The presence and abundance of harmful dinoflagellate algae related to water quality in Jakarta Bay, Indonesia

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Abstract. *Takarina ND, Nasution AK, Thoha H. 2021. The presence and abundance of harmful dinoflagellate algae related to water quality in Jakarta Bay, Indonesia. Biodiversitas 22: 2909-2917.* Dinoflagellate is a single-celled organism that commonly occurs in large numbers in marine environment. When environment changes, harmful dinoflagellate algae often emerge as a response to change in water quality. Jakarta Bay, Indonesia is the meeting point of 13 rivers that carry anthropogenic effluents, not only from agriculture and human settlements, but also industrial activities with some initial evidence showed the increasing growth of harmful algae population and decreasing water quality. This study aims to assess the correlations between dinoflagellate abundance and water quality parameters (i.e., dissolved oxygen, pH, salinity, temperature, and turbidity) in Jakarta Bay. Dinoflagellates were sampled in July 2020 at four river mouths, namely Ancol, Muara Baru, Muara Angke, and Muara Karang, each with three replications. Results showed that five dinoflagellates categorized as harmful were recorded. The following order of dinoflagellates based on abundance was *Noctiluca > Ceratium > Gonyaulax > Gymnodinium > Dinophysis*. Dinoflagellate abundance ranges were as low as 353,857 cells/m^3 for *Dinophysis* and as high as 85,279,547 cells/m^3 for *Noctiluca*. In terms of location, Muara Baru had the highest dinoflagellate abundance. There were correlations between dinoflagellate abundance with water quality. The dinoflagellate abundance was positively correlated with DO (*Gymnodinium* 0.5152; *Dinophysis* 0.5262; *Gonyaulax* 0.3701; *Noctiluca* 0.0429; *Ceratium* 0.4168) and temperature (*Gymonodium* 0.3894; *Ceratium* 0.3627; *Gonyaulax* 0.3428;*Dinophysis* 0.2536) but negatively correlated with pH (*Ceratium*-0.5558; *Dinophysis*-0.4868; *Gymonodinium*-0.4284; *Noctiluca*-0.4201; *Gonyaulax*-0.3881), turbidity (*Dinophysis*-0.2336; *Gonyaulax*-0.0105; *Noctiluca*-0.1164; *Ceratium*-0.0896), salinity (*Gymnodinium*-0.2176; *Dinophysis*-0.0888; *Ceratium*-0.0434).

Keywords: Abundance, correlation, dinoflagellate, Jakarta Bay, water quality

INTRODUCTION

Dinoflagellates are single-cell microorganisms which commonly live in marine ecosystem (Guiry 2012, Le Bescot et al. 2016). In this ecosystem, dinoflagellates are autotrophic organisms that play an important role as marine primary producers and grazers (Horiguchi 2015). In marine ecosystem, dinoflagellates can move around the ocean due to currents, storms, dredging of the ocean bottom and when cysts act as ballast on ships (Smayda 2007). The presence and abundance of dinoflagellates are affected by environmental factors such as temperature, light, or oxygen level changes or even resuspension of dinoflagellate's cysts by storms (Prabowo and Agusti 2019). In general, dinoflagellates will thrive when nutrient level increases and cell division is so rapid, resulting in extremely high cell counts under conditions of extremely high nutrient levels (Davidson et al. 2014). This condition is known as algal bloom or red tides.

Among dinoflagellates, several species are considered harmful since they can release toxins such as saxitoxin, gonyautoxin, brevetoxin, yessotoxin, ciguatoxin, maitotoxin, palytoxin and azaspiracid (Lassus et al. 2016). Those toxins

are released by dinoflagellate genera included *Alexandrium, Gymnodinium, Pyrodinium, Kerenia, Chatonella, Fibrocapsa, Heterosigma, Protoceratium, Lingulodinium, Gonyaulax, Gambierdiscus, Protoperidinium*, and *Ostreopsis* (Lu and Hodgkiss 2004; Wang 2008). It is estimated that there are 60 dinoflagellate species considered harmful. These harmful species belong to the pennate diatoms which are long and thread-like. Some species such as *Alexandrium catenella* (Nagai et al. 2019), *Gymnodinium catenatum* (Clemenston et al. 2004) and *Dinophysis acuta* (Díaz et al. 2016) have been clearly reported.

