Comprehensive analysis of harmful algal blooms in indonesia: from occurrence to impact

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Abstract. The occurrence and frequency of harmful algal blooms have become a significant problem in Indonesia's coastal waters since 1991. This article aims to thoroughly analyze the diversity of algal species involved in these harmful algal blooms (HABs). It highlights that some algae, such as toxic species, can produce dangerous toxins, while others, such as non-toxic algae, remain harmless. This article reviews research studies that describe the occurrence, frequency, and causative types of bloom events in several contaminated coastal regions of Indonesia. The blooms had many consequences for fisheries, the aquatic environment, the economy, and public health. Among the identified species, *Pyrodinium bahamense var. compressum* is known for its high toxicity. The most common taxa contributing to bloom tragedy are *Chaetoceros, Noctiluca,* and *Skeletonema*. The study recognizes that human-induced nutrient enrichment is a major and significant factor in triggering the bloom phenomena. The paper recommends various management strategies and further research initiatives to prevent and reduce the impacts of HABs in Indonesia.

1 Introduction

An algal bloom is a notable rise in the biomass, population size, or abundance of microalgae. It has a detrimental effect on human health and industries, including tourism, aquaculture, and fishing. Algal blooms are becoming one of the most significant issues that require immediate attention and should be brought to the attention of the public, scientists, and the government due to their rising occurrence, amplitude, and impact [1,2].

An international maritime phenomenon, harmful algal blooms (HABs) are also significantly affecting Indonesia's waters. Indonesia's coastal waters have suffered dramatically due to harmful algal blooms. Hazardous algal blooms have recently become more frequent and widely distributed in Indonesian coastal waters. For the past ten years, and even now, algae blooms have been observed in several coastal waters. Additionally, the causing species have been found in certain areas where they have never before created bloom issues. An algal bloom is a seasonal occurrence that occurs naturally in the maritime environment. It is a sign of eutrophication, characterized by increased nutrient concentrations [1]. Seawater becomes discolored due to frequent phytoplankton blooms, especially in coastal waters [2].

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Algae can proliferate in water systems, producing toxic algal blooms that endanger humans and marine life. Despite being natural events, there are circumstances in which they could become hazardous. One of these is the overabundance of biomass, which might affect the oxygen content of the water. Algal blooms are usually attributed to anthropogenic activities that provide nutrients to the marine ecosystem [3]. Eutrophication is the primary cause of algal blooms [2,3]. Algal bloom epidemics are closely related to human activities along the coast, such as fishing, tourism, aquaculture, and marine pollution [4]. Algal blooms have been related to eutrophication, industrialization, domestic coastal areas, and global climate change [5].

Their primary causes are twofold: first, anthropogenic forces that cause eutrophication, and second, natural processes like circulation, buoyancy, and river flow. Most people agree that anthropogenic activity is the main factor behind all blooms. When algae meet favorable climatic circumstances, they multiply and create dense concentrations of cells known as blooms [4,5]. Because specific algal blooms can develop toxins, they can disturb microbial ecosystems, cause mass fish fatalities, and contaminate seafood. An algal bloom of this kind is referred to as toxic or hazardous [6].

There are three known hazardous algal blooms. Toxic algae blooms are the first to kill large numbers of fish and other marine life by producing solid poisons. The second bloom is not hazardous, but because of the low oxygen content in the water, it is detrimental to aquatic life. The third is safe for marine life but non-toxic. Few non-toxic blooms have detrimental impacts; most only tint water. Numerous toxic plants can bloom without turning the water a different hue. On the other hand, when the water is clear and the concentration of algae is low, bad things can happen [6,7]. Mass fish fatalities, disturbance of the marine ecosystem, financial losses for fishermen, and poisoning of tourists and customers are only a few of the negative consequences of a hazardous algal bloom [6].

