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Phytoplankton Dynamics and Its Relation to Physicochemical Parameters in the Dry Season of Maninjau Lake, West Sumatra, Indonesia

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ABSTRACT

Physicochemical parameters play a significant role in determining phytoplankton structure and dynamics in the lake. The present study investigated the phytoplankton dynamics and their correlation with physicochemical parameters in the dry season of Maninjau Lake. The parameters measured, including temperature, transparency, pH, DO, TN, and TP concentrations, were collected from seven lake locations, i.e., in the middle of the lake, near domestic, hydropower, endemic fisheries, and aquaculture cage areas, and inlet-outlet rivers. Phytoplankton samples were collected from the middle of the lake, near domestic and aquaculture cage areas. TSI analysis shows that Maninjau Lake was hypereutrophic, with an average TSI of 101.15. The phytoplankton community comprises six classes and 22 species dominated by *Microcystis aeroginosa* and *Synedra acus*. Bacillariophyceae had the highest phytoplankton concentration, while Cyanophyceae had the highest density. The diversity and equity index of the phytoplankton community structure were low and less evenly distributed, confirming that the lake was hypereutrophic. The highest diversity index was found in the middle of the lake or the most profound part, while the lowest was near the domestic area. Among the physicochemical parameters, transparency has a strong correlation with dominant phytoplankton.

Keywords: Eutrophication; Maninjau Lake; physicochemical; phytoplankton; trophic state index (TSI).

INTRODUCTION

It is commonly known that phytoplankton is the primary producer in aquatic ecosystems and plays a vital role in maintaining freshwater ecosystem health (Sharma et al., 2016). The structure of the phytoplankton community is influenced by several physical, chemical, and biological factors. Nutrients are often considered a critical factor controlling phytoplankton abundance, growth, and metabolism. The excessive nitrogen and phosphorus input is the primary source for lakes changing from an oligotrophic to a hypertrophic condition (Li et al., 2017). As a result, changes in the composition of phytoplankton species and a rise in biovolume are followed by reduced water clarity, unpleasant odors, oxygen depletion, and biodiversity loss (Kolzau et al., 2014). The dynamics and structure of phytoplankton, which are generally represented by chlorophyll-a concentrations, are controlled by the physicochemical parameters of the waters (Li et al., 2017). Therefore, phytoplankton can be a biological parameter used to evaluate water quality before reaching conditions that appear to be extreme such as eutrophication (Vajravelu et al., 2018).

A few papers have reported the physiochemical parameter characteristics of Indonesian lakes located in tropical areas. These deep, oligomictic, or meromictic lakes are subjects that inevitably impact human activities and climate warming (Fukushima et al., 2018). As a tropical country, Indonesia has tiny annual temperature variations and differences in surface and bottom water temperatures (Tonolla et al., 2017). As is known, the variation of temperature cause the change in density gradient in the water column and will change the intensity and duration of mixing, stability of temperature, and thermocline afterward (Mosello et al., 2018).

Maninjau Lake, located in West Sumatra, has become one of the top 15 Indonesian lakes that must be preserved because of its important role, i.e., as a hydroelectric power plant, capture fishery, tourism, and fish farming with the aquaculture cage (Kementerian Lingkungan Hidup Republik Indonesia, 2015). The lake temperature is 26.5 to 30 °C from the surface to the bottom, with a 3.5 °C difference (Nomosatryo, 2016). Meanwhile, very high pH and DO values were recorded in 2008, 2009, and 2011, suggesting that the lake experiences eutrophication. Wind speed over the lake can be faster than 10.4 m s^{-1}. In this case, mixing and dilution occur across the water body (Fukushima et al., 2018). Mixing will cause nutrients and other dissolved substances to be raised to the surface, degrading water quality.

Maninjau Lake is presently one of the priority lakes to be protected, so it is necessary to estimate the impact of increasing aquaculture and anthropogenic activities around the lake on aquatic ecosystems, especially on the dynamics of phytoplankton. Regarding its function in food webs and lake productivity, understanding the dynamics of phytoplankton due to changes in environmental conditions is crucial. Therefore, this study aims to determine the dynamics of phytoplankton's diversity, composition, and abundance in response to various environmental parameters during the dry season due to activities around the lake.

MATERIALS AND METHODS

Study area

Maninjau Lake is located in the district of Tanjung Raya, Agam Regency, West Sumatera Province, Indonesia, at points of S: 00°12'26.63" – S: 00°25'02.80" and E: 100°07'43.74" – E: 100°16'22.48" (Fig. 1) at an altitude of elevation at 461.50 m above the sea level. The lake is 9.737.50 acres, 7.5 km wide, and has a maximum depth of 168 m. Its average depth is 105.2 m and its volume is 10,226,001,629.20 m^3 (Balai Wilayah Sungai Sumatera V, 2016) The average wind speed in Maninjau Lake ranges from 0.0 to 0.3 m/s. The rainfall data from the Manggopoh Batang Antokan Station 1982–2012 shows that the monthly rainfall pattern is spread relatively during the year. With an annual rainfall of 9,122.4 mm, the average monthly rainfall is 325.8 mm. November has the higher rainfall, while June has the slightest rain. About 23,359 aquaculture cages around the lake were reported in 2022, and it has increased considerably since its establishment in 1992 (Hendra, 2022).