The presence of harmful dinoflagellates causes problems in many parts of the world, for example in Africa (Probyn et al. 2000; Fawcett et al. 2006), America (Cuellar-Martinez et al. 2018; León-Muñoz et al. 2018), and Asia (Furuya et al. 2018). In recent decades, many coastal countries in Southeast Asia also experience an increasing trend of harmful algal bloom, resulting in mass mortalities of wild and cultured fishes and shellfishes (Soon and Sulit 2017). The impacts of harmful algae bloom in Southeast Asia regions include shellfish poisoning (ciguatera, diarrhetic, paralytic, tetrodotoxin), fish kills, and tainting of fish and shellfish (Corrales and Maclean 1995). Several marine ecosystems in Indonesia also experience harmful

dinoflagellate bloom. According to Praseno and Sugestiningsih (2000), in Indonesia's coastal and sea waters there were about 30 genera of harmful alga blooms (HABs). The presence of harmful dinoflagellates had been reported in Jakarta Bay, Ambon Bay, Kao Bay and Lampung Bay (Wiadnyana et al. 1996; Matsuoka et al. 1999; Sidharta 2004; Aditya et al. 2013; Thoha et al. 2019). For example, Barokah et al. (2016) reported the abundance of 13 harmful dinoflagellates in Lampung Bay with *Ceratium* sp. was the most common genus with abundance of 1800 cells/L.

Jakarta Bay is one of marine ecosystems in Indonesia that have been frequently studied regarding the presence of harmful dinoflagellates. Harmful algal bloom events in Jakarta Bay continue to increase in recent years, causing massive fish kills and leading to economic losses in local fisheries, a decrease in water quality, and threat to people consuming fish from the bay. In this bay, harmful dinoflagellate population growth was accelerated by the high input of nutrients caused by anthropogenic factors. Thoha et al. (2007) found discoloration of a green-brown color in the water of Jakarta Bay in May and November 2004 with dinoflagellate abundance recorded as much as 2.5-4.2 x 106 cells/L, represented by eight dinoflagellate species. Recently, a study in Jakarta Bay confirmed the abundance of harmful dinoflagellate with total of eleven species (Sidabutar et al. 2016). Further, Sidabutar et al.

(2020) conducted a study about the variability of phytoplankton species that potentially caused alga bloom events in Jakarta Bay.

Despite the growing research on dinoflagellate presence in Jakarta Bay, information about environmental factors related to the distribution and abundance of dinoflagellate is still limited. Considering the rapid anthropogenic development in Jakarta Bay with potentially adverse effects on water quality, thus understanding dinoflagellate as function of water quality is urgently required. Therefore, this study aims to investigate the correlations between dinoflagellate abundance and water quality parameters (i.e., dissolved oxygen, pH, salinity, temperature, and turbidity) in Jakarta Bay. This information is essential to anticipate the potential harmful dinoflagellate algal blooms in the future.

