    | -    | √    | -    | -    | -    | -    | √    |
| Alexandrium sp.     | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | -    | √    |

Sources: Data cited from the published articles [12-15] and reports/documents by RCO-LIPI [23-28] and BBBL Lampung [29-39]. Notes: (√): occur as the dominant; (-): not occur as the predominant. *Cause discoloration in bloom events, while the other just predominant species such as Pyrodinium sp., Dinophysis sp., and Pseudo-nitzia sp. Predominant: the abundant ≥10 percent of the total population.

3.3. The causative species of HABs in Lampung Bay

Table 2 shows the causative species of harmful algal blooms in Lampung Bay until 2014. These causative species mainly belong to diatom, dinoflagellate, and cyanobacteria. At least six causative species belong to diatoms, namely Thalassiosira sp., Rhizosolenia sp., Chaetoceros sp., Skeletonema sp., Pseudo-nitzia sp., and Phaeocystis sp., where only one species as a toxic diatom, such as Pseudo-nitzia sp. When cells concentration in shellfishery > 10^3 cells/L; therefore, at that location, a toxin measurement must be carried out immediately [47]. This species can produce domoic toxins; however, its toxicity still needs to be reconfirmed. Most of these causative species are high biomass bloom makers and usually cause discoloration in the surface water. And, some show no discoloration in the surface water, such as Thalassiosira sp. and Rhizosolenia sp. These two diatoms occurred abundantly in this bay several times, but no color changes and fish-killing happened during that time. The causative species identified as harmful can cause fish mortality when blooming, such as Trichodesmium sp., Chaetoceros sp., Skeletonema sp., and some harmless such as Thalassiosira sp. and Rhizosolenia sp. When harmful species appear in high biomass, it can harm fish due to oxygen depletion, mainly during dark times.

The other causative species belong to dinoflagellates, such as Noctiluca sp., Dinophysis sp., Prorocentrum sp., Pyrodinium sp., Closchidium sp., and Alexandrium sp. So far, Noctiluca sp., is known as the most frequent causative species, occurred bloom in this bay and cause green discoloration,. Fish mortality usually happens due to oxygen depletion or gills blocking during high bloom events. The most potent toxic among this dinoflagellate species is Pyrodinium sp. This species is frequently observed abundantly in the fish farming around Hurun Cove, on the west side of Lampung Bay, close to the mangrove area [54]. The other toxic species of dinoflagellates, such as Dinophysis sp., and Prorocentrum sp., were never found discoloring the surface water; however, they usually occur together with the other predominant phytoplankton species. Some countries implemented a limit on shellfishery regarding toxic species such as Dinophysis acuminata, concentration around > 10^5 cells/L [47]. The last group bloom maker in this bay is cyanobacteria Trichodesmium sp. These species make the color of the surface water to be red-purple. Usually, their occurrence often coincided with the presence of Noctiluca sp.

Most of the blooms were mainly occurring in locations where fish farming operates on the west side of the bay. While on the eastern coast of the bay, there are several industrial activities, including a harbor. It seemed that there is a connection of algal bloom phenomena with fish farming floating nets. An increase in aquaculture has been blamed for the pollution of the ecosystem, especially in Asia [50, 51].
The other causative species, *Pyrodinium* sp., was first recorded in 2005 without discolorization of the waters. The bloom of *Pyrodinium* sp. often reappears without visible color in the surface water. Usually, in the case of *Pyrodinium* sp., their occurrence at a concentration of 200 cells/L \[47\], meaning that their presence is dangerous because they can produce a very potent toxin such as saxitoxin. *Pyrodinium* sp. often occurs in Hurun Cove, where there are a lot of mangroves. The other causative species, such as *Cochlodinium* sp. and *Alexandrium* sp., occurred significantly lately; however, only *Cochlodinium* sp. bloom has caused fish mortalities in this bay.

### Table 2. The predominant species when blooming occurred in Lampung Bay.

| No | Causative Species (predominant) | Potentiacy | Impact          |
|----|--------------------------------|------------|----------------|
| 1  | *Trichodesmium* sp.*           | Harmful    | Fish mortality |
| 2  | *Thalassiotrix* sp.**          | Harmless   | Discoloration  |
| 3  | *Rhizosolenia* sp.**           | Harmless   | Discoloration  |
| 4  | *Chaetoceros* sp.**            | Harmful    | Fish mortality |
| 5  | *Skeletonema* sp.**            | Harmful    | Fish mortality |
| 6  | *Noctiluca* sp.***             | Harmful    | Fish mortality |
| 7  | *Ceratium* sp.**               | Harmful    | Fish mortality |
| 8  | *Pseudonitzchia* sp.**         | Toxic      | -              |
| 9  | *Phaeocystis* sp.**            | Harmless   | Discoloration  |
| 10 | *Dinophysis* sp.**             | Toxic      | -              |
| 11 | *Prorocentrum* sp.***          | Toxic      | -              |
| 12 | *Pyrodinium* sp.***            | Toxic      | Discoloration  |
| 13 | *Cochlodinium* sp.***          | Toxic      | Fish mortality |
| 14 | *Alexandrium* sp.***           | Toxic      | -              |