Sample collection

Water samples were collected at three time points from April to July 2018. The sampling location was decided considering lake water usage, near the pollutant source, the middle of the lake, and the lake inlet and outlet. Samples were taken at seven stations consisting of 2 stations each at the lake inlet and outlet and five stations at the lake, conducted from April to July 2018 (Fig. 1). The water samples were collected at three time points from April to July 2018. Water sampling used a vertical water sample carried out in a depth composite referred to Indonesian National Standard (Badan Standardisasi Nasional, 2008). The samples were taken from all stations to measure the total phosphorus (TP), total nitrogen (TN), and chlorophyll-a concentration. Phytoplankton sampling was conducted at three stations in the lake, representing the nearest polluted and non-polluted locations, i.e., the domestic area, the aquaculture cage, and the middle of the lake stations. During the sampling activity, some parameters included Secchi depth (transparency), temperature, pH, and dissolved oxygen (DO) directly carried out. A description of the physical conditions of each sampling station can be seen in Table 1.

Physicochemical parameters

The physicochemical parameters were measured in situ using LUTRON DO-5510 to measure the DO level and temperature. The HI 9813-5 pH meter was used for measuring pH, and a Secchi disk was used to measure the transparency of water. TN, TP, and chlorophyll-a were measured accordingly based on the standard methods for water and wastewater examination (Standard Methods for the Examination of Water and Wastewater, 2017).

The chlorophyll-a concentration was calculated using Stricland and Parson's (Standard Methods for the Examination of Water and Wastewater, 2017) formula (Eq. 1). The TN, TP, and chlorophyll-a analysis was conducted in the Water Laboratory in the Department of Environmental Engineering Faculty of Engineering of Universitas Andalas.

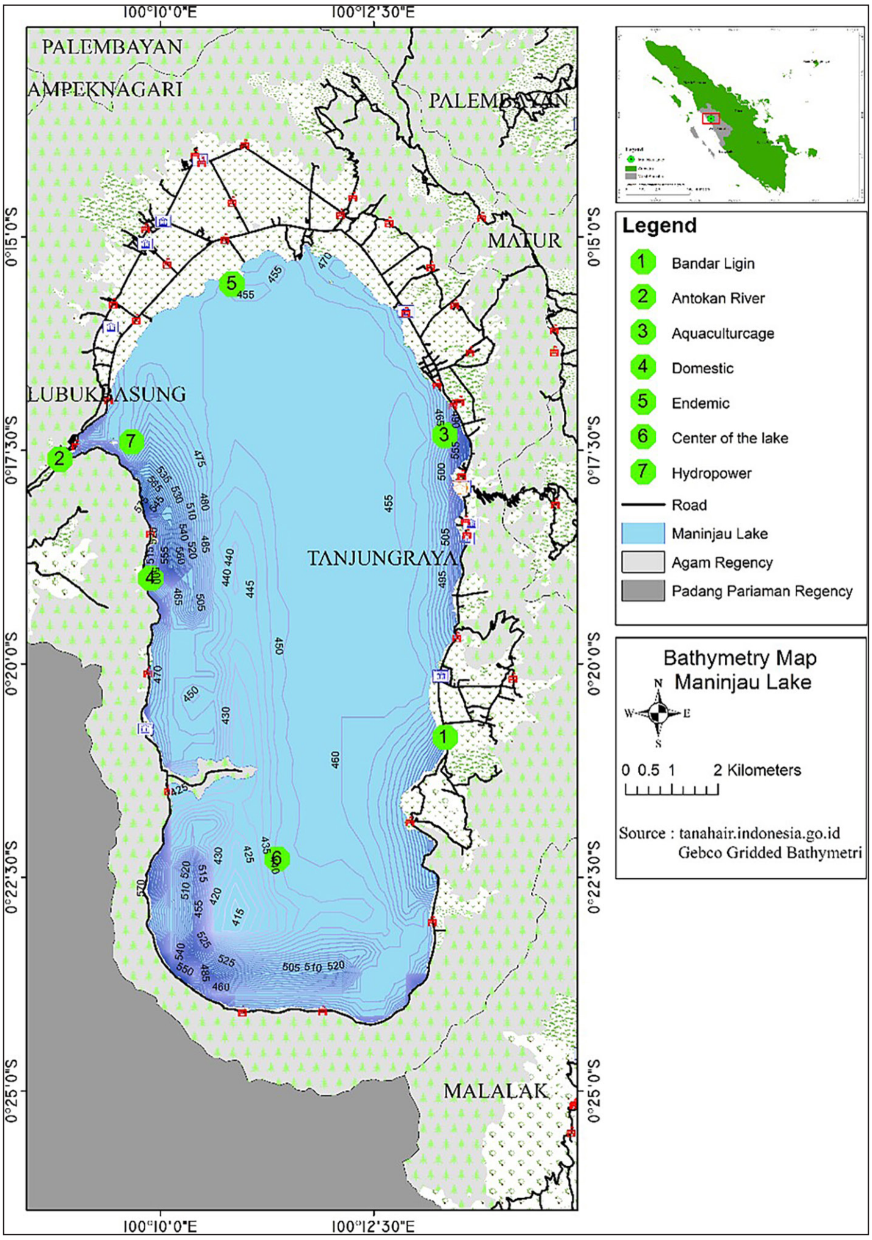


Figure 1. Bathymery map of Maninjau Lake, West Sumatera. (1) Bandar Ligin; (2) Antokan River; (3) aquaculture cage; (4) domestic area; (5) endemic fisheries area; (6) middle of the lake; 7. hydropower