MATERIALS AND METHODS

Study period and area

The study was conducted in July 2020 at four river mouths located in Jakarta Bay, north of Jakarta, Indonesia (Figure 1). The study location is characterized by shallow bay with an average depth of 15 m and shoreline of 149 km long covering an area of approximately 595 km^2.
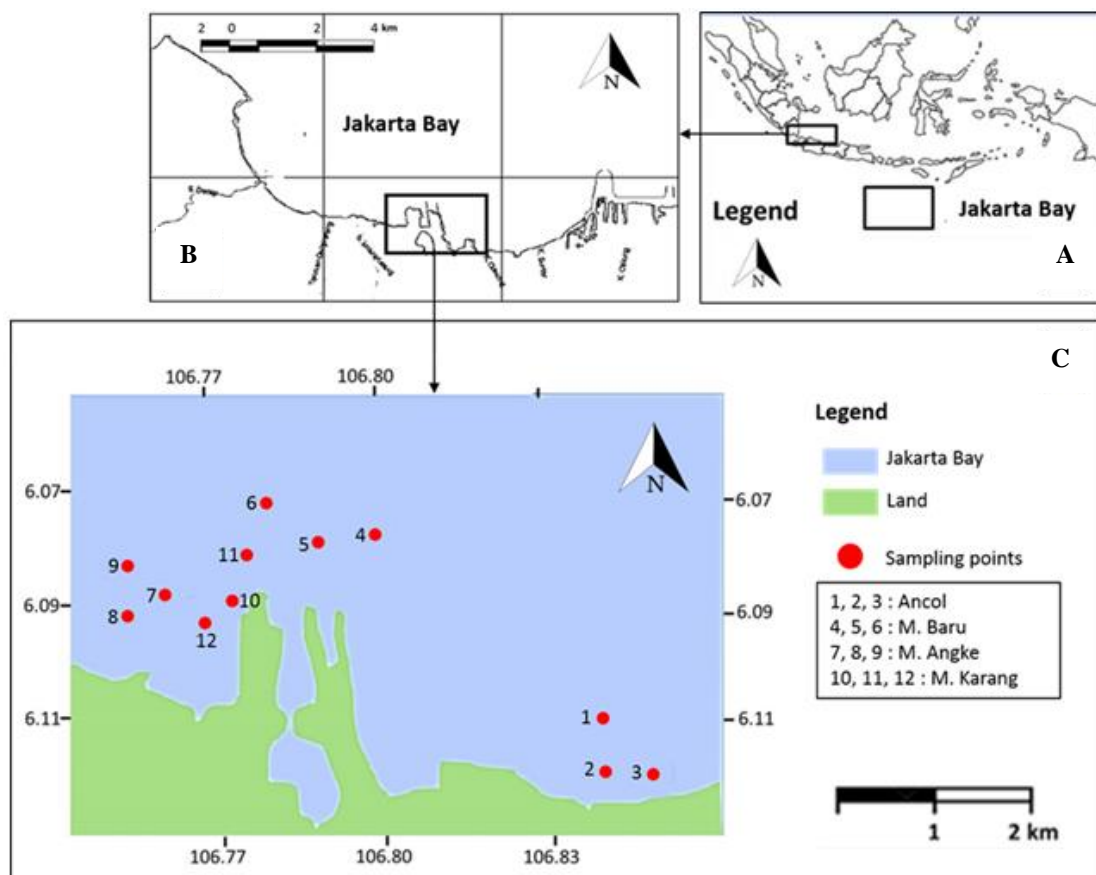

Figure 1. Map of study location showing Indonesia (A); Jakarta Bay (B); and twelve sampling points in Jakarta Bay (C)

Twelve sampling points were established with three sampling points at each river mouth, i.e., Ancol (sampling point number 1, 2, and 3), Muara Baru (sampling point number 4, 5, and 6), Muara Angke (sampling point number 7, 8, and 9) and Muara Karang (sampling point number 10, 11, and 12). The geographical coordinates of each sampling point were recorded using Global Positioning System (GPS) handheld Etrex Garmin. Land uses surrounding Ancol was dominated by open fields and vegetations. Urban residential areas, settlements, fish auction, and ports dominated the land uses in Muara Baru and Muara Karang. While land uses surrounding Muara Angke were dominated not only by combinations of fishermen housing and vegetations, but also restaurants (Riqqi et al. 2019).

Procedures

Harmful alga sampling

The collection of harmful dinoflagellate from water in each sampling point followed the method by Sidabutar et al. (2016) using modified plankton net with mesh size of 150 microns. Collected samples were stored in bottles and preserved in 37% formaldehyde. The filtered water volume was calculated using equation of $v = \pi r^2$ multiplied by d; with v: filtered water volume; r: radiant of net opening and d: plankton net depth lowered into the water. The identification of dinoflagellate was performed using a light microscope with 400x and 1000x magnifications, and the classification was carried out using Book of Illustrations of the Marine Plankton of Japan by Yamaji (1966) and Book of Marine Phytoplankton of the Western Pacific by Omura et al. (2012). While dinoflagellate abundance counting was performed using Sedgwick-Rafter counting chambers and the obtained abundance results expressed in cells/m^3.

Water quality measurement

Water quality variables were measured in situ at each sampling point with 3 replications (Table 1).