In Indonesia, studies on HABs have been carried out regularly. Nonetheless, many algal bloom occurrences in this nation have not been made public or recorded. Several investigations have documented algal blooms; these studies have identified the primary drivers for algal blooms [7]. The algal bloom producer changes from a non-toxic to a toxic species, and the bloom events happen randomly. An overview of red tide, or HABs, species, and algal blooms in Indonesian coastal waters from 1990 to 2019 is the goal of this page. Most of our conclusions were derived from our observations and our examination of previous reports and documents, including unpublished data. This research aims to present a thorough understanding of the different elements influencing Indonesia's seas and the effects of HABs on marine equilibrium. We will also be able to determine interventions that can assist in raising the standard of the nation's water. We want to use this study to educate the public and policymakers about the several elements influencing Indonesia's waters and how organic pollution affects the ocean's equilibrium.

2 Methods

2.1 Research Location

The tragedy of an algal bloom situation in Indonesian coastal waters was first documented in 1990, and it is still happening today. Nevertheless, many algal bloom incidents in Indonesian seas have not been documented or published. Conversely, algal bloom occurrences in Indonesian waters are becoming more prevalent. We monitored several Indonesian coastal waters, such as Jakarta Bay, Ambon Bay, Kao Bay, and Lampung Bay, where algal blooms were common. Figure 1 displays a map of Indonesia along with the research location. These investigations were carried out by the Research Center for Oceanography (RCO-LIPI) as a component of the Indonesian HABs monitoring program. The majority of area investigations are the result of the HABs' growing experience. The experiments were mainly carried out in the middle of the dry season and during the March–April–May transition period from the wet to the dry season (June-Jul-Aug). The rainy or western season runs from October to March, whereas the dry or eastern season is from April to September.

2.2 Sampling phytoplankton

A cone-shaped phytoplankton net with a squeeze device attached to the end was used to gather concentrated phytoplankton samples. The mouth opening diameter measures 25 cm, the net length measures approximately 125 cm, and the pore size, or mesh size, is 20 m. Ballast was attached to the net's end to aid in vertical pulling down. In the sampling approach, the phytoplankton net is dropped vertically to a depth of 7–10 m, and from that point on, it is continuously and gently pulled to the surface. We put the gathered samples into vials that had been preservative-infused. The samples were promptly preserved in an acidic Lugol solution [8]. Using an Olympus inverted microscope, the preserved phytoplankton samples were taken to the lab for additional quantitative and qualitative investigation (model IX50-S8F2). Phytoplankton identification and cell abundance calculations using the Sedgwick-Rafter Counting Cell [8]. Sources for identifying phytoplankton with [9–11]. using the technique outlined in [8] to count the quantity of phytoplankton cells. Each station's total number of phytoplankton cells was measured per cubic volume.

2.3 Nutrient and oceanographic parameters

Most of the nutrients were dissolved inorganic, including phosphate (PO_4-P) and nitrogen (NO_3-N). At every fixed station, water samples were taken to analyze the nutrients. Using a Kemmerer sampler, surface waters are sampled at a depth of 1.0 m for nutrient analysis. Every fragment was promptly moved to a container cleaned with acid and acidified using 1% v/v HNO3. A spectrophotometer with wavelengths of 690 nm for phosphate and 543 nm for nitrate was used to measure the concentration of each nutrient. Following the procedures [12], Millipore filter paper with a pore size of 0.45 m was used to filter the water sample. The Philips PYE Unicam spectrophotometer model (model PU8600) was utilized. All samples were generally examined as quickly as possible after being collected, especially if the concentration was low. On-site measurements comprised oceanographic characteristics such as salinity, temperature, dissolved oxygen, and water depth. A YSI dissolved oxygen meter (Model 59) was used to directly detect the water's temperature. An ATAGO handheld refractometer determined the salinity (in parts per mille). By submerging the electrode, the pH meter of the TOA model of the HM-IK model measures saltwater's acidity (pH).

