EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(2), 272–280
https://doi.org/10.12912/27197050/176314
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Received: 2023.11.30
Accepted: 2023.12.15
Published: 2024.01.01

Identification of Environmental Factors Determining the Diversity and Abundance of Phytoplankton in Menjer Lake, Wonosobo, Indonesia

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ABSTRACT

Phytoplankton are primary producers in aquatic ecosystems, their abundance is determined by environmental changes, so phytoplankton are often used as bioindicators of waters. The aim of this research was to determine the diversity and abundance of phytoplankton in Menjer Lake, to measure the environmental factors that determine the diversity and abundance of phytoplankton, and to determine the environmental factors that most influence the diversity and abundance of phytoplankton in Menjer Lake. This research uses a survey method in 5 areas (inlet, middle of the lake, aquaculture using floating net cage, tourism, and outlet). The parameters observed were the diversity and abundance of phytoplankton as well as the concentration of water quality parameters that determine the presence of phytoplankton (temperature, light penetration, pH, DO, TSS, TDS, PO_4 and NO_3). To determine the environmental factors that most influence the diversity and abundance of phytoplankton were analyzed using the principal component analyses method with Past 4.10 software. The community structure of phytoplankton in Menjer Lake was dominated by Bacillariophyta (83%). The factors determining the development of phytoplankton in Menjer Lake are influenced most by light penetration and PO_4 concentration. The input of PO_4 concentration from the water catchment area must be controlled to prevent phytoplankton blooming in Menjer Lake.

Keywords: phytoplankton, Menjer Lake, water quality.

INTRODUCTION

Menjer Lake is located in Maron Village, Garung District, Wonosobo Regency, formed due to the eruption of Mount Pakuwaja which has been used as a hydroelectric power plant since 1982 [Amalia & Sudarmadji, 2016]. Apart from that, Menjer Lake is also used for tourism, agricultural irrigation and floating net cages (Kumalasari et al., 2015). Human activities often cause eutrophication problems with phytoplankton blooms. Eutrophication is the process of enriching nutrients, especially nitrogen and phosphorus, from human activities such as fisheries, agriculture and household waste (Piranti et al., 2018).

Phytoplankton in a body of water is influenced by several environmental parameters and physiological characteristics [Derot et al. 2019]. The composition and abundance of phytoplankton will change at various levels in response to changes in physical, chemical and biological environmental conditions [Mukharomah et al., 2018]. The factors supporting phytoplankton growth are very complex and interact with water physico-chemical factors such as temperature, light intensity, dissolved oxygen, and the availability of nitrogen and phosphorus nutrients [Mukharomah et al., 2018]. Phytoplankton have certain tolerance limits to physicochemical factors so that they will form different phytoplankton community structures. Community structure is the composition of a community including the number of species and their relative abundance. Community structure can be studied based on species diversity and relative abundance [Krebs, 2014].

The Menjer Lake has experienced quite high environmental quality degradation because many human activities use the lake, including for floating net cages and tourism [Kumalasari et al. 2015]. The water entering the lake comes from land in the catchment area carried by runoff water containing a number of nutrients [Piranti et al., 2023]. Therefore, in certain months there has been a phytoplankton bloom in Menjer Lake [Piranti et al., 2022]. It is possible that there have been changes in water quality and this will then be followed by changes in the composition and dominance of phytoplankton which can be used to describe the current water quality conditions of Menjer Lake.

The aim of this research was to determine the diversity and abundance of phytoplankton in Menjer Lake, to measure the environmental factors that determine the diversity and abundance of phytoplankton in Menjer Lake, as well as to determine the environmental factors that most influence the diversity and abundance of phytoplankton in Menjer Lake.