Table 1. Parameters of water quality at the four study sites in Jakarta Bay, Indonesia

Sampling point		Variable				
		DO (ppm)	pH	Temp. (ºC)	Salinity (‰)	Turbidity (NTU)
Ancol	1	7.23	5.70	30	35	0.75
	2	6.15	8.26	30	35	0.12
	3	5.50	7.74	30	35	0.26
Average		6.29	7.23	30	35	0.37
Muara	4	7.30	5.73	27.9	38	0.71
Baru	5	6.50	5.82	29.5	38	0.51
	6	8.40	5.53	30.1	38	0.17
Average		7.40	5.69	29.1	38	0.46
Muara	7	7.60	8.80	25	35	0.36
Angke	8	7.20	8.20	25	35	0.76
	9	7.00	8.50	25	36	1.21
Average		7.33	8.50	25	35.3	0.77
Muara	10	4.50	6.23	27.6	35	0.77
Karang	11	7.70	5.19	28.6	36	0.59
	12	7.90	6.03	30.5	38	4.20
Average		6.70	5.82	28.9	36.3	1.85

The measured variables included dissolved oxygen (DO), pH, salinity, temperature, and turbidity. DO and temperature was measured using multi-parameter (Lutron DO 5510), pH with pH meter (Lutron PH 208), salinity was measured with refractometer (Atago), and turbidity with turbidity meter (Ezdo TUB-430).

Data analysis

The abundance of harmful dinoflagellate and water quality data were presented as relative abundance (%). Pearson's R correlation analysis (Gharib et al. 2011) was used to test correlation significance between harmful dinoflagellate abundance and water quality variables. Principal Component Analysis (PCA) was used to group the sampling points according to their dinoflagellate abundance and water quality assemblages.

RESULTS AND DISCUSSION

Water quality

The result of water quality measurement in Jakarta Bay is presented in Table 1. The highest pH (8.5) was recorded in Muara Angke, with Muara Baru and Muara Karang were more acidic (5.69-5.82) (Table 1). There are settlements and ports in Muara Baru, while in Muara Karang there is an Electric Steam Power Plant (PLTU) (Annisa et al. 2019) which causes heat (high temperature) in the surrounding environment. Temperature plays a significant role in pH measurement (Hagens and Middelburg 2016). As the temperature rises, the molecule vibration increases, resulting in the ability of water to ionize and form more hydrogen ions. As a result, the pH will drop. Some of these low pH values were not considered the range of values that were still good for phytoplankton growth. According to Hinga (2002), pH of water in coastal environment is within the range of 7.5-8.5, while in the laboratory, the optimal pH for phytoplankton growth is between 6.3 and 10.

The water temperature of Jakarta Bay ranged from 25 to 30.56ºC (Table 1). These temperatures are still within the range of values that support the growth of phytoplankton. Several phytoplankton genera including marine dinoflagellates can grow well in temperatures up to 35ºC (Boyd et al. 2013). The salinity in Jakarta Bay ranged from 35 to 38 ppt with Muara Baru was more saline than other sampling points (Table 1). These values are still needed for phytoplankton. Raymont (1980) explained that salinity range of 10-40 ppt is optimum for the growth of phytoplankton. Salinity is one of the environmental factors that can change the community structure of phytoplankton (Sew and Todd 2020) and affect the production of phytoplankton (Barron et al. 2002).

Muara Karang, the location where PLTU existed, had the highest average turbidity with 1.85 NTU (Table 1). Turbid waters become warmer as suspended particles absorb heat from sunlight, causing oxygen levels to fall (warm water holds less oxygen than cool water). Photosynthesis decreases with lesser light, resulting in even lower oxygen levels. The occurrence of phytoplankton blooms in estuarine and coastal waters is also codetermined

by the export of fluvial nutrients and other water properties such as turbidity. Phytoplankton community structures are affected by turbidity, here, cyanobacteria often dominate because of their ability to become buoyant.

The range of DO values in Jakarta Bay ranged from 4.53-8.43 mg/L with Muara Baru had the highest DO average than other sampling points. In Muara Karang, the average DO was relatively low, which is likely due to its high turbidity. Oxygen is used by microorganisms to break down the particles in water column (Azam 1998; Liu et al. 2018). Temperature in Ancol was the highest, causing decreased oxygen content. As the temperature of the water increases, the solubility of oxygen decreases (Rahmawati and Surilayani 2017).

Harmful algal abundance

In this study, there were 5 genera of dinoflagellates recorded from twelve sampling points in Jakarta Bay, namely *Ceratium*, *Dinophysis*, *Gonyaulax*, *Gymnodinium*, and *Noctiluca* (Table 2). The abundance of dinoflagellate was significantly different ($P < 0.05$, $F = 2.539$) among genera (Figure 2). The genus of *Noctiluca* had the highest abundance with 85,279,547 cells/m^3 followed by *Ceratium* (7,360,226 cells/m^3), while *Dinophysis* was the lowest with 353,857 cells/m^3. The order of abundance based on genera was *Noctiluca* > *Ceratium* > *Gonyaulax* > *Gymnodinium* > *Dinophysis*.