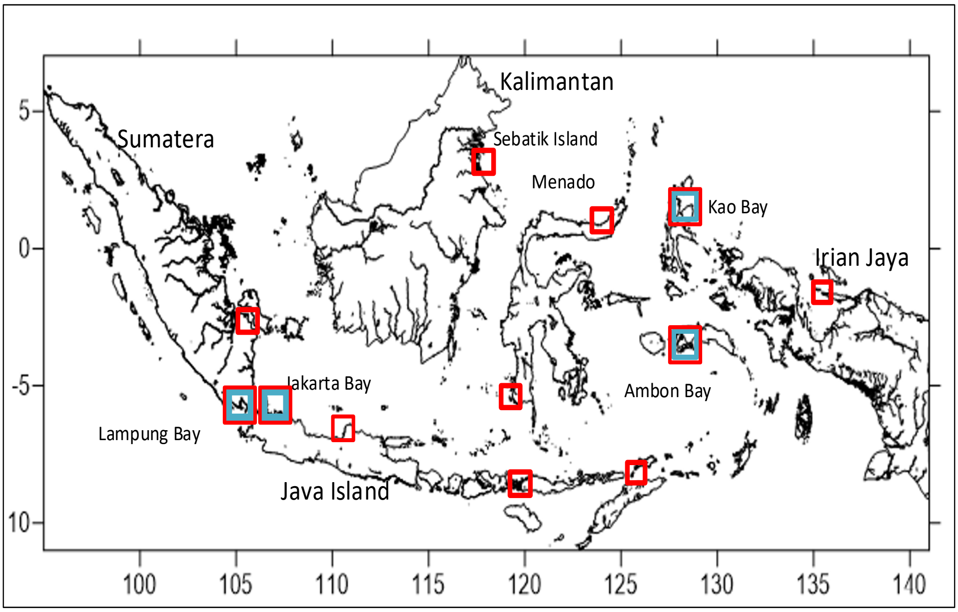

Fig. 1. Diagram depicting algal bloom incidents in the marine regions of Indonesia. Although not every algae outbreak resulted in fish kills, such events have been confirmed in Jakarta, Lampung, Ambon, and Kao bays (red and blue box in the middle). (A red box indicates algae blooms).

3 Results and Discussions

3.1 Harmful Algal Bloom (HABs) in Indonesian waters

The first tragedy of red tide (algal bloom) in Indonesia was documented in 1980 when an outbreak of the toxic dinoflagellate *Pyrodinium bahamense var compressum* caused a red color in Kao Bay. This led to the first recorded report of a dangerous algal bloom in Indonesia's coastal waters. The causative species causing problems in Malaysia, Papua New Guinea, and the Philippines is similar to this toxic species [13,14]. What was notable was the fact that most of the bloom spread near the mangrove regions. There were also many dead fish floating near the shore. The earthquake in eastern Indonesia in 1980 was the cause of the bloom episode in this bay. Dinoflagellate cysts deposited on bottom sediments were likely transported and destroyed by the earthquake. Under unstable conditions, the dinoflagellate forms cysts or resting cysts and is deposited in the bottom sediments over extended periods [15]. After being cleared of sediment and placed in environments with improved salinity, temperature, oxygen levels, and light intensity, the cysts hatch. This deadly species has never previously bloomed, as evidenced by a dormant cyst in depositional mud [15-17]. Some residents near the bay consider the red color of blood in the water to be a superstitious belief or a curse. Luckily, their superstitious beliefs proved extremely useful, as people avoided poisoning by refusing to eat fish or shellfish caught from the water during the episode [13,18].