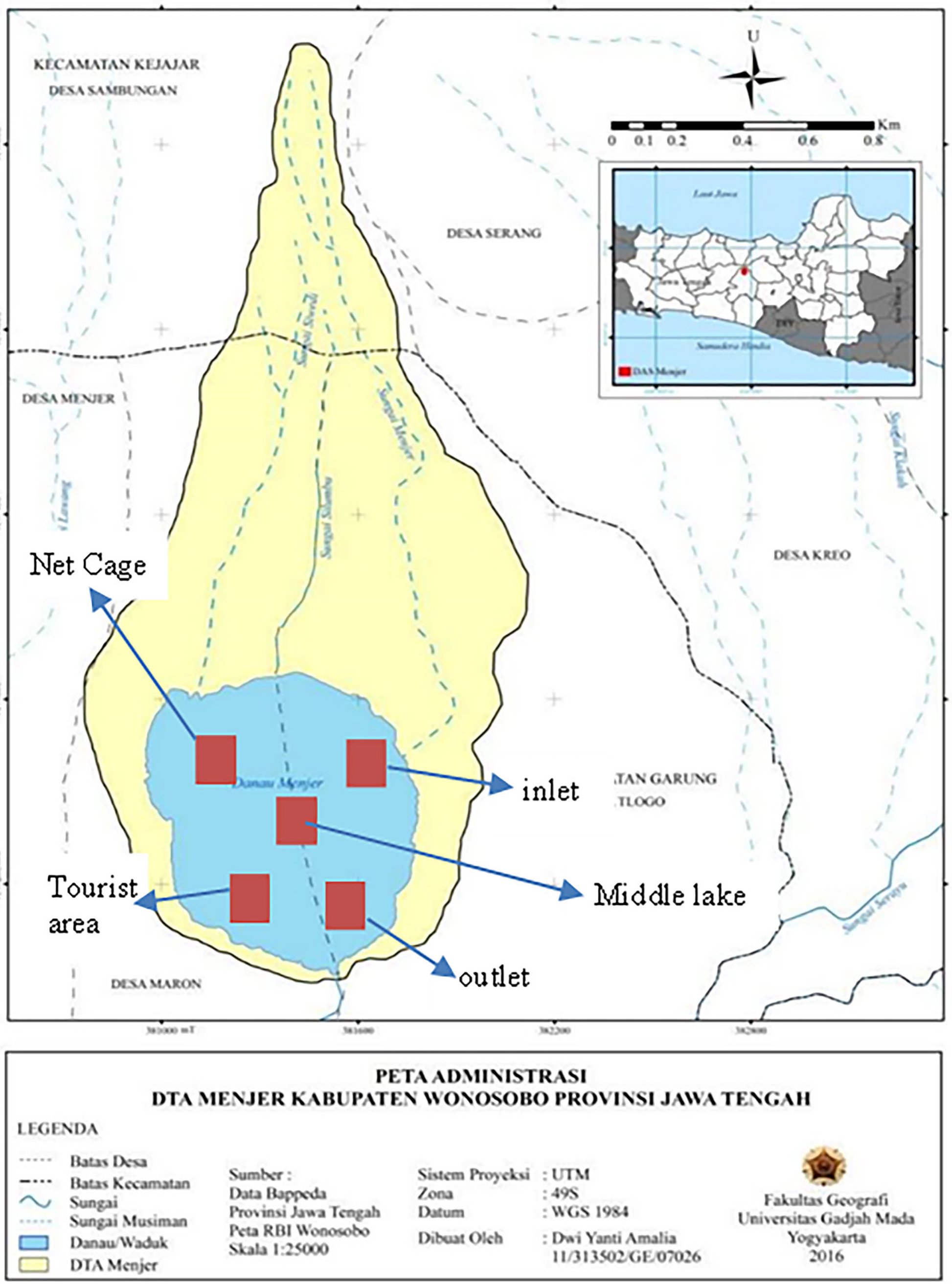

Figure 1. Map of the research location

RESEARCH METHOD

Reaserch was conducted by survey in Menjer Lake, Wonosobo, Indonesia (Fig. 1) during period of September – October 2023. The research objects were phytoplankton samples and water samples of Menjer Lake. The sampling was carried out purposively during the day at 10.00 AM – approximately 03.00 PM at 5 sites including the area of inlet, middle of the lake, aquaculture using floating net cage, tourism and outlet.

The phytoplankton samples were taken in the euphotic zone (approximately 0.3–0.5 m below the surface) at each site by filtering 100 liter lake water using plankton net, then transferred to sample vials with 2–3 drops each of 40% formalin and Lugol's solution, and then sealed tightly to prevent spilling. An additional 2 liters of water was collected in a 2 liter sample bottle for measuring environmental factor including TSS, TDS, phosphate and nitrate. For measuring environmental factor of temperature, pH, DO and light penetration were conducted in situ, whereas the TSS, TDS, phosphate and nitrate were analyzed ex situ in the laboratory based on APHA (2012).

