Eutrophication and distribution of dinoflagellates as an indicator of water quality in the Probolinggo coast, East Java, Indonesia

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Abstract. Eutrophication can trigger the spread of phytoplankton which is toxic and dangerous for the other aquatic biota. Dinoflagellates are a type of plankton that is dangerous and toxic. This study aimed to analyze the status of eutrophication and distribution of dinoflagellates in the coastal waters of Probolinggo, East Java. The method used in this study is a survey method with descriptive data analysis. The research was carried out in June-September 2022, during a period which is divided into two seasons, namely the west season and the east season. The results obtained were the level of eutrophication in the Mayangan and Binor waters, included in the oligotrophic to eutrophic category. The distribution of dinoflagellates in Mayangan from June to September comprises *Alexandrium*, *Gambierdiscus*, *Glenodinium*, *Gymnodinium*, *Pyrodinium*, *Prorocentrum*, *Ceratium*, *Peridinium*, *Dinophysis*, *Ostreopsis*, *and Amphidinium*. The distribution of dinoflagellates in Binor from June to September comprises *Scrippsiella*, *Amphidinium*, *Alexandrium*, *Glenodinium*, *Protoperidinium, Dinophysis*, *Cochlodinium*, *Gymnodinium*, *Bysmatrum*, *Peridinium*, *Ceratium* and *Pyropharus*. The abundance of phytoplankton in Mayangan and Binor waters consisted of 81–11,214 cells ml^{-1}. Mayangan and Binor waters showed almost the same water quality characteristics between locations and seasons. Nitrate and phosphate affect the abundance of dinoflagellates in both Mayangan and Binor waters, while temperature and pH only affect the abundance of dinoflagellates in Binor waters. The conclusion of this study is the high level of eutrophication in Mayangan and Binor waters resulting in several species of dinoflagellates that can endanger the environment. Therefore, it is necessary to control the quality of water and nutrients that enter the waters on a regular basis to protect the aquatic environment, especially the coastal areas of Probolinggo, by avoiding high eutrophication and an abundance of harmful phytoplankton such as dinoflagellates.

Key Words: phytoplankton, nutrient, trophic status, coastal, Pasuruan.

Introduction. Eutrophication represents an increase in the rate of primary productivity and accumulation of organic matter. This condition is usually caused by an excessive increase in nutrients from anthropogenic activities, causing unwanted changes in ecosystems. Eutrophication is part of a global phenomenon, with significant effects on food webs, water quality and aquatic biota (Rabalais et al 2014). Eutrophication is considered as one of the causes of algal blooms in coastal waters because this condition is characterized by uncontrolled growth of phytoplankton and aquatic plants, causing a decrease in water quality (Sidabutar et al 2020).

Some of the microalgae can cause mass death of fish, disruption of microbial ecosystems, and contamination of seafood because they can produce certain toxins. This type of bloom is caused by toxic or dangerous algae (Sidabutar et al 2020), among which the group of Dinoflagellates. Dinoflagellates are a dangerous species of phytoplankton that often experience population explosions and cause problems in coastal areas (Rachman et al 2021). Dinoflagellate species are one of the causes of harmful algal blooms (HABs), which causes water discoloration and can produce various toxins. In several studies, dinoflagellates are used as indicators to detect anthropogenic eutrophication processes in coastal areas. Therefore, the distribution of dinoflagellates in waters and sediments will increase the understanding of anthropogenic pollution areas and HABs events (Narale & Anil 2017).

Water quality is an important factor in the success of activities in coastal areas, especially capture fisheries and aquaculture. Water quality parameters can include water primary productivity, diversity and density of plankton, macroalgae and other marine organisms. Besides, the main factors that cause changes in the coastal environment are pollution indicators, geomorphological changes, land use and physical changes due to the impact of tidal floods (Fahmi & Setyono 2015).

Probolinggo waters are coastal waters that receive a lot of input from land in the form of anthropogenic loads caused by high community activity and the presence of steam power plants (PLTU) and other industries (Fahmi & Setyono 2015). These activities can trigger changes in water quality that cause eutrophication and the emergence of dangerous species such as dinoflagellates. Thus, the purpose of this study was to analyze the level of eutrophication and distribution of dinoflagellates as an indicator of water quality in the Probolinggo coastal waters, East Java.