There are three different types of harmful algal blooms (HABs) in Indonesia. The first cause is an accumulation of toxic algae, leading to many marine life's extinction. Most blooms that are not harmful change the color of the water, but few are harmful. The second type of HAB involves a toxic algal bloom that either paralyzes or poisons shellfish, thereby killing them (diarrhea shellfish poisoning). There are times when toxic plankton blooms do not change the color of the water. The bloom of harmful plankton with loads below the permissible limit is not flagged as an HAB event. For this reason, not every bloom of toxic plankton is recorded as an HAB event. The color of the water seemed to depend on what species were blooming in it. Much of the color comes from the mixture of one or two species in the phytoplankton population during bloom

Table 1. The frequency of discoloration due to algal blooms in Jakarta Bay

Month	**Periods**										**Frequency**
	2004	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2013**	**2015**	
Jan	-	-	-	-	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-	-	-	-	-
Mar	x	-	-	-	-	-	-	-	x	x	3
Apr	x	x	-	x	x	x	x	x	x	x	9
May	x	x	x	x	x	x	x	x	x	x	10
Jun	x	-	x	-	-	x	x	x	x	x	7
Jul	x	-	-	x	-	-	-	-	x	x	4
Aug	x	-	-	x	-	x	-	-	-	-	2
Sep	x	x	x	x	x	x	x	x	x	x	10
Okt	x	x	x	x	x	x	x	x	x	x	10
Nov	-	-	x	x	x	x	x	x	x	x	8
Dec	-	-	-	-	-	-	-	-	-	-	-

Note: Periods 2004-2007, according to Wouthuyzen *et al*. (2007)

In 2000, algal blooms occurred more frequently and in more locations in Indonesia's coastal waters. In Indonesian waters, diatoms, dinoflagellates, and cyanobacteria are the main species causing blooms. Some are toxic, such as *Pyrodinium bahamense var. compressum* (Pbc). This type of HAB is dinoflagellates, and these organisms are known to produce potent toxins. The most common bloom species include *Noctiluca, Skeletonema, Chaetoceros, Trichodesmium, Thalassiosira*, and *Ceratium furca*. HABs are associated with various conditions in the region, including a reverse monsoon wind, river run-off, rising coastal waters with southwest and northeast winds, and near-shore eutrophication. To date, poisonous or toxic species have been found in four locations: Ambon Bay, Kao Bay, Jakarta Bay, and Lampung Bay. *Pyrodinium* (Pbc), *Alexandrium, Gymnodinium,* and *Pseudonitschia* are poisonous species already known to inhabit these locations. Ambon Bay, Kao Bay, and Lampung Bay are the most dangerous places because of the toxic species *Pyrodinium* (Pbc), which produces saxitoxin. Due to the increasing number of blooms, the occurrence of this species in Lampung Bay is becoming increasingly problematic. The dinoflagellate *Pyrodinium* (Pbc) typically forms a dormant cyst during blooming. This cyst can remain in the sediment for a long time. Therefore, integrated planning, including constant monitoring, is carried out in Lampung Bay, Kao Bay, and Ambon Bay.

3.2 Harmful Algal Bloom (HABs) in Jakarta Bay

Since 2000, the most common algal bloom in Indonesia has been observed in Jakarta Bay. Table 1 shows the frequency of algal bloom-related discoloration in Jakarta Bay between

2004 and 2015. From 2004 to the present, algal blooms have become more frequent and widespread. Algal blooms typically reoccur in a specific bay region near the mouth where thirteen rivers flow into that bay. The algae bloom in Jakarta Bay has worsened and now poses a significant threat to the ecosystem and is affecting the local economy and fisheries. Jakarta Bay is already known for its severe eutrophication. A sign of eutrophication [19,20], characterized by increased nutrient concentrations, especially phosphorus and nitrogen [21,22], is the appearance of algal blooms. Increasing inputs of phosphorus (P) and nitrogen (N) are often the leading cause of coastal eutrophication [23]. Nowadays, red tide or algal blooms are often associated with coastal eutrophication in Jakarta Bay [24-27]. The leading cause of the bloom of the phytoplankton population in Jakarta Bay is the eutrophic condition or nutrient enrichment [21,22].