Table 1. Description of the sampling stations in Maninjau Lake

Station	Sampling location	Geographical position	Description
1	Bandar Ligin	S: 00º20'51,6" E: 100º13'20,4"	Inlet of the lake, agriculture, densely populated settlement
2	Antokan River	S: 00º17'36,1'' E: 100º08'49,5''	Outlet of lake
3	Aquaculture cage	S: 00º13'13,3" E: 100º10'08,8"	Densely aquaculture cage
4	Domestic	S: 00º18'59,9" E: 100º09'53,3"	Densely populated settlement areas
5	Endemic	S: 00º15'33,2" E: 100º10'50,5"	Endemic fisheries areas
6	Middle of the lake	S: 00º22'17" E: 100º11'22,3"	The deepest part of the lake
7	Hydropower	S: 00º17'24,1" E: 100º08'58,8"	Hydropower intake, conservation area, tourist area

$$\text{Chlo-a} = \frac{((11{,}05 \times \text{E664}) - (1{,}54 \times \text{E647}) - (0{,}08 \times \text{E630}))}{\text{Vs} \times \text{d} \times \text{Ve}} \quad (1)$$

where: Chlo-a – chlorophyll-a (µg/L);
E664 – absorbance 664 nm 750 nm;
E647 – absorbance 647 nm 750 nm;
E630 – absorbance 630 nm 750 nm;
Ve – volume of acetone extract (ml);
Vs – volume of filtered water sample (L);
d – cuvette diameter (cm)

Trophic status analysis

The modified Carlson method was used to determine the trophic status index (TSI) of the water (Lyu et al., 2022). The following equations were used to compute the TSI based on the values for TP, chlorophyll-a, and Secchi depth.

$$\text{TSI (Chl)} = 10 \times \left(2.46 + \frac{\ln(\text{Chla})}{\ln 2.5}\right) \quad (2)$$

$$\text{TSI (TP)} = 10 \times \left(2.46 + \frac{6.71 + 1.15 \times \ln(\text{TP})}{\ln 2.5}\right) \quad (3)$$

$$\text{TSI (SD)} = \left(2.46 + \frac{3.69 - 1.52 \times \ln(\text{SD})}{\ln 2.5}\right) \quad (4)$$

$$\text{TSI (Ave)} = 0.54 \times \text{TSI (Chla)} + 0.297 \times \text{TSI (SD)} + 0.163 \times \text{TSI (TP)} \quad (5)$$

Where the TSI scores of the three indicators [Eq. 2, 3, and 4] vary, and the average TSI score is based on the TSI chlorophyll-a, TP, and Secchi depth [Eq. 5] obtained to determine the trophic state of water. TN is not included in these calculations since it's considerably a weak indicator that contributed to eutrophication. It can sometimes be included if the TSI scores are incompatible, such as where the lake condition has a problem with the invasion of macrophytic or when N is examined as a limiting factor (Nomosatryo, 2016). The TSI scores are classed based on the standard trophic categories (Lyu et al., 2022). An oligotrophic TSI < 30, mesotrophic $30 \leq \text{TSI} < 50$, light eutrophic $50 \leq \text{TSI} < 60$, moderately eutrophic $60 \leq \text{TSI} < 70$, and hypereutrophic $\text{TSI} \geq 70$.

Phytoplankton analysis

Phytoplankton sampling refers to Ecological Methods for Field and Laboratory Investigation (Michael, 1984). In each sampling location (Table 1), water samples were taken from the surface water (0 m depth) and incubation zone (Secchi depth) during optimal sunlight (9.00 am to 2.00 pm). Surface water samples were collected from 100 liters of water using a 10-liter bucket (ten replications). Samples were filtered using a plankton net with a mesh size of 25 microns. The filtered sample water was put into a 100 ml sample bottle and preserved using Lugol. Water samples were stored in a cool box, then brought to the laboratory and stored in a refrigerator.

Determination of phytoplankton communities and physico-chemical parameters from water samples was conducted at the Laboratory of Ecology, Department of Biology, Universitas Andalas. Phytoplankton samples were observed with a Binocular XSZ 107BN Yazumi Microscope with 10x40 magnification. Species identification was done according to Baker & Fabbro (1999), Prescott (1951), Scott & Prescott (1961), Yamaji (1980), and Bold & Wynne (1978). Online databases (Algaebase.org) were also used for identification.

Phytoplankton density is the number of individuals taken from 100 L of water through a phytoplankton net. The density obtained was used to determine the number of species densities that dominate or the species diversity in a class. Phytoplankton density was calculated using Equation (6).

$$K = \frac{a \times c}{l} \quad (6)$$

where: K – density of phytoplankton (ind/L);
a – the average number of individuals of a species in 1 ml;
c – volume of sample concentrate;
l – volume of filtered water.

The determination of relative density (RD) refers to Eq. 7. Relative density is a percentage of the phytoplankton density.

$$RD(\%) = \frac{\textit{density of species}}{\textit{density of all species}} \times 100\% \quad (7)$$

To determine the diversity of phytoplankton, the diversity index (H') was used as shown in Eq. 8. The diversity index obtained can be classified as low diversity if $H' < 2.3026$, with medium for $2.302 < H' < 6.078$ and high for $H' > 6.078$ (Michael, 1984).

$$H' = -\sum_{i=l}^{s} p_i \ln p_i \tag{8}$$

where: H' – diversity index;
$p_i – n_i/N_i$ (ratio of a species with all species);
S – number of all species (ind/L).

The similarity index (SI) was determined using Equation 9. The similarity index shows the similarity in the presence of phytoplankton between the two stations being compared. The results obtained were classified into two criteria: the same if the SI > 50% and not the same if SI < 50% (Michael, 1984).

$$SI = \frac{2C}{A+B} \times 100\% \tag{9}$$

where: C – number of types that are equally present at the two stations being compared;
A – total of a species at station A;
B – total of a species at station B.

The equity index (E) is calculated to determine the level of uniformity of the phytoplankton in the waters calculated by Equation 10. The results obtained ranged from 0–1 with several classifications, namely uneven if the value of E is in the range 0.0–0.25, less even at 0.26–0.50, fairly even at 0.52–0.75, almost even at 0.76–0.95, and even at 0.96–1.0 (Poole, 1974).

$$E = \frac{H'}{Hmax} \tag{10}$$

where: E – index of uniformity;
H' – Shannon-Wienner diversity index;
$Hmax$ = ln$s$ (s – number of species).