The genus of *Noctiluca* had the highest abundance across ten sampling points except in sampling points 1 and 3 (Ancol) (Table 2). The relative abundance of *Noctiluca* reaches more than 50% in those sampling points (Figure 3). The *Ceratium* showed similar distribution with *Noctiluca* which is absent in sampling points 1 and 3 (Table 2). The abundance of *Ceratium* genus was observed high in sampling points 5, 6 (Muara Baru), 8 (Muara Angke) and 12 (Muara Karang) with relative abundance in range of 16-33% (Figure 3). *Gonyaulax* was the only genus found in sampling point 1 (with relative abundance 100%; Figure 3) and was also in high abundance in sampling point 3 (Table

2). *Gymonodinium* was absent in sampling points 1, 5, 7, 9 and 10. This genus has high relative abundance in sampling point 3. On the other hand, the genus of *Dinophysis* had only limited distribution and abundance across sampling sites which only found in sampling points 4, 6 (Muara Baru) and 11 (Muara Karang). The relative abundance of this genus was in range of 0.22-2.34% (Figure 3).

In regard to sampling location, the abundances were observed to be concentrated and high in Muara Baru with 50,176,929 cells/m^3, followed by Muara Karang with 28,308,563 cells/m^3, while Ancol had the lowest abundance with 5,520,170 cells/m^3 (Table 2). The order of dinoflagellate based on location sampling was Muara Baru > Muara Karang > Muara Angke > Ancol. Looking at more detail, the abundance of dinoflagellate was also different among sampling locations (Figure 4). Sampling point 4 located in Muara Baru had the highest abundance with 31,493,277 cells/m^3, followed by sampling point 11 in Muara Karang with 15,640,481 cells/m^3, while sampling point 3 in Ancol had the lowest with 141,543 cells/m^3 (Table 2).

Principal Component Analysis has separated sampling points 1, 3, 8 since these sampling points have significant low dinoflagellate abundances (Figure 5). This supports finding in Figure 4 and Table 2, the abundance of those three stations is lower than another sampling (below one million cells/m^3).

Table 3 presented water variables that can promote and limit the dinoflagellate abundance based on Pearson correlation values. DO was positively correlated with the presence of all dinoflagellates. Whereas turbidity and pH had negative correlations with the presence of all dinoflagellates except turbidity versus *Gymnodinium*. Temperature was positively correlated with *Ceratium*, *Gonyaulax*, *Gymnodinium* and *Dinophysis* except for *Noctiluca*. Salinity had negative correlation with *Ceratium*, *Dinophysis*, *Gymnodinium* and positive correlation with *Gonyaulax* and *Noctiluca*.

Table 2. The abundance of dinoflagellate (cells/m^3) across genera and twelve sampling points in Jakarta Bay, Indonesia

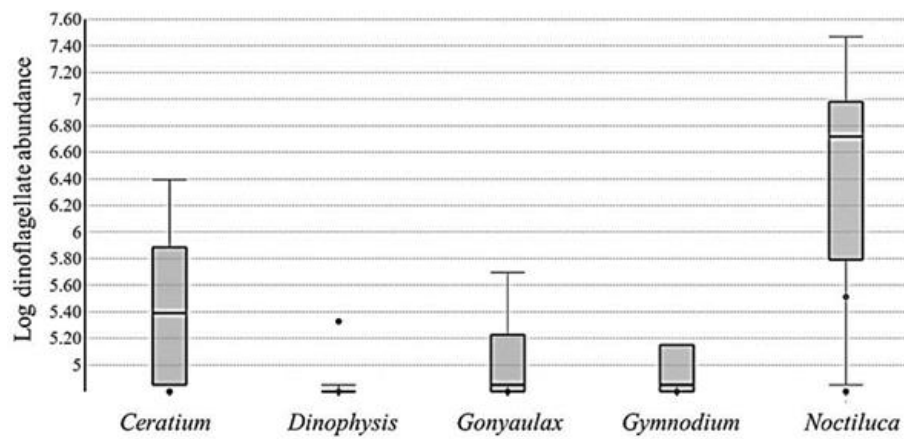| Sampling points		Dinoflagellate abundance (cells/m^3)					Total
		Ceratium	*Dinophysis*	*Gonyaulax*	*Gymnodinium*	*Noctiluca*	
Ancol	1	-	-	283,086	-	-	283,086
	2	283,086	-	141,543	70,771	4,600,142	5,095,541
	3	-	-	70,771	70,771	-	141,543
Muara Baru	4	1,344,657	70,771	495,400	141,543	29,440,906	31,493,277
	5	1,627,742	-	-	-	7,997,169	9,624,912
	6	2,476,999	212,314	283,086	141,543	5,944,798	9,058,740
Muara Angke	7	212,314	-	70,771	-	1,273,885	1,556,971
	8	70,771	-	-	70,771	70,771	212,314
	9	70,771	-	-	-	9,412,597	9,483,369
Muara Karang	10	141,543	-	-	-	9,907,997	10,049,540
	11	495,400	70,771	-	141,543	14,932,767	15,640,481
	12	636,943	-	141,543	141,543	1,698,514	2,618,542
Total		7,360,226	353,857	1,486,200	778,485	85,279,547	