In Jakarta Bay, algal bloom phenomena occurred mainly from March to June, with sporadic occurrences from September to November (transition from dry to wet season). Algae blooms do not discolor surface water between December and February, the rainy season. The phenomenon of algal bloom in Jakarta Bay is related to the dry season, when sufficient nutrients, especially nitrogen and phosphorus, are in the water after the rainy season. It has also been observed that algal blooms in Jakarta Bay typically occur in March and April, towards the end of the rainy season [30]. During our study, several algal blooms occurred in Jakarta Bay between 2008 and 2015. But not every algae bloom ends with fish mortality. In April and November 2008, and again in November and December 2015, fish died from two algae bloom events. Physical elements that harm fish and other aquatic life have been linked to bloom events. The main driving force for this phytoplankton bloom is eutrophication. But other elements, such as water stratification and currents, can also influence bloom development. The most often tragic fish killing during the bloom in Jakarta Bay was caused by the depletion of oxygen concentration in the water, with the DO concentration in the surface water during the bloom being less than 2.0 ppm and even close to zero at the bottom [30].

3.2 Harmful Algal Blooms (HABs) in Lampung Bay

The first algal bloom disaster was documented in Lampung Bay in 1991 when many farmed shrimp died in brackish water ponds on the east coast. The brackish water pond is the only place in the bay where fish kills occur frequently during the bloom. *Trichodesmium erythraeum* was identified as the most causative species [31]. *Pyrodinium* was found in Lampung Bay in 1999, mainly concentrated in Hurun Bay, and this has been linked to an algal bloom tragedy in the bay [32]. The *Pyrodinium* species can cause shellfish poisoning and lead to paralysis when consumed by humans via infected shellfish. However, there were no reports of fish kills in this bay during the *Pyrodiniu*m bloom.

Table 2. The primary causative species of algal bloom in Jakarta Bay

No	Causative Species	Potentially	Impact
1	*Skeletonema sp*	Harmful	Discoloration, fish kill
2	*Chaetoceros sp*	Harmful	Discoloration, fish kill
3	*Thalassiosira sp*	Harmless	Discoloration
4	*Trichodesmium sp*	Harmful	Discoloration, fish kill
5	*Noctiluca (green)*	Harmful	Discoloration, fish kill
6	*Ceratium furca*	Harmless	Discoloration
7	*Alexandrium sp*	Toxic	-
8	*Pseudo-nitzchia sp*	Toxic	-
9	*Dinophysis sp*	Toxic	-

10	*Coscinodiscus sp*	Harmless	Discoloration
11	*Leptocylindricus sp*	Harmless	Discoloration
12	*Thalassiotrix sp*	Harmless	Discoloration
13	*Bacteriastrum sp*	Harmless	Discoloration
14	*Pyrodinium* (Pbc)	Toxic	-
15	*Gymnodinium sp*	Toxic	-

In August 2005, Lampung Bay (Hurun Cove) recorded a *Noctiluca* bloom with the highest abundance of 10^5 cells/L. During the bloom period, fish deaths occur in the floating fish culture nets (KJA). An increase in fish mortality in floating net fish farms at these locations has been linked to *Noctiluca* blooms. Table 3 lists the algal bloom periods in Lampung Bay between 2002 and 2013. Between 2002 and 2013, Lampung Bay experienced an increase in algal blooms. Since the 2000s, there have been repeated outbreaks of the phytoplankton population in Lampung Bay. Phytoplankton blooms, which occur throughout the year, have also tended to increase in quantity, frequency, and range. During the algae bloom of 2002-2004, there were no significant fish deaths; only a few dead fish appeared in some floating net cages. However, there were significant fish losses owing to the 2008 *Noctiluca* bloom. Since then, the re-occurrence of *Noctiluca* blooms has led to a decline in fish kills and die-offs in the wild, particularly among fish kept in floating net cages.