Correlation of phytoplankton and physicochemical parameters

The simple linear regression method was used to analyze the correlation of environmental physicochemical parameters to the concentration of chlorophyll-a and phytoplankton density. Environmental physicochemical parameters include transparency, temperature, pH, DO, and nutrients (TN and TP). Furthermore, the correlation between physicochemical parameters and chlorophyll-a, as well as phytoplankton density, was determined through the correlation coefficient (r).

RESULTS AND DISCUSSION

Physicochemical parameters of Maninjau Lake

The physicochemical parameters of lake water at each sampling station in Maninjau Lake were almost similar (Table 2). The temperatures ranged from 27.17 to 31.47 °C, and the pH ranged from 8.09 to 9.2. There tended to be alkaline waters and high dissolved oxygen at the water surface, i.e., 6.5–8.83 mg/L, indicating high photosynthetic activity by the phytoplankton. The DO range of 6.5–8.83 mg/L and pH 8.09–9.2 in lake water shows high dissolved oxygen and alkaline, indicating photosynthesis.

During the day, due to photosynthesis, the carbon dioxide was depleted and produced dissolved oxygen. Therefore the pH and DO of the water increase (Khattab & Merkel, 2015). It was also strengthened by Henny et al. through the observations made during 2005–2011, showing that DO in the surface water ranged between 9–11 mg/L. DO was then reduced to a 20 m depth to reach anoxic conditions (Nomosatryo, 2016).

Meanwhile, the pH of the surface was gradually raised from 9–11, and at the below, it decreased to 7–6. It shows photosynthesis still occurs, although the pH and DO values have decreased slightly. The Secchi depth was low, only reaching a maximum of 1.4 m depth. Low Secchi depth means that photosynthesis only takes place at the depth that the light penetrates. The TN concentration ranged from 0.80 to 1.12 mg/L, the TP concentration ranged from 0.28 to 0.58 mg/L, and the chlorophyll-a concentration ranged from 0.6 to 0.98 mg/L. High TN and TP concentrations in inlet and outflow rivers (stations 1 and 2) were produced by anthropogenic activities such as household and agricultural activities, which contribute to nutrient intake into the river. Meanwhile, except for hydropower, the TN and TP concentrations in the lake region at the other stations (aquaculture cage, residential, endemic fisheries areas, and lake center stations) are high and even. Waters near residential areas (station 4) had the highest TN concentration, whereas the aquaculture cage (Station 3) had the lowest. All TP concentrations in all locations have exceeded Government Regulation Number 82 of 2001 on Water Quality Management and Water Pollution Control for Class 2 (Pemerintah Republik Indonesia, 2021). While TN concentrations still meet the standard quality of the Ministry Regulation of

Table 2. Physicochemical parameters of each station

Parameter	Station						
	1 (Mean±SD)	2 (Mean±SD)	3 (Mean±SD)	4 (Mean±SD)	5 (Mean±SD)	6 (Mean±SD)	7 (Mean±SD)
TN (mg/L)	1.12±0.02	1.07±0.01	0.94±0.01	1.02±0.01	0.94±0.01	0.92±0.01	0.80±0
TP (mg/L)	0.49±0	0.42±0.06	0.58±0.03	0.43±0.02	0.51±0	0.44±0.02	0.28±0.04
Chl-a (mg/L)	0.95±0.09	0.6±0.05	1.05±0.03	0.98±0.05	0.76±0.03	0.78±0.04	0.81±0.05
SD (m)	0.6±0	0.73±0.04	1.33±0.04	$1.4\pm2{,}22\times10^{-16}$	1.37±0.12	1.13±0.04	1.3±0
Temperature (°C)	27.17±2.35	29.67±1.99	28.13±0.18	31.47±0.28	31.23±0.36	30.4±0.43	29.93±0.26
DO (mg/L)	7.43±0.24	6.5±0.29	7.9±0.14	8.83±0.09	7.5±0.6	8.5±0.14	8.5±0.08
pH	8.09±0.5	8.37±0.02	9.2±0.27	8.57±0.11	9.4±0.27	9.03±0.26	8.76±0.04

Environmental and Forestry (Kementerian Lingkungan Hidup dan Kehutanan, 2009). Compared to previous studies in 2015 the Sechi depth values, TN and TP parameters i.e. 5.1 to 0.8 m, 0.582–1.299 mg TN/L, 0.03–0.075 mg TP/L respectively (Sulastri et al., 2015) were lower than those in the present study. Sechi depth values were recorded as increased i.e. 1.4 to 0.6 m depth. An increase in the value of these parameters indicates a decrease in water quality and the tropical state of the lake. Aquaculture activities such as fish cage farming have an impact on water quality, as evidenced by significantly higher levels of nitrates, phosphates, and TDS in aquaculture sites, as well as continued low DO and transparency values (Querijero & Mercurio, 2016).

Fish feed waste released from aquaculture results in high levels of TN and TP in the water. TP played the major trigger for the blooming of toxic Mycrocystis, which is very dangerous to aquatic biota (Vajravelu et al., 2018b). The uncontrolled growth of the aquaculture and the turnover that lifts toxic compounds such as ammonia and hydrogen sulfide from the bottom to the water surface (Lukman et al., 2013) may cause death to the fish. There have been numerous documented instances of fish deaths brought on by declining lake water quality (Nomosatryo, 2016).