Material and Method

Research time and place. This research was carried out in Mayangan and Bhinor Coastal Waters, Probolinggo, East Java, for a 4 months period, from June to September 2022. The research time was divided between the 2 seasons, namely the West season, in June–July, and the East season, in August–September. The analysis of water quality parameters and identification of plankton were carried out at the Laboratory of Freshwater Fisheries Technical Implementation Unit and Hydrobiology Laboratory of the Aquatic Environment Division, Faculty of Fisheries and Marine Sciences, Universitas Brawijaya. The research location can be seen in Figure 1.

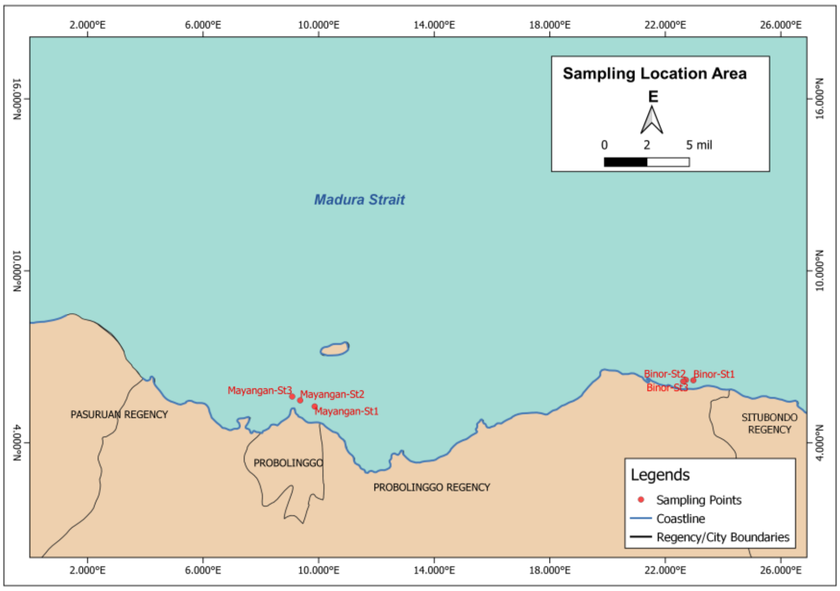

Figure 1. Research location map.

Research method. The research was conducted using a survey method with descriptive data analysis. Plankton sampling locations were determined by purposive sampling, each location consisting of three station points based on land use. On the Mayangan Coast, station I is a mangrove vegetation area, station II is a fishing port area and station III is an industrial area, while the Bhinor Coast consists of station I, which is the Paiton PLTU area, station II, which is the fishing ground area, and station III, which is the river estuary area.

Research variables. The research variables were measuring the eutrophication status using the Trophic State Index (TSI) method, the abundance, and community of phytoplankton as well as the distribution of dinoflagellates and environmental parameters which included physical parameters, namely temperature and brightness. Chemical parameters include pH, DO, salinity, nitrate, orthophosphate, and Total Organic Matter (TOM).

Data analysis

Trophic state index. Determination of trophic status (eutrophication) is based on Carlson's (1977) Trophic State Index (TSI), which involves, as main parameters, the depth of the Secchi Disc (TSI-SD), total phosphate concentration (TSI-TP) and Chlorophyll-a content (TSI-Chl). TSI is calculated using the following equation:

$$\mathrm{TSI} = \frac{(\mathrm{TSI-SD}) + (\mathrm{TSI-Chl}) + (\mathrm{TSI-TP})}{3}$$

Where:
SD - secchi disk (m);
Chl - chlorophyll-a (mg L^{-1});
TP - total phosphorus (mg L^{-1}).

The Trophic State Index (TSI) class is presented in Table 1 (Pomari et al 2018).

Table 1

Trophic State Index (TSI) scale factor

TSI classification	*TSI carlson*
Ultraoligotrophic	<20
Oligotrophic	21 – 41
Mesotrophic	41 – 50
Eutrophic	51 – 60
Hypertrophic	>61

Plankton abundance. Plankton abundance is calculated using the following formula (APHA 1989):

$$N = \frac{T \times V}{\mathrm{L} \times \mathrm{p} \times \mathrm{v} \times \mathrm{W}} \times n$$

Where:
N - total abundance of plankton (cell mL^{-1});
T - cover glass area (20 × 20 mm);
V - the volume of plankton sample in the container bottle;
n - the number of plankton in the field of view;
L - wide field of view;
P - number of visual fields;
V - the volume of plankton;
W - volume of filtered sample water.

