Journal of Natural Resources and Environmental Management
13(1): 27–36. http://dx.doi.org/10.29244/jpsl.13.1.27–36
E-ISSN: 2460-5824
http://journal.ipb.ac.id/index.php/jpsl

Phytoplankton response to differences in light and the addition of phosphorus in Lake Cikaret

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Article Info:
Received: 05 - 08 - 2022
Accepted: 05 - 10 - 2022

Keywords:
Community structure, lake cikaret, light fluctuation, phosphorus concentration

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Abstract. *The composition and abundance of phytoplankton in the waters are strongly influenced by the supply of phosphorus and light intensity. Observations were made to obtain the optimum phosphorus concentration with a certain level of light which caused the high abundance of phytoplankton in Lake Cikaret. A 2 x 2 factorial design was used to see the effect of three levels of phosphorus (0.03 mg/L, 0.09 mg/L, and 0.15 mg/L) and three levels of light (30%, 70%, and 100% luminance) on the abundance and composition of phytoplankton. The parameters observed were the abundance and composition of phytoplankton, dissolved oxygen, pH, temperature, turbidity, light intensity, and total phosphorus. The results showed that the addition of phosphorus in the waters increased the abundance of phytoplankton. The abundance of Chlorophyta was high in the first week, followed by the abundance of Bacillariophyta and Chlorophyta in the second week until the end of the observation.* Synedra sp. *(Bacillariophyta) tended to be high in abundance at a low light intensity, while* Mougeotia sp. *(Chlorophyta) tended to be high at all light intensities.*

How to cite (CSE Style 8th Edition):
Sulawesty F, Rahayu SYS, Yustiawati, Chrismadha T. 2023. Phytoplankton response to differences in light and the addition of phosphorus in Lake Cikaret. JPSL **13**(1): 27–36. http://dx.doi.org/10.29244/jpsl.13.1.27–36.

INTRODUCTION

The growth of the urban environment increases the vulnerability of urban lakes. The main threats to urban lakes are pollution and eutrophication. Small lakes are shallow waters. Hence the input of organic materials from the catchment area or surrounding land will accelerate the fertilization of the waters (Wetzel 2001). Eutrophic waters can be indicated based on the structure of the phytoplankton community. Several studies have shown a relationship between the fertility conditions of the waters with the composition, abundance, and biomass of phytoplankton (Pratiwi et al. 2013; Sulastri et al. 2015; Sulastri et al. 2016). The interaction between light and nutrients affects the algal community in aquatic ecosystems (Cymbola et al. 2008).

Nutrient enrichment will stimulate the growth of phytoplankton in lakes (Lv et al. 2011). Phosphorus is the least abundant element among the main nutrients in the waters but is needed for the growth of phytoplankton in freshwater (Wetzel 2001). Although it is needed in small amounts, phosphorus is a limiting factor for phytoplankton growth in most lake waters. Excessive input of phosphorus nutrients may cause eutrophication, which has an impact on increasing phytoplankton biomass. Light is a source of energy needed by phytoplankton to carry out photosynthesis. Therefore, the high or low light intensity will affect the productivity of phytoplankton in the waters. Observations from Cymbola et al. (2008) showed that phosphorus from sediments stimulates phytoplankton growth, but its effect on phytoplankton dynamics is also influenced by other factors, such as light. Other observations showed that the phytoplankton community is affected by light and the supply of nutrients (phosphorus) to the waters (Marzetz et al. 2020).

Lake Cikaret, which is located in the area of the office of the Government of the Regency of Bogor, residential area, and hospital, is a part of the Ciliwung watershed with a catchment area of 8.46 km^2, water body area of 16.90 ha (Supriyadi et al. 2015), and a maximum depth of 5.2 m (Sulastri et al. 1994). Lake Cikaret had experienced a decrease in water quality and an increased trophic status. Based on the content of total phosphorus, total nitrogen, and phytoplankton composition, Lake Cikaret is categorized as eutrophic (Sulastri et al. 1994) with a low plankton diversity index value and high dominance index (Soliha et al. 2016).

The study was conducted on the relationship between phosphorus concentration and light level in the phytoplankton community, which aimed to obtain the optimum phosphorus concentration with a certain light level that can cause high phytoplankton abundance. This experimental approach will provide a more realistic assessment of the response of phytoplankton to phosphorus enrichment in a certain light so that later it can be used to simulate eutrophication conditions in the waters. The results of this study can be used as a reference in supporting eutrophication control and management in Lake Cikaret.