Figure 2. Box plots of log of the abundance of dinoflagellate (cells/m^3) across genera in Jakarta Bay, Indonesia
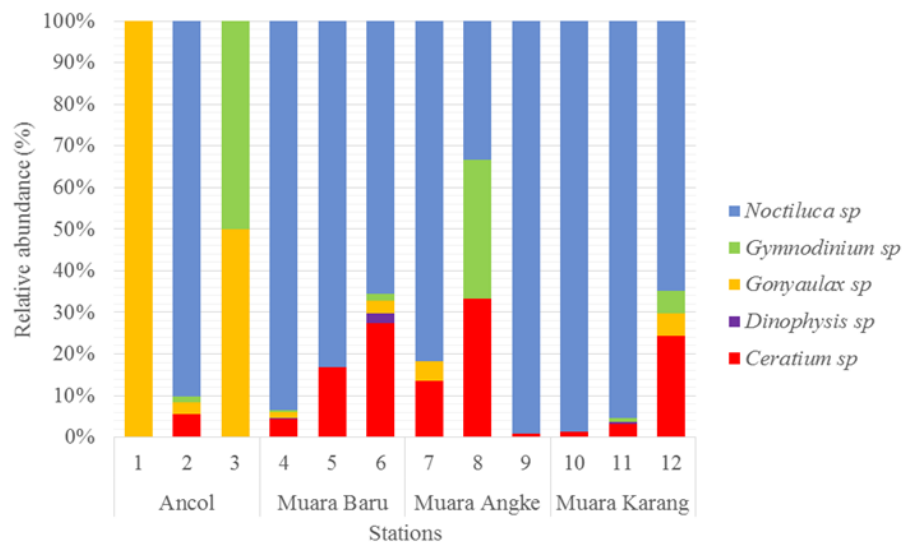

Figure 3. Relative abundance (%) of dinoflagellates across genera and twelve sampling points in Jakarta Bay, Indonesia
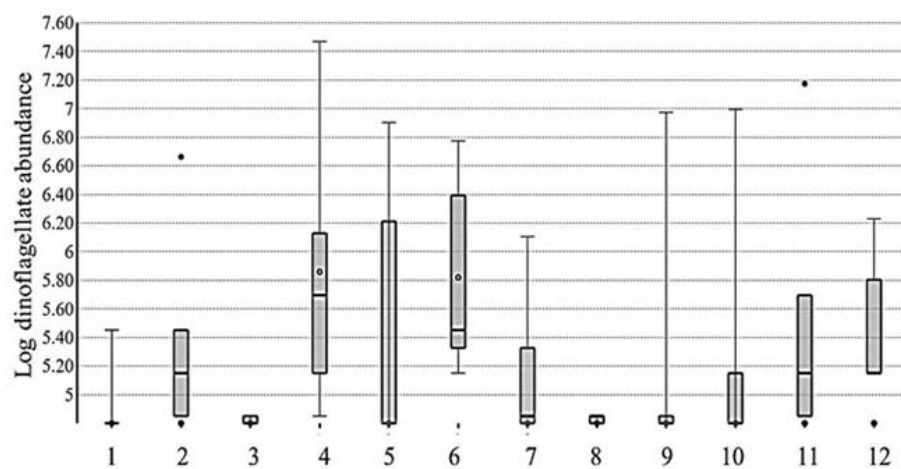