Relative abundance. Relative abundance can be calculated by the following formula (Odum 1994):

$$KR = \frac{ni}{N} \, x \; 100 \;\%$$

Where:
KR - relative abundance;
Ni - number of individuals of the i^{th} type (ind);
N - total number of individuals (ind).

Diversity index. The diversity index can be formulated using the Shannon-Weiener formulation as follows (Odum 1994):

$$H' = -\sum_{i=s}^{s} (\mathrm{Pi} \ln Pi)$$

Where:
Pi - ni/N;
H’ - diversity index;
Ni - number of individuals of the i^{th} type (ind);
N - total number of individuals (ind).

Dominance index. The plankton dominance index is calculated by the following formula (Odum 1994):

$$D = \sum pi^2$$

Where:
D - dominance index;
Pi - ni/N;
ni - number of individuals of the i^{th} type (ind);
N - total number of individuals (ind).

Results

Eutrophication Level of Mayangan and Binor Coastal Waters. Based on TSI calculations, the level of eutrophication in the coastal waters of Mayangan & Binor (2021) obtained a score of 39—60, with the lowest score found in Mayangan waters station 1 in August (oligotrophic category), while the highest level of eutrophication was found in Binor waters station 3 in July (eutrophic category). According to Carlson (1977), the water fertility levels, based on the TSI, are: <30—40, belonging to the oligotrophic status, 40—50 belonging to the mesotrophic status, 50—70 belonging to the eutrophic status and 70—100 belong to the hyper eutrophic status (Pratiwi et al 2020). There is a difference in the trophic status between the west and east monsoons: in the west monsoon (June-July), the average level of eutrophication is higher, compared to the east monsoon (August-September). The TSI calculation results can be seen in Figure 2.

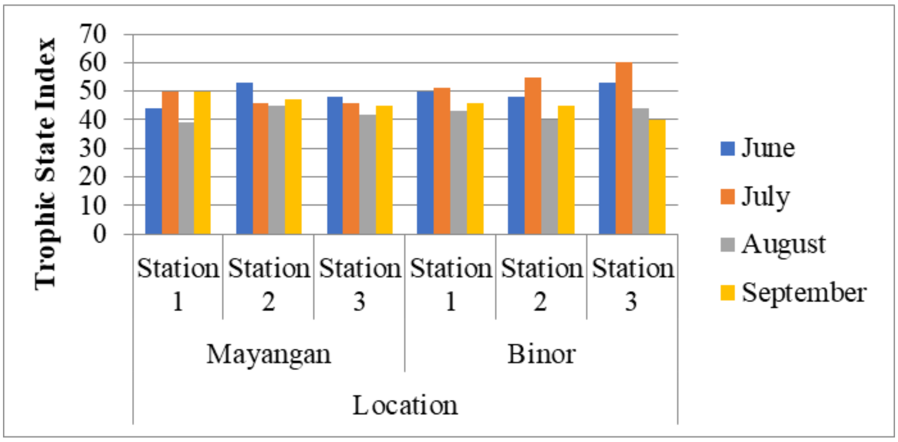

Figure 2. Diagram of the TSI, calculated according to Carlson (1977).

Distribution of dinoflagellates in Mayangan and Binor waters. The abundance of dinoflagellates in Mayangan and Binor waters ranged from 0–1301 cells mL^{-1}. The lowest abundance was found in Binor waters at station 2 in August and station 1 in September, which was 0 cells mL^{-1}, which means that dinoflagellates were not found in these stations. Meanwhile, the highest abundance value was found in Mayangan waters station 1 in June of 1301 cells mL^{-1}. This shows that there are differences in the abundance of dinoflagellata in the west and east monsoons, where in the west season (June-July) more dinoflagellates were found when compared to the east season (August-September) (Figure 3).