METHODS

Lake Cikaret is located in Cibinong, Bogor, Indonesia, which functions as flood control, raw water supply for irrigation and fisheries, recreation, and water absorption area (Sulawesty 1996; Sudarso et al. 2016; Sulistianingsih et al. 2019; Sulastri et al. 1994; Supriyadi et al. 2015). The water comes from the Bantenan River and the Kebantenan River, while the water goes out into the Tambakan River and the Cikaret River. The water quality condition of Lake Cikaret on December 8, 2021, and January 25, 2022, is presented in Table 1.

Table 1 The results of water quality measurements in Lake Cikaret

Time	Chlorophylla (mg/m^3)	TP (mg/L)	TN (mg/L)	Temperature (°C)	DO (mg/L)	pH	Turbidity (NTU)
8 Dec 21	1.6289	0.0493	2.4368	29.00	6.7	8.52	16.85
25 Jan 22	11.0827	0.0796	2.0224	28.05	2.5	7.13	3.73

This research is experimental. Water was collected at the sub-surface of northern Lake Cikaret; 450 liters of lake water were sampled into 30 plastic bottles with a volume of 15 liters, and each bottle was filled with 12.5 liters. Nine bottles were placed each in 3 fiber tubs filled with water to stabilize the temperature. For the control sample, water from Situ Cikaret/Lake Cikaret was also used. This experiment was conducted at Research Centre for Limnology and Water Resources, National Research and Innovation Agency.

Table 2 Light intensity range at 30%, 50%, and 100% irradiation

Irradiation percentage	Light Intensity (Lux)
30%	3,003 - 54,714
50%	5,005 - 91,190
100%	10,010 - 182,380

The light treatments used in this study consisted of three different intensities. The light that enters the tubs is regulated by providing shade over the surface of the tubs using a paranet. The determination of the light level used consists of three light levels; 30% (70% shading), 50% (50% shading), and 100% (without shading) based on Widiastuti et al. (2004). To determine the value of the light intensity, measurements were carried out continuously on 26 January 2022 until 23 February 2022, using a Lutron LXA 01001 data logger. The results of these measurements are used to determine the range of light intensity at 30%, 50%, and 100% irradiation (Table 2).

The determination of the total phosphorus concentration (TP) in this study was based on "The Lake Trophic Status Criteria" for total phosphorus (TP) levels issued by the Ministry of the Environment in 2009, which were 0.03 mg/L (mesotrophic), 0.09 mg/L (eutrophic), and 0.15 mg/L (hypereutrophic). Phosphorus with variations of concentrations of 0.03 mg/L (in the form of K_2HPO_4), 0.09 mg/L, and 0.15 mg/L was added to each bottle. Sampling was carried out every week for four weeks, from 26 January 2022 to 23 February 2022. The code for each treatment is presented in Table 3.

Table 3 The code for each treatment

Code	Description
F1C1	0.03 mg P/L with 30% light intensity
F1C2	0.03 mg P/L with 50% light intensity
F1C3	0.03 mg P/L with 100% light intensity
F2C1	0.09 mg P/L with 30% light intensity
F2C2	0.09 mg P/L with 50% light intensity
F2C3	0.09 mg P/L with 100% light intensity
F3C1	0.15 mg P/L with 30% light intensity
F3C2	0.15 mg P/L with 50% light intensity
F3C3	0.15 mg P/L with 100% light intensity
K	Control

The observed parameters were composition and abundance of phytoplankton, dissolved oxygen (DO), pH, turbidity, temperature, and total phosphorus (TP). Water quality was measured by a Lutron DO-5509 water meter (for dissolved oxygen), Lutron PH-201 (for pH), Lutron TU-2016 (for turbidity), Lutron YK-2001 PH (for temperature). The total phosphorus analysis was carried out in the laboratory with the APHA 4500-P and 4500-PE methods (APHA 2017).