Trophic status

Maninjau Lake's Trophic State Index (TSI) was calculated according to Lyu (Lyu et al., 2022) can be seen in Table 3. The TSI for TP is 168.77–177.76, with the highest location in fish cages and the lowest in hydropower. Chlorophyll-a has the highest TSI in the Bandar Ligin River with a value of 102.36, and the lowest is in hydropower. The location with the most increased transparency is the same as the highest TN and chlorophyll site, i.e., the Bandar Ligin River, with a value of 73.34, and the lowest is domestic areas, with an index of 59.29. The total TSI of all stations shows that Maninjau Lake is hypertrophic, ranging from 94.46 to 114.16. The highest trophic status index was at station 2, Batang Antokan, with a TSI of 114.16. Overall, the average trophic status index in Maninjau Lake is 107.16, indicating that the lake is hypertrophic, and this state has spread evenly throughout the Maninjau Lake area. Visually, this condition is emphasized by green waters in almost all lake areas.

Henny et al. revealed that the trophic status of Maninjau Lake from 2008 to 2013 was still eutrophic (Nomosatryo, 2016). However, in July 2013, Maninjau Lake's trophic status increased to heavily eutrophic with a TSI average

Table 3. Trophic state index of Maninjau Lake

Stations	TSI (TP)	TSI (Chl)	TSI (SD)	TSI (Ave)	Trophic Status
1	175.68	102.36	73.34	94.46	Hypereutrophic
2	173.76	101.64	70.09	114.16	Hypereutrophic
3	177.76	101.26	60.14	110.95	Hypereutrophic
4	174.03	99.53	59.29	110.95	Hypereutrophic
5	176.20	99.19	59.65	100.00	Hypereutrophic
6	174.36	98.81	60.14	111.10	Hypereutrophic
7	168.77	96.24	60.52	108.51	Hypereutrophic
Ave TSI	174.37	99.86	63.31	107.16	Hypereutrophic

score of 77.58–80.08 (Syandri, 2016). Lake TSI increases with increasing levels of nitrogen and phosphorus nutrients resulting from fish excretion and excessive fish feed. Compared to the previous study, the current TSI study is way higher. The rapid increase in the number of fish cages is a crucial cause of excess nutrients and the accompanying degradation in lake water quality. A similar condition occurs at Lake Cilala in Bogor Regency, West Java, where fish farming activities caused poor water quality (Wisnu et al., 2019).

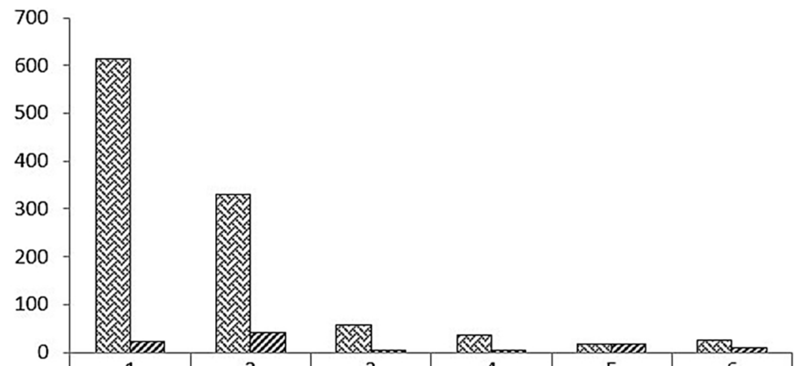
Composition of phytoplankton communities

The phytoplankton abundance and composition during the study are shown in Table 4. The phytoplankton found in Maninjau Lake consists of 6 classes and 22 species, namely Bacillariophyceae/diatoms (9 species), Chlorophyceae (4 species), Cyanophyceae (5 species), Desmideaceae (2 species), Dinophyceae (1 species), and Rhodophyceae (1 species). The phytoplankton density at each station obtained did not differ significantly between the lake's middle and the domestic station, i.e., 130.8 ind/L and 126.4 ind/L. The Aquaculture Cage Station had a lower density of 64.8 ind/L. Although the density was different, the species were still dominated by *Microcystis aeroginosa* from the Cyanophyceae class and *Synedra Acus* from the Bacillariophyceae class. The highest density of *M. aeroginosa* was at the Domestic Areas Station, followed by the Middle of the Lake and Aquaculture Cage Stations. *S. Acus* was found in the middle of the Lake and Domestic Area Stations but not at Aquaculture Cage Station. The phytoplankton distribution from all stations is represented in Figure 2. The phytoplankton density of each class obtained in this study, i.e., Cyanophyceae 613.8 ind/L, Bacillariophyceae 331.2 ind/L, Dinophyceae 57 ind/L, Rhodophyceae 37.2 ind/L, Desmidiaceae 24.6 ind/L, and Chlorophyceae 16.8 ind/L, respectively.

Table 4. Phytoplankton genera identified in Maninjau Lake

Phyla	Genera
Bacillariophyceae	1. *Gomphonema lanceolatum*
	2. *Cymbella turgidula*
	3. *Navicula distans*
	4. *Staurastrum planctonicum*
	5. *Navicula placentula*
	6. *Synedra acus*
	7. *Synedra ulna*
	8. *Fragilariopsis cylindrus*
	9. *Thalassiothrix antarctica*
Cyanophyceae	1. *Merismopedia punctata*
	2. *Chroococcus dispersus*
	3. *Microcystis aeruginosa*
	4. *Anabaena planctonica*
	5. *Chroococcus turgidus*
Chlorophyceae	1. *Micractinium pussilum*
	2. *Scenedesmus acutus*
	3. *scenedesmus ecornis*
	4. *Pachycladon umbrinus*
Desmidiaceae	1. *Staurastrum paradoxum*
	2. *Staurastrum spiniceps*
Dinophyceae	1. *Peridinium lubiniensiforme*
Rhodophyceae	1. *Porphyridium purpureum*

The high phytoplankton density did not indicate that the distribution of phytoplankton



	1	2	3	4	5	6
Density (Ind/L)	613.8	331.2	57	37.2	16.8	24.6
Species distribution (%)	23	41	4	5	18	9

Figure 2. Density and species distribution of phytoplankton, (1) *Cyanophyceae*, (2) *Bacillariophyceae*, (3) *Dinophyceae*, (4) *Rhodophyceae*, (5) *Chlorophyceae*, (6) *Desmidiaceae*

species was also increased. Referring to the species distribution of each class, Bacillariophyceae had the highest distribution percentage of 41%, while the lowest was the Dinophyceae at 4%. Cyanophyceae had the second-largest species distribution at 23%. followed by Chlorophyceae at 18%, Desmideaceae at 9%, Rhodopyceae at 5%, and Dhynopyceae at 4%.