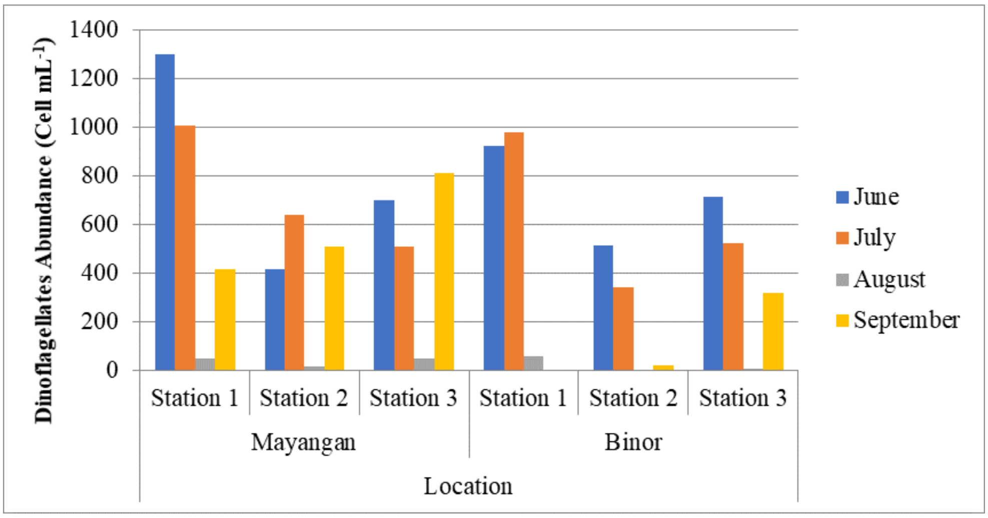

Figure 3. Dinoflagellate abundance.

Dinoflagellate distribution in Mayangan and Binor waters in different seasons can be seen in Figure 4 and Figure 5.

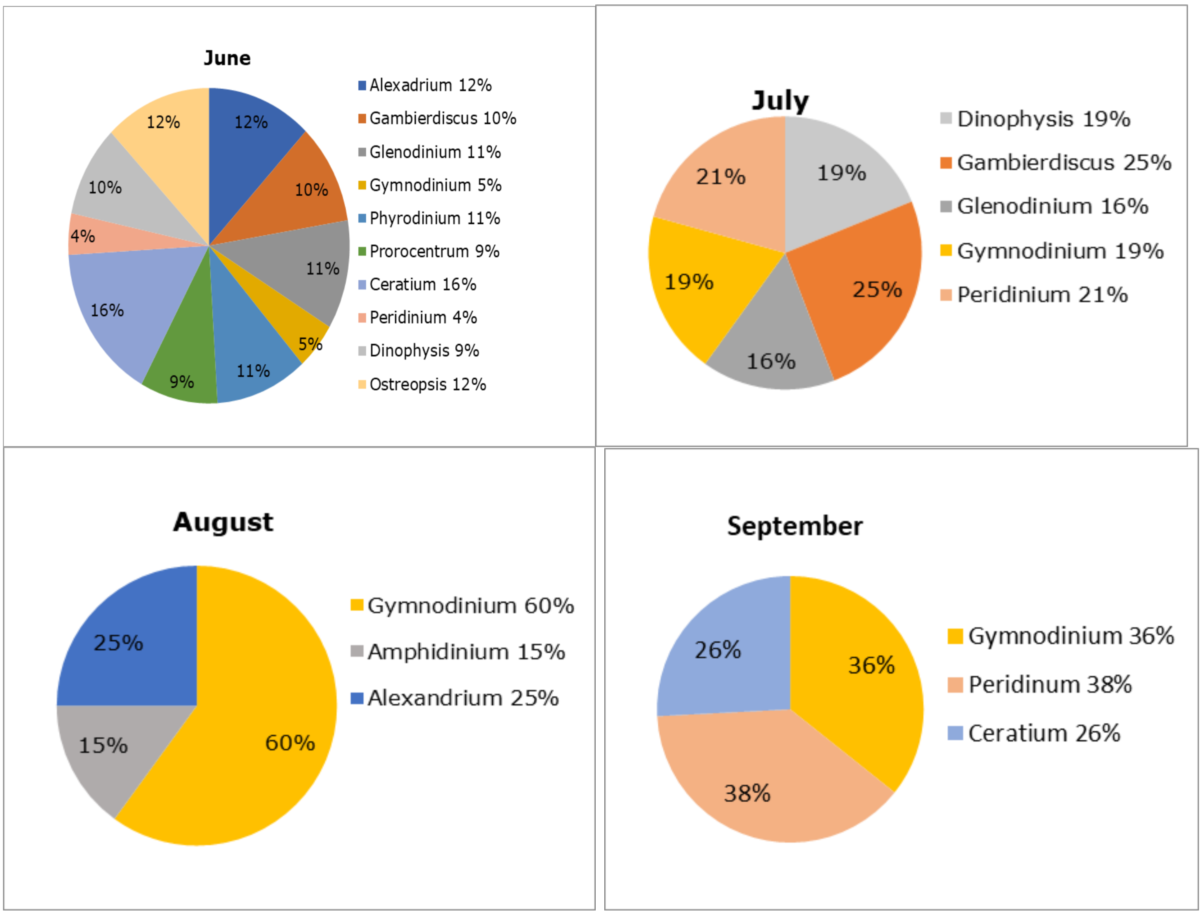

Figure 4. Dinoflagellate distribution in Mayangan waters.