The identification of phytoplankton was conducted in the laboratory using a microscope and an identification books of Bellinger & Sigee (2011), Guiry & Guiry (2022). The abundance of phytoplankton is calculated as follows (APHA 2012):

$$N\ (\text{mg per liter}) = \frac{T}{L} \times \frac{P}{p} \times \frac{V}{v} \times \frac{1}{W} \tag{1}$$

where: N – number of phytoplankton organisms per liter;
T – area of the cover glass (mm^2);
L – field of view (mm^3);
P – total number of phytoplankton organisms;
p – number of observed organisms in the field of view;
V – volume of filtered phytoplankton samples (mL);
v – volume of phytoplankton sample under the cover glass (mL);
W – volume of filtered phytoplankton samples (liter).

To determine the level of species diversity in a community is using the Shannon-Wiener index (H') using formula (Magurran 2004):

$$H' = \sum_{i=1}^{N} Pi \ln Pi \tag{2}$$

where: H – index of species diversity;
Pi – probability function for each part as a whole (ni/N);
ni – number of individuals of type-i;
N – total number of individuals.

The level of diversity is categorized as follow: low (H < 2), medium (2 < H < 3), and high (H > 3). The results of environmental factor measurement including temperature, brightness, pH, TSS, TDS, DO, phosphate, nitrate were compared each with water quality standards based on Government Regulation Number 22 of 2021 to determine the water quality status of each parameter as a determining factor for the diversity and abundance of phytoplankton.

To determine the environmental factors that most influence the diversity and abundance of phytoplankton in Lake Menjer the data of abundance of phytoplankton and water quality were analyzed using the principle component analysis by means of Past 4.10 software.

RESULT AND DISCUSSION

Diversity and abundance of phytoplankton

The phytoplankton community obtained was 13 species consisting of 3 divisions, namely Bacillariophyta (5 species), Chlorophyta (6 species), and Cyanophyta (2 species). Algae groups such as Bacillariophyta (diatoms), Chlorophyta (green algae), and Cyanophyta (blue-green algae or cyanobacteria) are commonly found in various waters. This diversity can vary depending on the type of water, surrounding environmental conditions [Ariani, et al., 2020]. The composition and abundance of phytoplankton found during research at Menjer Lake are presented in Table 1.

The diversity shows the richness of species in a community and the balance of the number of individuals of each type. On the basis of Table 1, it was shown that the Bacillariophyta division consists of 5 species, namely *Melosira variant, Melosira Granulata, Synedra ulna, Synedra acus, and Navicula sp*. The phytoplankton species from the Bacillariophyta division that dominates quite a lot in Menjer Lake is *Melosira variance* of up to 48.13% and next is *Synedra ulna* with 23%. Other species have a dominance of only 0.9–10.69%.

Chlorophyta division consists of 6 species, namely *Oocystis solitaria, Coelastrum*

Table 1. Diversity and abundance of phytoplankton in Menjer Lake (ind.L^{-1})

No.	Spesies	Sampling sites					∑ Ind.L^{-1}	RA %
		Inlet	Middle area	Floating net cage	Tourist area	Outlet		
Division Bacillariophyta								
1	*Melosira varians*	8020	7600	7100	6600	1020	30340	48.13
2	*Melosira granulata*	160	80	100	160	80	580	0.92
3	*Synedra ulna*	3040	100	40	800	2760	6740	10.69
4	*Synedra acus*	-	5160	5200	1300	3160	14820	23.51
5	*Navicula sp.*	-	-	-	-	40	40	0.06
Total Bacillariophyta								83.31
Division Chlorophyta								
6	*Oocystis solitaria*	720	1500	600	-	-	2820	4.47
7	*Coelastrum microporum*	-	180	820	280	40	1320	2.09
8	*Chlorella sp.*	120	-	80	140	380	720	1.14
9	*Pachycladon umbrinus*	-	-	20	-	-	20	0.03
10	*Pediastrum simplex*	-	-	-	40	-	40	0.06
11	*Closterium ehrenbergii*	-	-	180	-	-	180	0.29
Total Chlorophyta								8.09
Division Cyanophyta								
12	*Oscillatoria limosa*	-	20	20	140	60	240	0.38
13	*Microcystis aeruginosa*	840	780	1180	1360	1020	5180	8.22
Total Cyanophyta								8.60
Kelimpahan total (Ind/l)		12900	15420	15340	10820	8560	63040	100

Note: RA – relative abundance; ∑ – total.

microporum, Chlorella sp., Pachycladon umbrinus, Pediastrum simplex and *Closterium ehrenbergii*. There is no species dominating for this division. The Chlorophyta division indicates that waters that are still classified as good condition of mesotrophic level (Amrillah et al., 2023).