*Note:*

*: cyanobacteria,

**: diatom

***: dinoflagellate

The data based on published articles \[12-15\] and unpublished reports by BBBLP Lampung [29-41], Research Centre for Oceanography/RCO-BRIN [23-28].

### 3.4. Nutrient enrichment and HABs

Over-enrichment of coastal waters by nutrients is a significant pollution problem due to human population growth and food production \[1-3\]. Nutrient availability plays a crucial role in the increasing phytoplankton in the waters \[50, 51\]. Therefore, a high phytoplankton abundance may indicate that this bay is experiencing eutrophication due to nutrient enrichment \[6, 47\]. An increase in anthropogenic activities has consequently increased nutrients in the coastal environment.

Figure 5 shows the fluctuation of nitrogen and phosphate in Lampung Bay in 2013. Nitrate concentration seemed to fluctuate and tended to increase until the end of the year. Meanwhile, phosphate concentration is relatively stable until the end of the year. However, nitrate and phosphate tend to be higher than usual after the wet/rainy season in March to June and the 2\(^{nd}\) transition from September to November. Usually, the higher concentration of nutrients after the rainy season is the driving factor of harmful algal blooms \[5\]. Much evidence shows that increased frequency and magnitude of algal bloom events worldwide are related to cultural eutrophication \[6, 57\], such as aquaculture, marine pollution, seafood industry, ballast water, tourism, and even global climate change \[58-60\].
Figure 5. Trend fluctuation of N and P concentrations in Lampung Bay during 2013. (Note: The graph is drawn based on the data from the annual report of BBPBL [35-41]).

Figure 6. The trend of discoloration appeared on the surface water due to algal blooms in Lampung Bay. (Sources: The graph is redrawn based on data from the annual report of BBBPL Lampung, RCO LIPI [23-41], and information from the fisherman).

Figure 7. The trend fluctuation of nutrients ratio in Lampung Bay in 2013 (Note: The graph is redrawn based on the data from the annual report of BBBPL Lampung [35-37]).
It seemed that harmful algal blooms in Lampung Bay depend on the season, as shown in Figure 6. It shows that harmful algal blooms occurred after the wet/rainy season (March to June) and the 2\textsuperscript{nd} transition from October to November. The nutrient concentration seemed to be the driving factor of HAB occurrences. Usually, the most critical factor triggering harmful algal blooms is mainly the ratio of the nutrients element or N:P ratio in the waters [58–60]. The consequence of a high N:P ratio will be an increase in phytoplankton blooms [59, 61, 62]; however, each phytoplankton species also has a specific response to N:P ratios in the waters.

The nutrient ratios are a decisive factor in governing the development of the 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 106:16:1:15. The nutrient in the minor condition for the development is considered the limiting nutrient [10, 50, 51, 63]; 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. A nutrient ratio that is higher than 16 (N:P >16) indicates that N plays a role as a triggering factor and P as a limiting factor [64, 65].

Figure 7 shows the fluctuation of the nutrient ratio of N and P in 2013. The nutrients ratio seemed higher after the rainy season (April to June) and the 2\textsuperscript{nd} transition of the season (September to November). The nutrient ratios are higher in that season, indicating that N plays a role as a triggering factor and P limits phytoplankton growth. The highest concentration of nitrogen will trigger the population of phytoplankton to grow faster. When phosphate is a limiting factor, a certain amount of phosphate must be available complementary to nitrogen availability; otherwise, phosphate deficiency would prevent the further growth of phytoplankton.

4. Conclusion

Lampung Bay has been experiencing harmful algal blooms for a decade, showing that the bay is in eutrophic condition. Nutrient enrichment (N, P) is mainly the driving factor of HAB occurrences in this bay. The leading cause of fish mortalities during blooming events in this bay is primarily due to oxygen depletion. Two species frequently occur blooming in Lampung Bay from 2004-2014, namely Noctiluca sp. and Trichodesmium sp. There are three toxic species recorded during the study in this bay: Pyrodinium sp., Cochlodinium sp., and Alexandrium sp. The most poisonous species among them is Pyrodinium sp., which produces harmful toxins to human health if infected fish are consumed.

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