Based on the relative abundance values in Mayangan waters, it was found that the distribution of dinoflagellates was of 10 genera with the highest abundance, 16%, in June, dominated by *Ceratium*, 5 genera with the highest distribution, 25%, in July, dominated by *Gambierdiscus*, 3 genera with the highest distribution in August, 60%, dominated by *Gymnodinium* at and 3 genera with the highest distribution, 38%, in September, dominated by *Peridinium*.

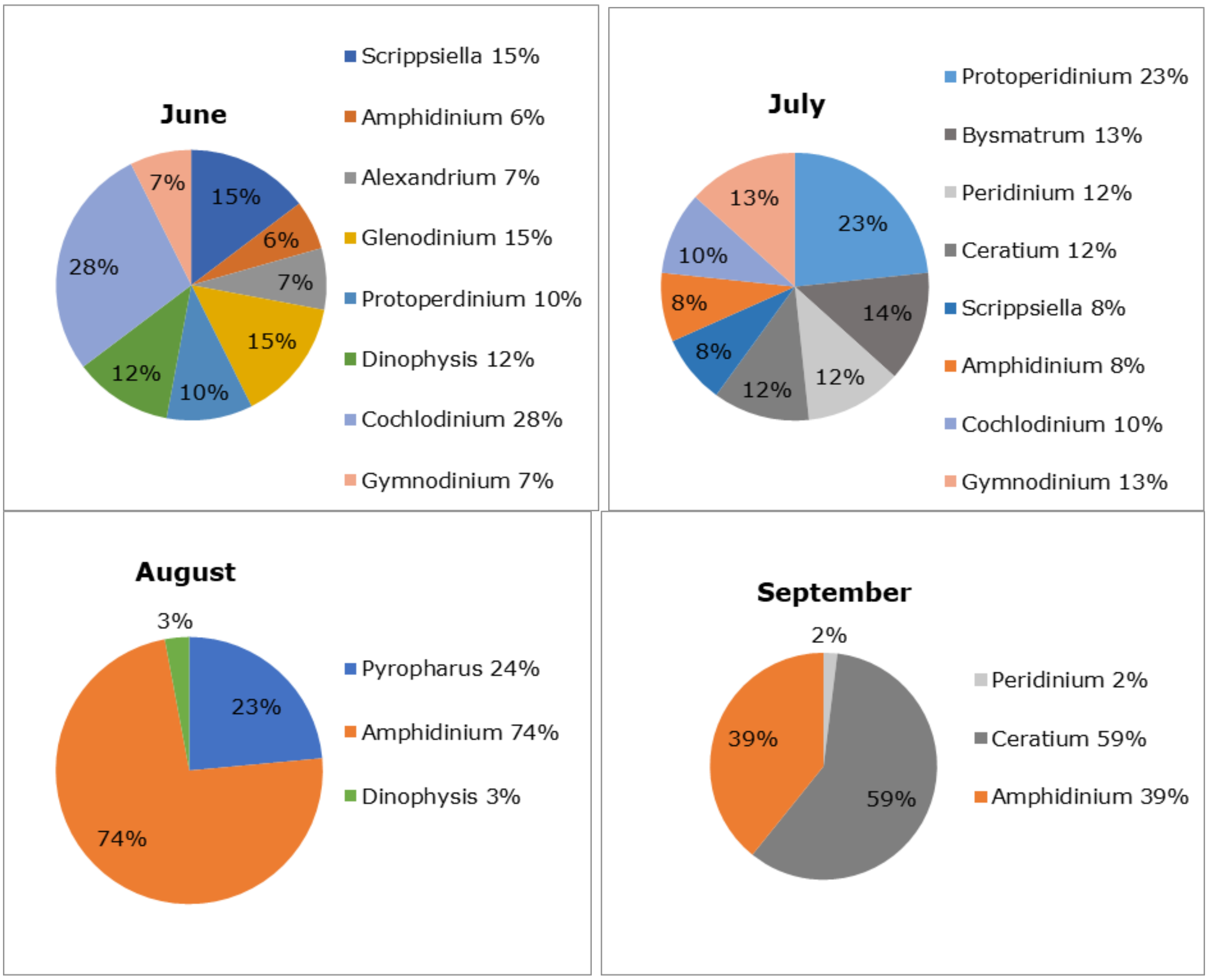

Figure 5. Dinoflagellate distribution in Binor waters.