Figure 4. Box plots of log of the abundance of dinoflagellate (cells/m^3) across 12 sampling points in Jakarta Bay, Indonesia
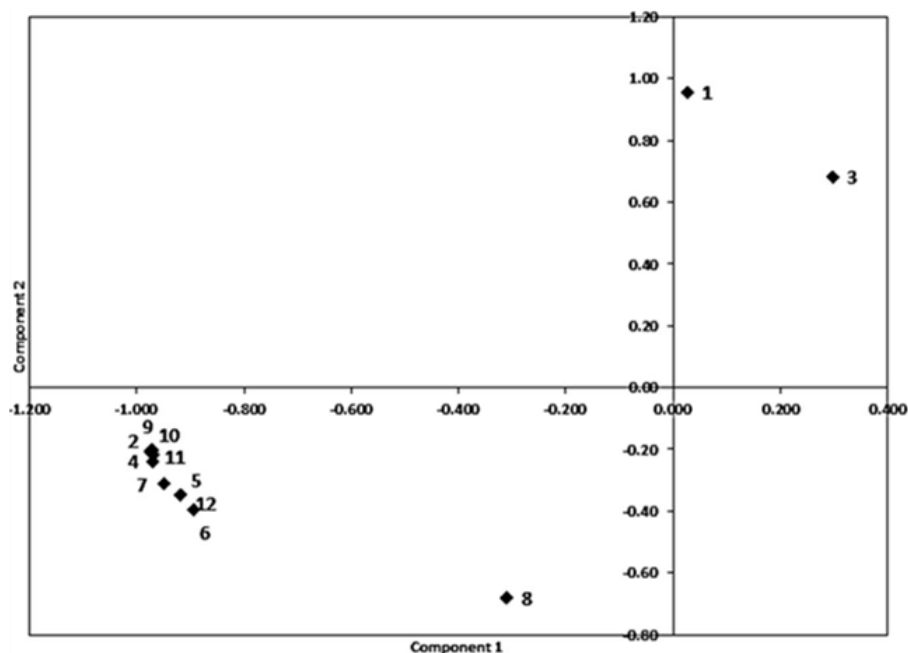
Figure 5. The results of Principal Component Analysis of twelve sampling points in Jakarta Bay, Indonesia

Table 3. Pearson's R correlation significance between harmful dinoflagellate abundance and water quality variables

	DO	pH	Temperature	Salinity	Turbidity
Gymnodinium	0.5152	-0.4284	0.3894	-0.2176	0.2713
Dinophysis	0.5262	-0.4868	0.2536	-0.0888	-0.2336
Gonyaulax	0.3701	-0.3881	0.3428	0.1080	-0.0105
Noctiluca	0.0429	-0.4201	-0.0759	0.0729	-0.1164
Ceratium	0.4168	-0.5558	0.3627	-0.0434	-0.0896

Discussion

Water quality parameters in Jakarta Bay obtained in this study were in agreement with another study (Nazula et al. 2019). In this bay, turbidity, temperature, salinity, and DO were water quality variables that have significant effects on the bay ecosystems. Ecologically, the temperature is an environmental factor that influences the presence of various aquatic organisms, including HABs. According to Bouman et al. (2003) and Ayadi et al. (2004), the temperature affects the changes in phytoplankton composition and size. DO values recorded here considered high which were within the range of 6-8 mg/L as reported by Martina and Radjawane (2019). This condition occurred because the research stations received freshwater inputs from the nearby rivers. The presence of rivers and freshwater will lead to the diffusion of oxygen in water and this will increase the DO.

Most apparent water quality can be observed in latitudinal turbidity data. Muara Baru and Muara Karang dominated by settlements that had higher turbidity, while Muara Angke and Ancol had lower values. Besides the presence of residential areas, turbidity values were also likely influenced by the presence of thirteen rivers at the head of Jakarta Bay. This similar condition was also reported by Yurista et al. (2015) in Green Bay (Lake of Michigan, Wisconsin). In their study, they observed river loading sets up the turbidity for a longitudinal along the Green Bay. Turbidity is related to the pollutants entering the bay most commonly via terrestrial run-off from rivers or through urban run-off carrying large amounts of residential wastes.