Cyanophyta division consists of 2 species, namely *Oscillatoria limosa* and *Microcystis aeruginosa*. The growth of those two of blue-green algae is influenced by temperature. Temperature is a significant factor influencing competition between Microcystis and Oscillatoria in eutrophic lakes (Chu et al., 2007). Oscillatoria is a superior competitor that is able to suppress Microcystis when the temperature is < 20 °C, while the opposite phenomenon occurs at 30 °C. The temperature of Menjer Lake is around 23–25 °C, so the abundance of *Mycrocystis aeruginosa* is greater than *Oscillatoria limosa* (Table 1).

On the basis of on categorization of phytoplankton diversity index that Menjer Lake had low diversity. Low phytoplankton diversity means that there are few types of phytoplankton in Menjer Lake. This may be due to factors such as environmental changes caused by pollution [Nopiantari et al., 2017] and predation on other organisms [Harvey and Menden-Deuer, 2012]. The macronutrients of Cu, NO_2, Si, and Na are the determining factors for algal blooming in the Menjer Lake [Piranti et al., 2022]. The effect of Cu, NO_2 and Si concentrations was inversely related to algal abundance, while the Ca, Na and Mo concentrations were in line with the abundance of algae [Piranti et al., 2012]. Low diversity can have a negative impact on ecosystem balance, because phytoplankton play an important role in the food chain or as the main primary producers in Menjer Lake. There are several reasons why phytoplankton diversity is low, namely competition for limited resources such as nutrients and sunlight. If this competition is high, stronger phytoplankton species will dominate, while weaker species will decline, causing low phytoplankton diversity. Phytoplankton is food for many planktonic animals. If the level of predation is too high, then the phytoplankton species which are the main prey of these planktonic animals will be under population control as a result there will be one organism that survives which will grow rapidly or bloom. The factors that influence diversity are human activities such as water pollution, changes in land use, and climate change can affect the condition of water ecosystems and affect phytoplankton communities. These changes can benefit some species while harming others, causing a decline in diversity. Evolutionary processes and natural selection may play a role in the formation of phytoplankton communities. The species that have better adaptation to environmental conditions or competition can become more dominant over time. Low phytoplankton diversity can have a negative impact on aquatic ecosystems because it can reduce trophic diversity and sensitivity to environmental changes. Therefore, further understanding of the factors that influence phytoplankton diversity is important to maintain the balance of aquatic ecosystems. On the basis of on the diversity index criteria according to Wheater et al. (2011), the waters of Menjer Lake are included in the low category, meaning that the distribution of the number of individuals for each type is low and the stability of the community is in the low category. As a result, in Menjer Lake, periodic blooming of Cyanobacteria species, especially *Microcystis* sp. with the local language "*Belerang*" [Piranti & Wibowo, 2020].

Bacillariophyta is the highest abundance in Menjer Lake. It makes up 83% of the phytoplankton community, Chlorophyta 8% and Cyanophyta 9% (Fig. 2). This is because the Bacillariophyta division easily adapts to the environment it lives in, such as changes in temperature, pH and DO content of waters, is cosmopolitan, resistant to extreme environmental changes, and has high reproductive power (Amelia, 2013). Previous research results from Kumalasari et al. (2015) also showed that Bacillariophyta was also found to be the most dominant in Menjer Lake.

Bacillariophyta, also known as diatoms, are a group of unicellular algae that have cell walls rich in silica which provide strength and protection against environmental factors, so that diatoms can survive and reproduce under various water conditions [Soeprobowati et al., 2022; Luo et al., 2017].