Noctiluca was the predominant species causing algal blooms in this bay from 2005 to 2010, as shown in Table 3. This species is the predominant or even dominant species during most blooming phases. Often, the outbreak of the *Trichodesmium* population occurs before or at the same time as the *Noctiluca* bloom. Other causative species, including *Pyrodinium bahamense var. compressum* (Pbc), were detected in water in 2005, 2006 and 2007 without discoloration. *Pyrodinium* blooms often occur in colorless surface water. However, its presence is dangerous as it can produce a highly potent toxin such as saxitoxin. The *Pyrodinium* species was predominantly observed in the pearl mussel and fish breeding area of Hurun Cove as the farming location. *Phaeocystis sp* was the most common causative species of bloom events in 2009, followed by *Dynophysis sp* in 2010 and 2011. *Trichodesmium sp* was widespread from 2002 to 2012, and *Ceratium sp* occurred in 2011. *Pseudonitzchia sp* was widespread from 2009 to 2012, and *Cochlodinium sp* was widespread from 2012 to 2014. A dinoflagellate species called *Alexandrium sp* was discovered in the bay in 2014, which outbreak after the disappearance of *Cochlodinium sp*. Nevertheless, no fish mortalities were reported [33].

Only a few bloom causative species in Lampung Bay are considered dangerous or toxic, including *Pyrodinium sp* and *Cochlodinium sp*. Some causative species are considered harmful or harmless or cause bloom-forming or surface water discoloration. The abundance of *Cochlodinium sp* was laying between 10^5 and 10^6 cells per liter during the bloom period in October 2012, harming many cultured fish in Lampung Bay. The bloom of this dinoflagellate species is the first event documented, recorded, and observed in the sample collected from this bay. So far, before this bloom incident, this species had never been detected, not even in the samples.

Table 3. The episode of causative species of algal bloom in Lampung Bay (2002-2014)

Species	**Occurrence**												
	2002	**2003**		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Pyrodinium	x	x	-	x	-	-	-	-	x	-	-	-	x
Noctiluca	x	-	x	x	x	x	x	x	x	x	x	x	x
Phaeocystis	-	-	-	-	-	-	-	-	x	x	-	-	-

Dinophysis	-	-	-	-	x	x	-	-	-	-	x	-	-
Trichodesmium	-	-	x	x	-	-	x	-	x	x	x	-	-
Ceratium	-	-	-	-	-	-	-	-	-	x	-	-	-
Prorocentrum	-	-	-	-	-	-	-	-	x	-	x	-	-
Pseudonitzchia	-	-	-	-	-	-	-	-	x	-	x	-	-
Cochlodinium	-	-	-	-	-	-	-	-	-	-	x	x	x
Alexandrim sp	-	-	-	-	-	-	-	-	-	-	-	-	x

Source: Modified from Muawanah [33]

The bloom of *Cochlodinium sp* was characterized by the deep reddish-brown coloring of some of the surface water, giving the impression of an oily suspension. Fish suffer breathing difficulties as the mucous membrane covers their gills, which is believed to cause fish mortality overnight until the early morning hours. Farmed fish such as snapper, grouper, pomfret, and cobia were killed in the bloom incident. When phytoplankton bloom reached 10^6 cells/L in mid-October 2012, fish kills occurred, which increased again at the end of October. As the bloom reached high density, fish kills occurred and worsened water quality. Although the first bloom lasts nearly two weeks, fish kills still occur in floating net cages on the west side of the bay. Similar *Cochlodinium* blooms also occurred in China, Japan, and Korea, causing fish mortalities [34-36].