All dinoflagellates recorded in this study were categorized as harmful algal genera as reported by other studies (Smayda 1997; Aissaoui et al. 2012). Kunzmann et al. (2018) reported that water quality can affect marine organism patterns as happened in coral reefs where the reefs have varied patterns along with the water quality. Hard corals increase along with the degradation of water quality while soft corals have positive correlation in locations where water quality improved. In Jakarta Bay, dinoflagellate abundance had positive correlation with DO and negative correlation with turbidity. This finding corroborates the report by Sahu et al. (2014) which stated that low turbidity will favor the dinoflagellate abundance. A similar trend was also observed in Makassar Bay (Mujib et al. 2015). Turbidity is one of the important variables affecting the growth of dinoflagellate (Hilaluddin et al. 2020, Ge et al. 2020). High turbidity in inshore of Jakarta

Bay will restrict the light penetration and this limits the dinoflagellate distribution in the water column.

In this study, the abundance of dinoflagellate was possibly related to human activities. Muara Baru and Muara Karang where the dinoflagellate abundances were notably high have coastal land uses dominated by settlements, industrial areas, and fish auction which include numerous factories and warehouses (Pratama and Tauchid 2018). Muara Angke is known for its 25.02 hectares of mangrove ecosystem and wildlife reserve in Jakarta (Cordova et al. 2021). Ancol has been one of the largest tourism complexes in Jakarta along with housing and industrial estates (Merrillees 2015). According to Gharib et al. (2011), coastal anthropogenic inputs can affect the distribution and composition of the phytoplankton assemblages. In coasts dominated by residential areas where anthropogenic nutrient inputs are more evident, phytoplankton abundance is strongly related to such nutrients.

Ceratium in Jakarta Bay was a dinoflagellate that occupied a large area especially in Muara Baru and Muara Karang. In these areas, *Ceratium* preferred more offshore than inshore areas. According to Mujib et al. (2015) with their study in Makassar Bay, *Ceratium* abundance was high in offshore and occupying a large area. The wide distributions of *Ceratium* that cover large areas were related to the adaption of this genus. *Ceratium* is known as dinoflagellate genus that has broad tolerance to the water quality including water with low salinity (Baek et al. 2008). In this study, *Ceratium* had negative correlation with salinity, meaning that its abundance was high when salinity was low. *Noctiluca* was dinoflagellate with the largest abundance, despite the fact that this genus has limited distribution. According to Mujib et al. (2015), *Noctiluca* has narrow tolerance to salinity and temperature. This narrow tolerance was supported by the findings by Tsai et al. (2018) that *Noctiluca* was correlated positively with salinity. As a result, *Noctiluca* abundance was high only in areas where salinity was high as well. *Dinophysis* and *Gymnodinium* were dinoflagellates that had low abundance and limited distribution. *Dinophysis* was distributed limited to the area that had low salinity. This preference for low saline water was similar to Mujib et al. (2015) results. Related to the morphology of *Dinophysis*, this genus has flagella to support its movement in the water. To enable the movement using flagella, *Dinophysis* requires appropriate water density and low saline water. *Gymnodinium* had positive correlation with turbidity and negative correlation with salinity. Most dinoflagellate requires low turbidity to grow, whereas considering its positive correlation with turbidity, *Gymnodinium* can inhabit complete dark water (Gómez 2003) with limited light penetration. According to Band-Schmidt et al. (2010), *Gymnodinium* has broad water quality tolerances. In Muara Angke, *Gymnodinium* was the only genus found there while other dinoflagellates were absent. In this location, the salinity was the lowest with 35 ppt while other dinoflagellates prefer salinity > 35 ppt. Gómez (2003) reported that *Gymnodinium* high abundance was associated with low salinity waters and this explains

the only negative correlation of this genus with salinity in Jakarta Bay.

This study has reported the abundance of harmful dinoflagellate as function of water quality. It was apparent that DO and turbidity shaped the dinoflagellate presence in Jakarta Bay. Water with high DO and low turbidity was preferred by dinoflagellates except *for Gymnodinium* that can tolerate high turbidity. Jakarta Bay receives freshwater from several rivers. This condition reduces the salinity and also can favor the dinoflagellate distribution pattern mainly for those genera that can tolerate low saline water since they had negative correlations with salinity. Dinoflagellate genera that widely distributed in the bay with low salinity included *Ceratium*, *Dinophysis* and *Gymnodinium*.

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