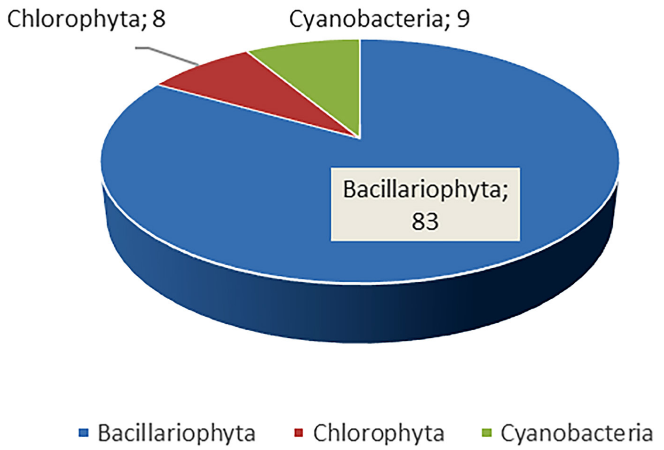

Figure 2. Phytoplankton composition (%) in Menjer Lake

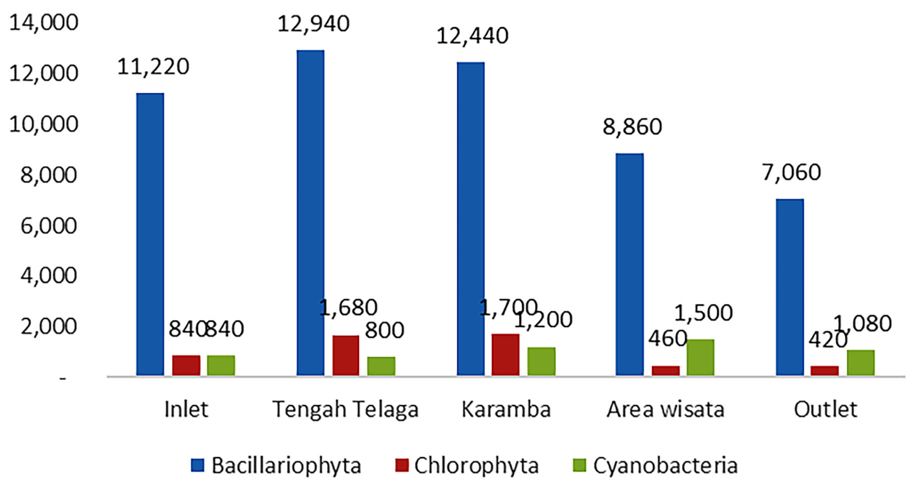

Figure 3. Spatial abundance of phytoplankton in Menjer Lake

Figure 3 shows the spatial abundance of phytoplankton in Menjer Lake. Each sampling location is dominated by the Bacillariophyta division. The highest abundance is found in the middle area and cage area. It is also relatively high in the inlet, then decreases in tourist areas and is lowest at the lake outlet.

Abundance in the middle of the lake is greatest because water flows from the inlet towards the middle of the lake and there is a collection of nutrients resulting from mineralization (nutrient recycling) thus supporting the growth of phytoplankton [Ishikawa et al., 2022]. The abundance of phytoplankton in the aquaculture area using floating net cage is also high because of the supply of nutrients from fish food waste, which fertilizes the phytoplankton in the area [Piranti et al., 2018]. The abundance of phytoplankton in the outlet area of Menjer Lake is caused by the large number of phytoplankton in the outlet. The power plant turbine door is operated periodically by opening the intake door which is the outlet of the lake so that the phytoplankton are carried out by the outflow so that the numbers are relatively small.

Water quality

Water quality status is the level of water quality conditions that indicate polluted or unpolluted conditions in a body of water at a certain time by comparing it with water quality standards [Government Regulation No. 22 of 2021]. When compared with class 1 and 2 quality standards, the water quality status in the inlet area has three parameters that exceed the water quality standards, namely the total suspended solid (TSS), DO and total coliforms (Table 2). However, compared to class 3 and 4 water quality standards, all parameters at each station meet the quality standards.

On the basis of the water quality standards, Menjer Lake is not suitable for use as a raw water of drinking and household needs; however, it is still suitable for fish cultivation and irrigation water purposes. There are 2 parameters that exceed class 1 and 2 quality standards, but still comply with class 3 and 4 quality standards, namely TSS and PO_4 parameters (Table 2). The TSS measurement results in Menjer Lake ranged from 68–94 $mg \cdot L^{-1}$. Total suspended solid consists of mud, fine sand and microorganisms due to soil erosion bring out into water bodies. Apart from that, TSS can also come from household activities, waste of agricultural, livestock as well as industrial sectors [Rahayu et al., 2018]. The outlet area has a higher TSS content than other stations. The high TSS is also caused by an increase in organic matter originating from domestic waste, faeces of fish and food waste that accumulates in waters [Muthifah et al., 2018].