Cochlodinium polykrikoides was identified as the causative species following the bloom incident [15]. The bloom of *Cochlodinium sp* has been reported in Southeast Asia [37]. This species is widespread, ranging from the waters of the Atlantic through Europe to Asia. This species has never been discovered in Indonesian seas before. The first bloom of *Cochlodinium* was reported in Southeast Asia, and the first bloom of *Cochlodinium* was reported until the 1990s. Subsequently, in the 1990s, South Korea's fishing industry lost approximately US$100 million annually [37]. Since then, this species has bloomed on the coasts of North America, Europe, and Asia. Three subgroups or ribotypes of *Cochlodinum polykrikoides* have been satisfactorily identified as belonging to this species. The Philippine ribotype, the US-Malaysia ribotype, and the Southeast Asian ribotype (the original Japan-Korea group) [15]. In addition, this species was spotted on the Italian Mediterranean coast in the late 1990s. In 2001, a significant bloom was observed in the Black Sea along Tanjung Big Utrish and Odesa (*http://phyto.bss.ibss.org.ua*). The bloom tragedy of this species was also observed in the north of Tarragona in 2011[38].

The phytoplankton responsible for the algal blooms in Lampung Bay included cyanobacteria, dinoflagellates, and diatoms (Table 4). These are usually diatoms, which are potentially dangerous because when they bloom due to a lack of oxygen, they harm fish and other marine life. When they bloom, some harmless species usually coexist with the other species and change the color of the surface water. Dinoflagellates, including *Pyrodinium* (Pbc), *Cochlodinium sp., Dynophysis sp., Alexandrium sp., and Prorocentrum sp.,* are among the most common poisonous species. *Pyrodinium* is the most toxic species belonging to the dinoflagellate. This species is typically found near the mangrove forest on the western side of Lampung Bay, where fish farms are located. In addition, the bloom of *Cochlodinium sp*. was also distributed on the western side of the bay where fish farms exist. Some typical species are also found among the other phytoplankton species, as the other toxic species, such as *Dynophysis sp., Alexamdrium sp., and Prorocentrum sp*., occur predominately but never discolor the surface.

Table 4. The main species responsible for algal blooms in Lampung Bay.

No	Causative Species	Potentially	Impact
1	*Trichodemium 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	*Ceratiun furca*	Harmful	Fish mortality
8	*Pseudo-nitzchia*	Toxic	-
9	*Phaeocystis sp*	Harmless	Discoloration
10	*Dinophysis sp*	Toxic	-
11	*Prorocentrum sp*	Toxic	-
12	*Pyrodinium bah. var. compressum*	Toxic	Discoloration
13	*Cochlodinium polykrikoides*	Toxic	Fish mortality
14	*Alexandrium sp*	Toxic	-

3.3 Harmful Algal Blooms (HABs) in Ambon Bay

An algae bloom occurred in the waters of Ambon in 1994 due to a *Pyrodinium* outbreak, which resulted in toxins when shellfish harvested from the bay were consumed. Shellfish collected from the coast resulted in the deaths of some people, and some should be hospitalized [14]. Since the tragedy of the *Pyrodinium* incident, another bloom belonging to *Trichodesmium* and *Noctiluca* occurred in Ambon Bay [39]. The bloom of *Trichodesmium erythraeum* in Ambon Bay in 1995 was the cause of the fish-killing event. In August, during the rainy season, other patches of blooms colored the surface water. There were no dead fish during this bloom in the bay. The outbreak of green *Noctiluca scintillans* appeared after the *Trichodesmium* bloom. It seems that these two bloom-maker species are causally related. The bloom of green *Noctiluca scintillans* occurred in late August during the rainy season. Bloom formation appeared on the surface during the calm conditions of the bay at low tide. The bloom formed a thick layer of green cells on the surface water. At the bloom time, the phytoplankton population had a total abundance of 10^4 cells/L, with 10^3 cells/L belonging to the *Noctiluc*a species. The first that occurred was *Trichodesmium* blooms and then followed by green *Noctiluca*. Green *Noctiluc*a are often found during the lowest tide period. No fish were killed, but the bloom resulted in declining fish production and baitfish numbers in that bay.