Based on the value of the relative abundance of dinoflagellates in Binor waters, it was found that there were: 8 genera with the highest distribution, 28%, in June, dominated by *Cochlodinium*, 8 genera with the highest distribution, 23%, in July, dominated by *Protoperidinium* 3 the genus with the highest distribution, 74%, in August, dominated by *Amphidinium* with and 3 genera with the highest distribution in September, 59%, dominated by *Ceratium*.

Composition of phytoplankton in Mayangan and Binor waters. Based on the results of the research conducted at 2 locations, namely in the waters of Mayangan and Binor, Probolinggo Regency, in two different seasons, it was found that the composition of phytoplankton in Mayangan waters consisted of: 6 phyla, namely Bacillariophyta, Cyanophyta, Chlorophyta, Ciliophora, Euglenophyta, and Dinoflagellates, in June; 6 phyla namely Bacillariophyta, Chlorophyta, Cyanophyta, Chrysophyta, Euglenophyta, and Dinoflagellates, in July; 3 phyla, namely Bacillariophyta, Cyanophyta, and Dinoflagellates, in August; 5 phyla namely Bacillariophyta, Chlorophyta, Charophyta, Ochrophyta, and Dinoflagellates, in September. In the waters of Binor, there were: 4 phyla, namely Bacillariophyta, Chlorophyta, Euglenophyta, and Dinoflagellates, in June; 7 phyla, namely Bacillariophyta, Chlorophyta, Cyanophyta, Charophyta, Chrysophyta, Euglenophyta, and Dinoflagellates, in July; 5 phyla, namely Bacillariophyta, Chlorophyta, Chrysophyta, Cyanophyta, and Dinoflagellates in August; 4 phyla namely Bacillariophyta, Chlorophyta, Cyanophyta, and Dinoflagellates, in September. The abundance of phytoplankton can be seen in Figure 6.

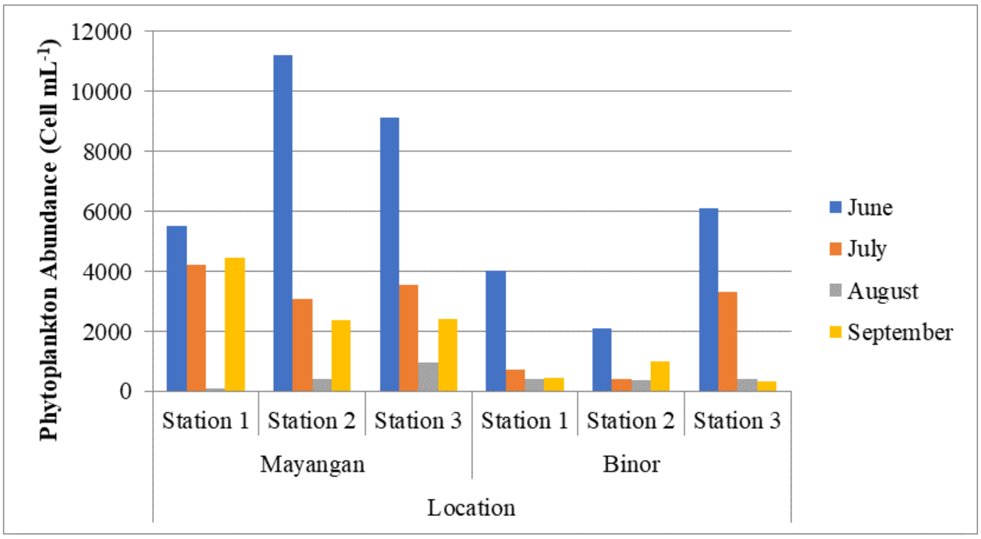

Figure 6. Phytoplankton abundance (cell mL^{-1}).