Phosphorus is one of the key elements required for the growth of plants and animals and in lakes it tends to be a limiting nutrient for eutrophication conditions which are characterized by the growth of algae and aquatic plants in aquatic ecosystems [Horne & Goldmann, 1992]. Orthophosphate (PO_4) is in ion form which can be directly used by algae and aquatic plants for their growth. On the basis of Table 2, the PO_4 concentration in Menjer Lake at all sampling locations has exceeded class 1 and 2 quality standards but 2 sites (tourist area and outlet) still met the class 3 designation. This means that based on the PO_4 concentration, Menjer Lake is still very suitable for use in aquaculture, while not suitable for a raw water drinking needs and for recreational purposes. However PO_4 concentration must be reduced by limiting human activities in the catchment area, for example excessive use of fertilizer, domestic activities as well as industrial waste.

Table 2. Water quality status of Menjer Lake

Parameter	Unit	Inlet	Middle	Net cage	Tourist area	Outlet	Mean	Water classification			
								1	2	3	4
Temperature	°C	23	24	23	23	25	23–25	Dev 3	Dev 3	Dev 3	Dev 3
Light penetration	cm	94	127.5	73.5	88	75.5	91.7	-	-	-	-
TSS	mg/l	87	77	79	68	94	81	40	50	100	400
TDS	mg/l	179	167	180	163	167	171.2	1000	1000	1000	2000
pH	pH unit	6.62	6.74	6.7	6.62	6.77	6.69	6–9	6–9	6–9	6–9
DO	mg/l	3.89	3.82	3.94	4.03	3.93	3.922	6	4	3	1
PO_4	mg/l	0.3	0.3	0.3	0.2	0.2	0.3	0.2	0.2	1	-
NO_3	mg/l	4.23	4.05	3.7	3.25	4.4	3.926	10	10	20	20

The efficiency of oxygen uptake for aquatic biota will decrease if the dissolved oxygen concentration is low. Low oxygen concentrations in waters can reduce the ability of biota to live normally [Anas et al., 2017]. To meet class 1 and 2 quality standards, the oxygen concentration should be at least 4–6 $mg \cdot L^{-1}$. The DO value in Menjer Lake ranges from 3.82–4.03 $mg \cdot L^{-1}$. Therefore, the designation of Menjer Lake only meets class 3 and 4 designations, so it is only suitable for use for fish cultivation and farming as well as irrigating plants.

Relationship between water quality and phytoplankton abundance

Phytoplankton play an important role as primary producers in the aquatic environment and are very sensitive to their physical environment [Yanti, 2017]. Phytoplankton diversity and abundance are related to water quality parameters. Environmental changes can cause changes in phytoplankton communities in terms of presence, abundance, diversity and dominance of species in their habitat [Kostryukova et al. 2018]. Thus, observation of phytoplankton populations can be a reliable tool for assessing the pollution status of water bodies in biomonitoring studies [Parmar et al. 2016; Singh et al. 2013]. Phytoplankton fulfills the requirements of suitable indicators, mainly due to its simple structure and function, so it can be used to investigate quantitative changes in water quality over large geographic areas [Parmar et al. 2016].

On the basis of the results of analysis using principle component analysis in Past 4.10 software. shows that phytoplankton abundance is 76% influenced by these water quality parameters (Figure 4) with a strong relationship strength.

The relationship between water quality and phytoplankton abundance at each sampling point shows that the inlet, middle and outlet locations have different phytoplankton abundance; however, for the cage location and tourist area the phytoplankton abundance is the same because they are on the same axis (Figure 4). On the basis of the length of the vector formed from each parameter that influences phytoplankton abundance, it shows that the longer the vector formed, the greater the diversity of data. On the basis of the angle formed from the 2 parameter vectors, it shows that there is a relationship between the two parameters. The angle formed becomes smaller indicating a positive correlation. Conversely, if the angle formed is larger and in the opposite direction, it shows a negative correlation. If the vector angle of the 2 parameters forms 90°, it shows that the two parameters are not correlated. On the basis of the results of the analysis of the relationship between phytoplankton abundance and water quality parameters, it shows that phytoplankton abundance is strongly and positively correlated with phosphate and brightness. Phosphate is a nutrient that determines phytoplankton growth [Piranti, et al, 2021]. This shows that an increase in phosphate and brightness will be followed by an increase in the abundance of phytoplankton in these waters and vice versa if the