Of the 22 identified phytoplankton species, it was found that the predominant phytoplankton in this study was Cyanophyceae and Bacillariophyceae. There were some changes in phytoplankton composition compared to the previous research. In 2001 and 2005, the dominant species was Chrysophyceae followed by Chlorophyceae, while in 2009 and 2014, the dominant species was Cyanophyceae (Sulastri et al., 2015). The number of species found in this study was lower when compared to the previous research (Merina et al., 2014), which recorded six classes and 94 species, namely Bacillariophyceae (17 species), Chlorophyceae (51 species), Cyanophyceae (17 species), Euglenophyceae (5 species), Dinophyceae (3 species), and followed by Chrysophyceae (1 species). The same class in this study is Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Dinophyceae.

There was a shift in the dominant microorganisms from 2001 to 2005, which were initially Chrysophyceae followed by Chlorophyceae, but from 2009 until the present study, the dominant species were Cyanophyceae and Bacillariophyceae. Physicochemical changes in water are considered to play an essential role in phytoplankton dynamics. pH levels that tend to be alkaline and high nutrient content are the main factors for changes in the composition and structure of phytoplankton. Similarly, a significant shift from diatom-rich phytoplankton to cyanobacterial phytoplankton has occurred in Lake Edward (East Africa), altering the algal biodiversity [Stoyneva-Gärtner et al., 2020]. The high number of heterocytous cyanobacteria and a relatively high C: N ratio suggest both N and light limitation, which is most severe at pelagic parts.

The following factors play a significant role in the predominance of bloom-forming Cyanophyceae, also known as Cyanobacteria or blue-green algae commonly found during the summer season, i.e., when water temperature higher than 25°C, low light intensity in water, low N:P ratio, and stability of the water column (Joanna et al., 2003). A Swedish national research project found that when the TP levels were higher than 20 µg/L or when the TN levels were higher than 500 µg/L, it indicated a higher risk of health-related problems connected with *Cyanobacteria* (Vajravelu et al., 2018a).

The dominance of *M. aeroginosa* from the Cyanophyceae class was due to the eutrophication in Maninjau Lake. If bloom occurs, it leads to various issues, such as turbidity in water, a decrease in species diversity of the phytoplankton and other organisms, and high primary production, respiration, and oxygen consumption. This then leads to creating the anoxic zone, the hydrogen sulfide at the bottom side will also be produced throughout the process and, in the end, will cause bad odors, followed by various toxins (Bukowska et al., 2017). Some toxins from phytoplankton harm aquatic organisms, even humans and animals that consume them.

A similar report was stated by Gilbert et al. that Cyanophyceae is classified as dangerous because it can cause Harmful Algal Blooms (HABs) and secrete a toxin that can kill fish (Glibert, P.M. et al., 2017). In contrast to *M. aeruginosa*, *S. acus* has a beneficial impact on aquatic biota as a food source for young and adult fish. Simultaneously, *S.acus* is helpful for fisheries and a biological indicator of pollution (Kumar & Jha, 2015). Synedra biomass reaches its maximum during a spring diatom bloom in Lake Paldang, Korea, at higher temperatures and Silicon: TP ratio >20 (Youn et al., 2020).

One of the phytoplankton groups that are commonly found in various water conditions is Bacillariophyceae. Bacillariophyceae is found in almost every sampling location with high nutrient levels, where the concentrations of TN and TP are hypereutrophic. Bacillariophyceae or diatom assemblages can live in any condition, even in extreme conditions, and adapt quickly (Mancuso et al., 2021). Cyanobacteria, which act as the primary producers, are predominant in surface waters but fall dramatically in summer and autumn in deeper waters. This dominant group in surface waters is due to its ability to carry out photosynthesis and nitrogen fixation in aerobic conditions (Yu et al., 2014). Chlorophyceae are found in sufficient light-intensity water, with the Dinophyceae class as the lowest percentage. This class is commonly found in sea waters (Pratiwi et al., 2018) and well-oxygenated waters with various pH and light conditions. Because of this reason, they are classified as oligotrophic environmental indicators (Pratiwi et al., 2018). Along with nutrients, water variables like inflow rate and retention time play an important role in controlling the growth of phytoplankton, biomass, and composition. In addition, variables like the suspended sediments that are carried out also affect the phytoplankton growth and photosynthesis process due to high turbidity and disturbance of lights (Pathak et al., 2021).

Phytoplankton community structure

The structure of the phytoplankton community was determined through the index value of diversity, similarity, and equability. The phytoplankton diversity index (Table 5) ranges from 1.42 to 2.20.

The phytoplankton similarity index in Maninjau Lake was 80–88.23%. The overall similarity index value indicated >50%, showing the similar station community composition. The equity index ranged from 0.27 to 0.41, with the highest value at the center of the Lake station, i.e., 0.41, followed by the aquaculture cage station at 0.36. the lowest was at the domestic station at 0.27. The most dominant species were *M. aeroginosa* from the Cyanophyceae class and *S. Acus* from the Bacillariopyceae class, which were considered to inhibit the growth of other species, although not eliminate them.