The abundance of phytoplankton in Mayangan and Binor waters ranged from 81 to 11.214 cells mL^{-1}. The lowest abundance was found in Mayangan waters at station 1, in August, with a value of 81 cells mL^{-1}. While the highest abundance was found in Mayangan waters at station 2, in June, with a value of 11.214 cells mL^{-1}. Based on these results, there are differences in the value of phytoplankton abundance in the west and east seasons: the abundance of plankton is higher in the west season (namely in June), compared to the east season. The results of the analysis of the diversity index in Mayangan and Binor waters were ranging from 0.130 to 1.967 (Table 2), corresponding to the low-medium category. According to Dwirastina & Riani (2019), a diversity index value (H') <1 indicates that the biota community in the waters is unstable; if the diversity index value is 1<H'<3 the community stability is said to be moderate and if the H' value >3, then the biota community unstable.

Table 2

Diversity index of Mayangan and Binor waters

Time	*Location*					
	Mayangan			*Binor*		
	Station 1	*Station 2*	*Station 3*	*Station 1*	*Station 2*	*Station 3*
June	1.920	1.470	1.790	1.776	1.329	1.338
July	1.182	1.282	1.862	0.292	0.197	0.294
August	0.291	1.595	1.200	0.760	0.130	0.594
September	1.967	1.177	0.843	0.893	1.440	0.630

The results of the calculation of the dominance index in the waters of Mayangan and Binor range from 0.014 to 0.90 (Table 3). The lowest dominance value was found at Binor station 1 in July, which showed that no genus dominated other genera, while the highest value was at Binor station 2 in August which indicated that there was a genus that dominated other genera. This is with Ramadhanty et al (2020): a dominance index that is close to a value of 1 indicates a high dominance, and vice versa, a dominance value close to 0 indicates a low dominance or no dominant species.

Table 3

Mayangan and Binor waters dominance index

Time	*Location*					
	Mayangan			*Binor*		
	Station 1	*Station 2*	*Station 3*	*Station 1*	*Station 2*	*Station 3*
June	0.126	0.238	0.198	0.158	0.370	0.210
July	0.340	0.395	0.128	0.014	0.041	0.03
August	0.831	0.520	0.385	0.36	0.90	0.676
September	0.156	0.230	0.558	0.593	0.229	0.176

Water quality analysis. Measurements of water quality that support plankton life in Mayangan and Binor waters can be seen in the following Table 4.

Table 4

Water quality in Mayangan and Binor waters

Parameter	*Time*	*Coastal*		*Quality standard*	*Reference*
		Mayangan	*Binor*		
Temperature (°C)	June	28-29	31-33	<35	Faturohman et al (2016)
	July	25-30	32-34		
	August	29-31	29-30		
	Sept	27-28	29-31		
Brightness (cm)	June	160-220	55-155	>45	Angraini et al (2021)
	July	100-162	100-282		
	August	167-258	118-201		
	Sept	133-217	145-280		
pH	June	7.1-7.6	7.6-8.1	6.5-8	Rahmah et al (2022)
	July	7.6-7.8	7.4–7.9		
	August	7.1-7.3	7.0-7.3		
	Sept	7.7-8.0	7.3-7.6		
Salinity (ppt)	June	27-32	25-30	>20	Yuliana et al (2012)
	July	30-35	27-30		
	August	32-34	28-31		
	Sept	33-35	28-34		
DO (mg L^{-1})	June	6.0-6.9	6.7-7.1	>5	Mariyati et al (2020)
	July	7.4-7.8	6.8–6.9		
	August	4.5-4.8	4.5-5.1		
	Sept	4.8-5.0	4.1-4.7		
Nitrate (mg L^{-1})	June	0.091-0.187	0.123-0.154	0.9–3.5	Nindarwi et al (2021)
	July	0.252-0.301	0.196-0.337		
	August	0.341-0.434	0.389-0.477		
	Sept	0.243-0.369	0.272-0.328		
Orthophosphate (mg L^{-1})	June	0.036-0.042	0.038-0.063	0.09-1.80	Nindarwi et al (2021)
	July	0.016-0.018	0.012-0.015		
	August	0.030-0.053	0.033-0.086		
	Sept	0.033-0.036	0.026-0.045		
TOM (mg L^{-1})	June	6.8-15.3	9.2-20.6	<40	Arfiati et al (2019)
	July	4.4-5.7	4.3-11.1		
	August	5.5-27.7	2.4-29.2		
	Sept	6.8-15.3	9.3-20.7		

Discussions. The high level of eutrophication in the waters of Binor station 3 in July was caused by the proximity to the river mouth: the nutrient content carried from the mainland through the river flow was higher than at other stations. In addition, July is included in the west season, where rainfall is high, so that nutrients from the land are carried away by rainwater flows and emptied into coastal areas. This is in accordance with Maier et al (2009): increased nutrient input into estuaries can cause eutrophication effects, including algae blooms, changes in species composition and anoxia of the water bottom. River estuaries are vulnerable areas contributing to the high concentrations of nitrogen (N) and phosphorus (F) entering the coastal waters.