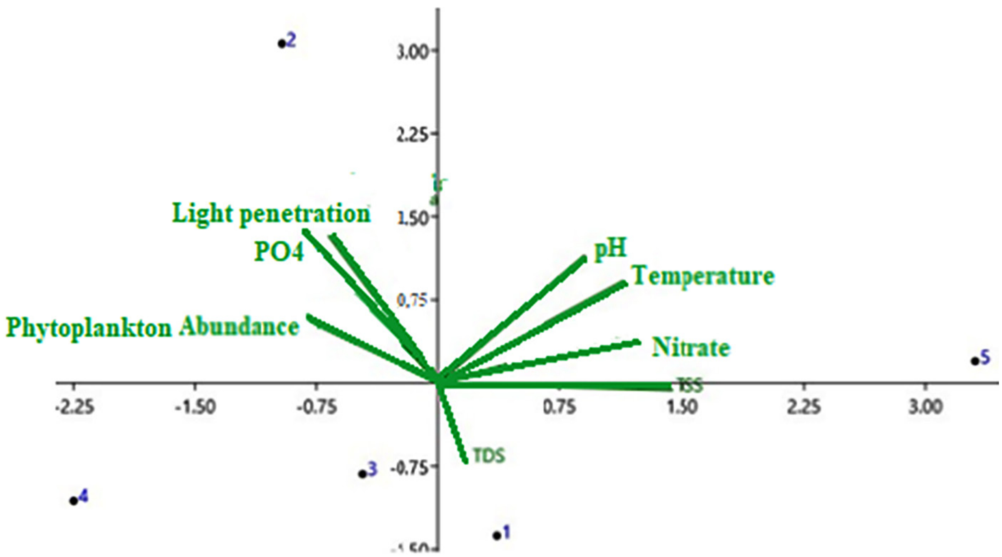

Figure 4. Biplot of water quality and phytoplankton abundance: 1 – inlet, 2 – middle area, 3 – net cage, 4 – tourist area, 5 – outlet

phosphate value and brightness decrease it will be followed by a decrease in the abundance of phytoplankton. Abundance is negatively correlated with TSS and TDS. Increasing TSS and TDS will cause the abundance of phytoplankton to decrease. According to Wisha et al., (2016), the abundance of phytoplankton is influenced by the TSS content, if the TSS content and turbidity are higher, there can be obstacles to the reach of sunlight from penetrating into the water so that it can disrupt the photosynthesis process. The abundance of phytoplankton obtained in Menjer Lake ranged from 8,560–15,420 ind/l. The highest phytoplankton abundance was 15,420 ind/l at station 2 (middle of the lake) and the lowest phytoplankton abundance was at station 5 (outlet).

Phytoplankton abundance will be higher at stations with higher phosphate and brightness, such as at station 2 (middle of the lake). The middle station of the lake has a phosphate content of 0.3 mg/l and a brightness of 127.5 cm. The phosphate content at this station comes from human activities such as floating net cages, animal husbandry, household and agricultural waste which is carried through surface water flows (Piranti et al., 2023). Phosphate is used by phytoplankton as a basic ingredient for making organic materials which are used as a primary food source in the food chain. However, the phosphate content used by phytoplankton has certain limits. The phosphate content that exceeds the utilized limit can trigger nutrient enrichment, known as eutrophication (Irianto & Triweko, 2019). Brightness is the main factor for phytoplankton in carrying out the photosynthesis process.

CONCLUSIONS

The phytoplankton community structure in Menjer Lake is dominated by Bacillariophyta (83%). There are 2 parameters above the water quality standard threshold (TSS and PO_4). Telaga Menjer Lake is no longer suitable for use as a source of drinking water and household needs, but is still suitable for fish cultivation and irrigation water needs. Light penetration and phosphate concentration are the factors that most influence the development of phytoplankton in Menjer Lake. The input of phosphate concentration from the catchment area must be controlled to prevent the growth of phytoplankton in Menjer Lake.

Acknowledgments

Thanks to Jenderal Sudirman University (LPPM Unsoed) which has provided research funding through the Grant Scheme of ”Fasilitas Guru Besar” in 2023 through the Keputusan Rektor Universitas Jenderal Soedirman Nomor 1537/UN23/PT.01.02/2023.

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