The phytoplankton diversity index in Maninjau Lake obtained, i.e., 0.27 to 0.41, is relatively low, while the equity index value ranges from 0.26 to 0.50, which means the uniformity is fairly even (Odum & Odum, 1959). The diversity index value of the middle lake station was higher than that of the fish cage and the domestic areas station. This indicates that the biodiversity in the middle of the lake with the most increased depth (pelagic zone) is better than in the shallow part (littoral site), i.e., the fish cage and the domestic areas station. Even though all stations, including those in the middle of the lake, are in the hypertrophic category, the levels of TN and TP in the middle of the lake are lower than in the other locations. On the contrary, the diversity index in the middle of the lake, which is the deeper part, was higher than in the shallower parts. The existence of fish cages in practically all regions of the lake contributes to the fact that the diversity index values in all lake locations are not considerably different. This result is in line with research in Lake Champlain that more profound parts of the lake are less susceptible to cyanobacteria blooms due to less favorable nutritional and physical conditions for cyanobacteria compared to shallow locations [Bockwoldt et al., 2017]. The majority of diatom assemblages from more eutrophic lake areas were found near more densely populated areas, while the majority of diatom assemblages from more oligotrophic lake areas were found in places with lower population density. The diversity of phytoplankton species is low due to exclusion competitiveness among species (Bužančić et al., 2016).

Table 5. Diversity index

Station	Diversity index (H')	E
Center of the lake	2.20	0.41
Cage aquaculture	1.82	0.36
Domestic	1.42	0.27

Note: *H'* Low: < 2.3026, Medium: 2.302 < *H'* < 6.078, and High: > 6.078 (Michael, 1984).
E uneven: 0–0.25, less evenly distributed: 0.26–0.50, fairly even 0.51–0.75, almost even: 0.76–0.95; and evenly distributed: 0.96–1 (Poole, 1974).

Based on the TSI, Maninjau Lake was hypereutrophic (107.16), which indicates that nutrients have heavily polluted the water. Although the physicochemical conditions obtained were still satisfying for certain species, there was a low species diversity, i.e., Dinophyceae, Rhodophyceae, Chlorophyceae, and Desmidiaceae. This low diversity value is related to the predominance of certain phytoplankton species, i.e., Bacillariophyceae and Cyanophyceae classes. Species diversity and community composition are affected by several physicochemical parameters and eutrophication. Due to eutrophication, the biomass of phytoplankton raised in numbers. However, its community composition remains homogeneous. It was discovered that cyanobacterial blooms were associated with decreased abundance of other phytoplankton species. However, Krasznai's study in sixty distinct types of surface water (reservoirs, oxbows, and gravel pit lakes) in Hungary discovered that rising cyanobacterial density had no negative effect on the species diversity of non-cyanobacterial assemblages (Krasznai et al., 2022). The study also revealed that the formation of cyanobacterial blooms caused shifts in species and compositional characteristics of phytoplankton assemblages.

Correlation of phytoplankton and chlorophyll-a with the physicochemical parameters

The correlation of phytoplankton and chlorophyll-a with the physicochemical conditions has been shown in Table 6.

The transparency parameter positively correlates with Cyanophyceae, Chlorophyceae, and Desmidiaceae. There is a strong relationship between the transparency of Cyanophyceae with an r-value of 0.9592. A positive relationship occurs between temperature for Cyanophyceae, Bacillariophyceae, Dinophyceae, and Desmidiaceae. Dinophyceae is a class with a significant correlation with temperature, with a correlation value of 0.8302. The same condition occurred between DO and Dinophyceae, which had a strong and positive relationship with an r-value of 0.8004. Only the Cyanophyceae class negatively correlates with the pH parameter, but the r-value shows a strong relationship, namely 0.7972. TN and TP showed the highest correlation values with chlorophyll-a and phytoplankton, but this negatively correlated with the *Bacillariophyceae* class. Chlorophyll-a concentration and phytoplankton density increased with the increasing TN and TP in the waters. There was a decrease in species or phytoplankton diversity, and the trophic state was increased.

Increasing values of TN and TP showed a high correlation with the existence of chlorophyll-a and phytoplankton. However, negatively correlated with the Bacillariophyceae class. There is a finding of decreasing state of phytoplankton's diversity and an increasing state in tropic status. This case happened when phytoplankton are stressed and cannot live in high eutrophic conditions due to toxins from Mycrocistis blooming (Sulastri et al., 2019). Water transparency also influenced the presence of chlorophyll-a and phytoplankton in the water. There are some negative correlations with clarity, namely Bacillariophyceae, Dynophyceae, and Rhodopyceae, while strong positive with Cyanophycae. The effects of algal blooms can vary depending on plankton structure, biodiversity, and ecosystem functioning. Ten tropical water reservoirs in Pernambuco state, Northeast, Brazil were reported during Cyanobacteria and combined blooms (Cyanobacteria plus Bacillariophyta, Chlorophyta, and/or Dinophyta), there was an intense deterioration of water quality, including higher pH, eutrophication, stratification, and lower water transparency. In contrast, Chlorophyta and Dinophyta blooms showed lower pH, eutrophication, stratification, and higher water transparency (Amorim & Moura, 2021). The results showed no association between phytoplankton growth and pH level, as both high and low individuals were detected at the same pH level. Nutrients like TN and TP were relatively high, although phytoplankton biomass and Chlorophyll-a were fairly low, and diatoms continued to dominate the phytoplankton in Karkamis Dam Lake (Sonmez et al., 2017). These data imply that factors other than nutrients may influence phytoplankton dynamics in Karkamis Dam Lake.