Eutrophication can occur due to changes in the physical characteristics of an environment or to an increase in organic and inorganic matter. Another cause that can lead to eutrophication is the natural or direct anthropogenic carbon enrichment. Eutrophication is more often associated with an excessive nutrient intake stimulating the growth of phytoplankton. Eutrophication will get worse if river discharge and fertilizer use increase (Rabalais et al 2014). According to Khokhar et al (2022), seasonal variations also affect the number of dinoflagellate species. The high abundance of dinoflagellates can also be associated with the effect of waste input from land, the influence of temperature, wind conditions, and upwelling, which affects the presence of dinoflagellates in every season. The abundance of dinoflagellates is generally higher during the rainy season. The high values of temperature and salinity during the rainy season directly cause the increase of the abundance of dinoflagellates during the rainy season (Silva et al 2021).

The distribution of dinoflagellates in the waters of Mayangan and Binor was different in the west and east monsoons: during the west monsoons, dinoflagellates were found to be more numerous compared to the east monsoons. The diversity of dinoflagellates in the west season is due to the high rainfall. The rainy season causes the high nutrient content into the waters, which triggers the growth of harmful algae in the waters. According to Kesaulya et al (2022), algal blooms in Ambon Bay occur during the rainy season, between early May and July, which causes upwelling in the Banda Sea and brings nutrient-rich waters to Ambon Bay, causing eutrophication and triggering the growth of harmful algae in that season. The fertility level, based on the abundance of phytoplankton in Mayangan and Binor waters, is classified into waters with oligotrophic-mesotrophic fertility status. The abundance of phytoplankton and the concentration of chlorophyll-a play a very important role in influencing the level of eutrophication of water (Nurfadillah et al 2021). Phytoplankton is a bioindicator of organic matter pollution, related to the level of abundance of organisms which increases with the water fertility (Rahayu et al 2020).

Relationship of water quality to dinoflagellata abundance. Based on the results of linear regression, the water quality parameters that affect the abundance of dinoflagellates in both Mayangan and Binor waters are the nitrate and orthophosphate, which have a significant value ($p<0.05$), while the temperature and pH values only affect the abundance of dinoflagellates in Binor waters. Nitrates and orthophosphates affect the abundance of dinoflagellates because they are nutrients. Seygita et al (2015) highlight that the abundance of dinoflagellates depends on the nutrient content in waters, which means that if water is rich in nutrients, the abundance of dinoflagellates will also be higher. Based on research by Meirinawati & Fitriya (2018), phosphate is a nutrient that affects the density of dinoflagellate cells. Dinoflagellates are pelagic microalgae that have the ability to survive under stressful conditions and physical environmental disturbances. The main influential agents for the distribution of dinoflagellates include light, temperature, salinity, and nutrition (Sahu et al 2014).

Conclusions. The coastal waters of Mayangan and Binor are at the oligotrophic-eutrophic fertility level, with TSI index values ranging from 39 to 60. In the western season (June-July), the average eutrophication rate is higher than in the east monsoon (August-September). The distribution of Dinoflagellates in Mayangan waters consists of 11 genera, namely: *Alexandrium*, *Gambierdiscus*, *Glenodinium*, *Gymnodinium*, *Phyrodinium*, *Prorocentrum*, *Ceratium*, *Peridinium*, *Dinophysis*, *Ostreopsis* and *Amphidinium*. The distribution of Dinoflagellates in Binor Waters consists of 12 genera, namely: *Scripsiella*, *Amphidinium*, *Alexandrium*, *Glenodinium*, *Protoperidinium*, *Dinophysis*, *Cochlodonium*, *Gymnodinium*, *Bysmatrum*, *Peridinium*, *Ceratium* and *Pyropharus*. During the west monsoon, there was a higher diversity of dinoflagellates, compared to the east monsoon.

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Conflict of interest. The authors declare no conflict of interest.

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