A yellowish-colored *Chaetoceros* bloom appeared in the Inner Ambon Bay in 1996 [39]. A bloom occurred in August, during the rainy season, but did not result in any fish kills. At that time, there were no fish kills in the bay's wilderness because there was no fish culture in the floating net. However, it is rare for multiple fish to be caught in the water during the blooming period. Up to 50% of the total population of phytoplankton species were diatoms, which dominated the bloom. The diatom *Chaetoceros sp.* was approximately 10^4 cells per milliliter. Neither the local fishing business nor the bay's environmental conditions were affected by the bloom. However, the aesthetic appeal of the bay was temporarily affected by the uneven bloom of phytoplankton on the sea surface.

At the beginning of November 1997, during the transition period, an unexpected bloom of *Alexandrium affine* occurred in Ambon Bay [40]. Although this species has occasionally been spotted in samples from this bay, this is the first time it has been seen in an abundance stage. Interestingly, this species thrived during the El Nino event, which resulted in an anomalous climate with higher-than-normal air temperatures and less precipitation. During the *Alexandrium sp* blooms, the inner bay was covered with a million cells per liter, turning the surface water reddish-brown. There were no fish kills during the bloom that could have threatened surrounding fisheries or other biota. Whether this type of dinoflagellate was poisonous or not was still a mystery.

After the 1998 El Niño events, the phytoplankton population tended to increase, in parallel with the rainfall in the area. The *Chaetoceros* outbreak, which was irregularly distributed across the inner and outer bays, was the cause of the bloom phenomena in July 1998. The patchy bloom turned the sea surface to a yellowish color. The number of *Chaetoceros* species exceeds 10^4 cells/L of the total abundance of the phytoplankton population, which reaches 10^5 cells/L. There were no fish deaths or human injuries during the bloom period. Table 5 lists the predominant bloom-forming species in Ambon Bay and their impacts.

Table 5. The primary causative species of HABs in Ambon Bay

Period	Occurrence	Causative species	Potential	Impact
1994	July	*Pyrodinum bahamense (Pbc)*	Toxic	Discoloration, fish kill
1995	August	*Trichodesmium sp, Noctiluca sp*	Harmless	Discoloration
1996	August	*Chaetoceros sp, Skeletonema sp*	Harmless	Discoloration
1997	November	*Alexandrium affine*	Toxic	Discoloration, fish kill
1998	March	*Chaetoceros sp*	Harmless	Discoloration
1999	August	*Noctiluca scintillans*	Harmless	Discoloration
2002	March	*Chaetoceros sp, Skeletonema sp*	Harmless	Discoloration
2003	April	*Chaetoceros sp, Skeletonema sp*	Harmless	Discoloration
2004	June	*Pyrodinium (Pbc)*	Toxic	Discoloration
2005	August	*Noctiluca scintillans*	Harmless	Discoloration
2006	April	*Chaetoceros sp, Skeletonema sp*	Harmless	Discoloration, fish kill
2009	June	*Pyrodinum (Pbc)*	Toxic	Discoloration
2012	June-July	*Pyrodinum (Pbc)*	Toxic	Discoloration

4 Conclusion

The three regions have different types of algae that cause HABs, as well as seasonal and annual changes. HABs are common in Jakarta Bay, Ambon Bay, and Lampung Bay. HABs occur in Jakarta Bay all year round, in the eastern half of the country from August to October and in the western region from April to June. Algal blooms are most commonly caused by diatoms such as *Skeletonema* and *Chaetoceros*. The most toxic species are dinoflagellates, including *Alexandrium sp., Pyrodinium bahamense* var. *compressum*, *Gymnodinium sp., and Cochlodinium sp*. Lampung Bay is often dominated by *Trichodesmium,* a species that produces HABs alongside *Noctiluca scintillans*. *Pyrodinium bahamense*, a poisonous species, is becoming increasingly common in Ambon Bay. In addition, the types of algae blooms triggered differed from year to year. The diatom genera *Thalassiosira, Chaetoceros,* and *Skeletonema* are common and seasonal species that play an essential role. In Indonesian coastal waters, the most common red tide species are *Skeletonema, Chaetoceros, Trichodesmium,* and *the Green Noctiluca.*

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