The temperature correlates moderately with chlorophyll, is strong on Dinophyceae, and weak on Desmidiaceae, and Cyanophyceae. Meanwhile, the temperature is reversed with Rhodophyceae, Chlorophyceae, and Desmidiaceae. Despite being controlled by temperature, phytoplankton's composition is influenced by light underwater, nutrients, wind speed, and direction (Zhou et al., 2021). Previous research revealed that solid content in lake water was high, 462-850 mg/L, and low Secchi disc values (Komala et al., 2019). During high turbidity, phytoplankton may avoid surface water since it has higher light intensity and instead moves to the bottom or floats upwards under poor underwater light conditions (Teubner et al., 2020).

Table 6. Correlation of chlorophyll-a and phytoplankton with the physicochemical environmental conditions

Specification	Secchi depth	Temperature	DO	pH	TN	TP
Chl-a (µg/L)	0.5798	*0.608	-0.4359	0.5374	*0.901	*0.6416
Cyanophyceae	*0.9592	0.356	0.3932	*-0.7972	0.1213	0.2039
Bacillariophyceae	*-0.7178	0.0778	-0.0996	0.4616	-0.4273	-0.4676
Dinophyceae	-0.1647	*0.8302	*0.8004	0.3971	*0.7085	*0.671
Rhodophyceae	-0.0199	-0.584	0.5459	0.1556	*0.916	*0.8922
Desmidiaceae	0.0027	0.4952	0.4568	0.0967	*0.9586	*0.941

Note: * – strong correlation.

The higher the temperature is, the higher the growth rate of phytoplankton becomes, also, it depresses the growth of diatom species (Sugie et al., 2020). Phytoplankton blooming also occurs in lakes in the Bangladesh region. Besides being influenced by the high nutrient content, it is also supported by water temperature in the range of 28–30 °C. Referring to the previous statement, the temperature obtained in the study was within the optimal temperature range for phytoplankton growth.

DO was strongly correlated with Dinophyceae, moderate with Rhodophyceae, but weak against Cyanophyceae, Chlorophyceae, and Desmidiaceae. DO range from 6.50–8.83 mg/L exceeded the DO saturation value, indicating eutrophication. Lakes are characterized by DO, pH, turbidity, high TP, and low DIN due to primary production and large algal biomass (Cavalcante et al., 2016). It reported that the various behaviors of Dinophycaeae at different lake trophic and bathymetric statuses explain that this species is easily adaptable to diverse environmental conditions and demonstrates morphological variability. pH parameters played a significant role in phytoplankton's life. pH affected the density of phytoplankton and the concentration of chlorophyll-a. Also, it has been proven that the lower the pH, the higher the phytoplankton abundance. Under low pH, phytoplankton grows in low to moderate light levels. High pH pressure also accelerates the accumulation of lipids in phytoplankton's body (Alkhamis et al., 2022). Phytoplankton is a well-adapting organism to any changes in aquatic environmental conditions (Irwin et al., 2015). Physico-chemical factors, such as TN, TP, water temperature, pH, and dissolved oxygen, can significantly affect the number of phytoplankton communities. However, transparency is a parameter strongly correlated with the dominant phytoplankton in this study.

The development of the TSI value of Maninjau Lake in the last ten years increased from 77.58 - 80.08 to 101.15, indicating a continuous deterioration of water quality. This condition is characterized by increased physicochemical parameters (TN, TP, and Chlorophyll-a) and decreased transparency. Lake waters once intended for hydropower, capture fisheries, tourism, and fish farming are now unsuitable. Eutrophication-related water quality degradation in many lakes is usually associated with harmful phytoplankton blooms and enormous fish mortality. Climate change accelerates the spread of cyanobacterial blooms, which increase in frequency, volume, and length globally (Huisman et al., 2018).

The number of cages cultivated in Maninjau Lake recorded this year is 23,359 units, exceeding the number set by the government, which is 6,000 units (Kementerian Lingkungan Hidup Republik Indonesia, 2015). To minimize further deterioration of the lake's water quality, this number should be reduced in the future by its capacity. Furthermore, the influence of other climatic factors, such as wind speed, rainfall, and changes in water level, on the abundance of phytoplankton in the future also needs to be evaluated.

CONCLUSIONS

Lake Maninjau contains TN values ranging from 0.80 to 1.12 mg/l and TP concentrations ranging from 0.28 to 0.58 mg/l. This lake is hypereutrophic, with an average TSI of TSI (TP) 174.37, TSI (Chl) 99.86, TSI (SD) 66.31, and TSI (Ave) 107.16. The phytoplankton found in Maninjau Lake consists of 6 classes and 22 species, namely Bacillariophyceae (9 species), Chlorophyceae (4 species), Cyanophyceae (5 species), Desmideaceae (2 species), Dinophyceae (1 species), and Rhodophyceae (1 species). Although the highest quantity of phytoplankton is Bacillariophyceae, in terms of density, Cyanophyceae is the highest. The diversity and equity index of the phytoplankton community structure were low <2.3026 and less evenly distributed (0.27–0.4), indicating the lake experienced hypereutrophic. On Cyanophyceae and Bacillariophyceae as predominant species, the influence of TN and TP is not significant. Only transparency significantly correlates to the predominance classes, while temperature, DO, and pH was not substantial. However, increasing values of TN and TP showed a high correlation with the existence of chlorophyll-a and phytoplankton. So it can be concluded that several types of phytoplankton are influenced by environmental parameters such as TN, TP, temperature, DO, and pH. Monitoring the lake water quality is required to obtain the relationship between the data of the physicochemical parameters of the water and the types of phytoplankton that appears. To avoid an explosion of phytoplankton in the lake area, the quality standards for the TN and TP parameters must be strengthened.

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