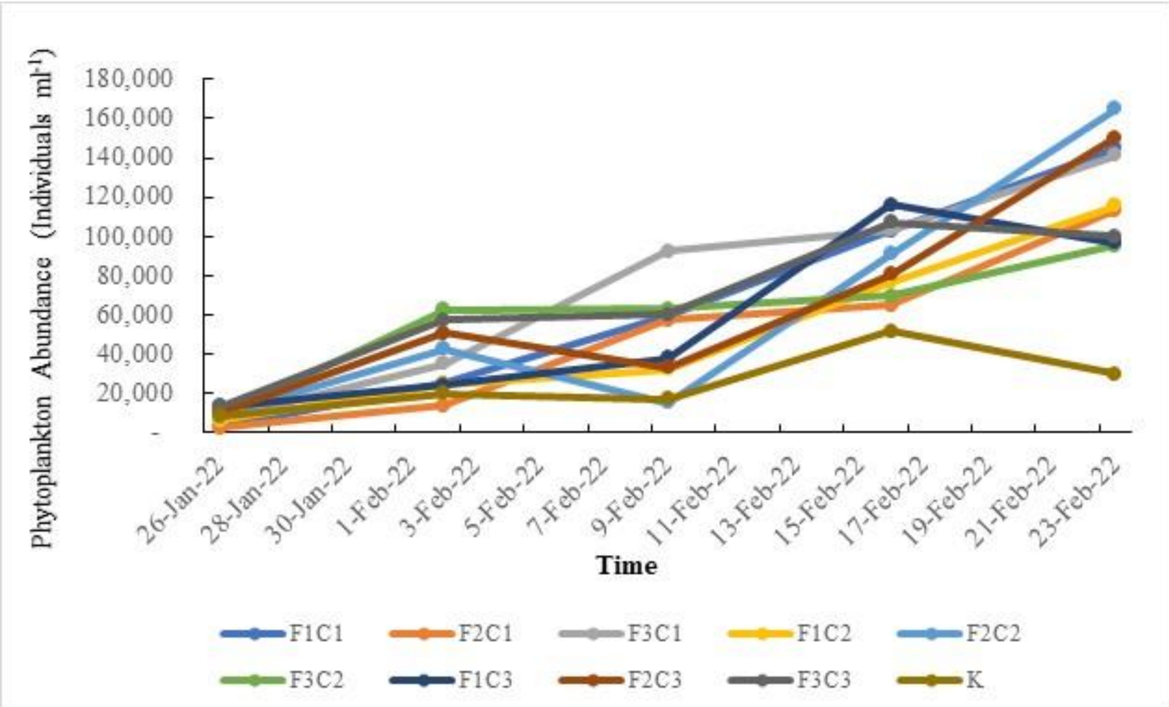
To study the phytoplankton community, a total of 15 ml water samples were taken from each research container and preserved using Lugol's solution until a yellowish color appeared (APHA 2017). Phytoplankton analyses were carried out using an inverted microscope NIKON Diaphot 300 at 100x, 200x, and 400x magnification. Phytoplankton identification was carried out at the genus level, based on Prescott (1951), Scott and Prescott (1961), Mizuno (1979), Taylor et al. (2007), and Bellinger and Sigee (2010). The phytoplankton abundance was calculated using the Sedgwick Rafter cell counting method (APHA 2017), colony and filamentous phytoplankton were counted as one phytoplankton unit (USEPA 2003). The community composition of phytoplankton was calculated based on the unit numbers.

Effects of phosphorus availability (0.03 mg/L, 0.09 mg/L, and 0.15 mg/L) and light intensity (30%, 50%, and 100%) on the abundance of phytoplankton were tested using two-way ANOVA. Normality was tested using the Kolmogorov–Smirnov test, and equal variance was tested using Levene's test. Sampling was carried out five times on January 26, 2022; February 2, 2022; February 9, 2022; February 16, 2022; and February 23, 2022. All statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS version 25), and statistical significance was accepted at $P < 0.05$.

RESULTS AND DISCUSSION

Water quality conditions during observations showed conditions that could still support the life of phytoplankton in the waters. Temperatures ranged from 25.4 - 29,1 °C, dissolved oxygen (DO) ranged from 4.2 – 7.1 mg/L, pH ranged from 8.34 – 9.94, turbidity ranged from 2.31 – 109.5 NTU, and total phosphorus (TP) ranged from 0.0095 – 0.2359 mg/L. The turbidity values tend to increase, especially starting from the second week, with the increasing abundance of phytoplankton. The concentration of TP decreased sharply in the first week (February 2, 2022), due to the maximum absorption by phytoplankton for growth.

The supply of nutrients (phosphorus) and different light intensities will give different responses to the composition and abundance of phytoplankton. The abundance of phytoplankton at the end of the observation showed a very high value compared to the beginning of the observation. This observation also indicated that the addition of phosphorus will increase the abundance of phytoplankton compared to treatments without phosphorus (Figure 1). According to Wieliczko et al. (2020), in their research on Lake Mangueira, nutrient enrichment indirectly contributes to an increase in species richness and the total amount of phytoplankton.



Description:

F1 = 0.03 mg/L P	C1 = 30% light	K = Control
F2 = 0.09 mg/L P	C2 = 50% light	
F3 = 0.15 mg/L P	C3 = 100% light	

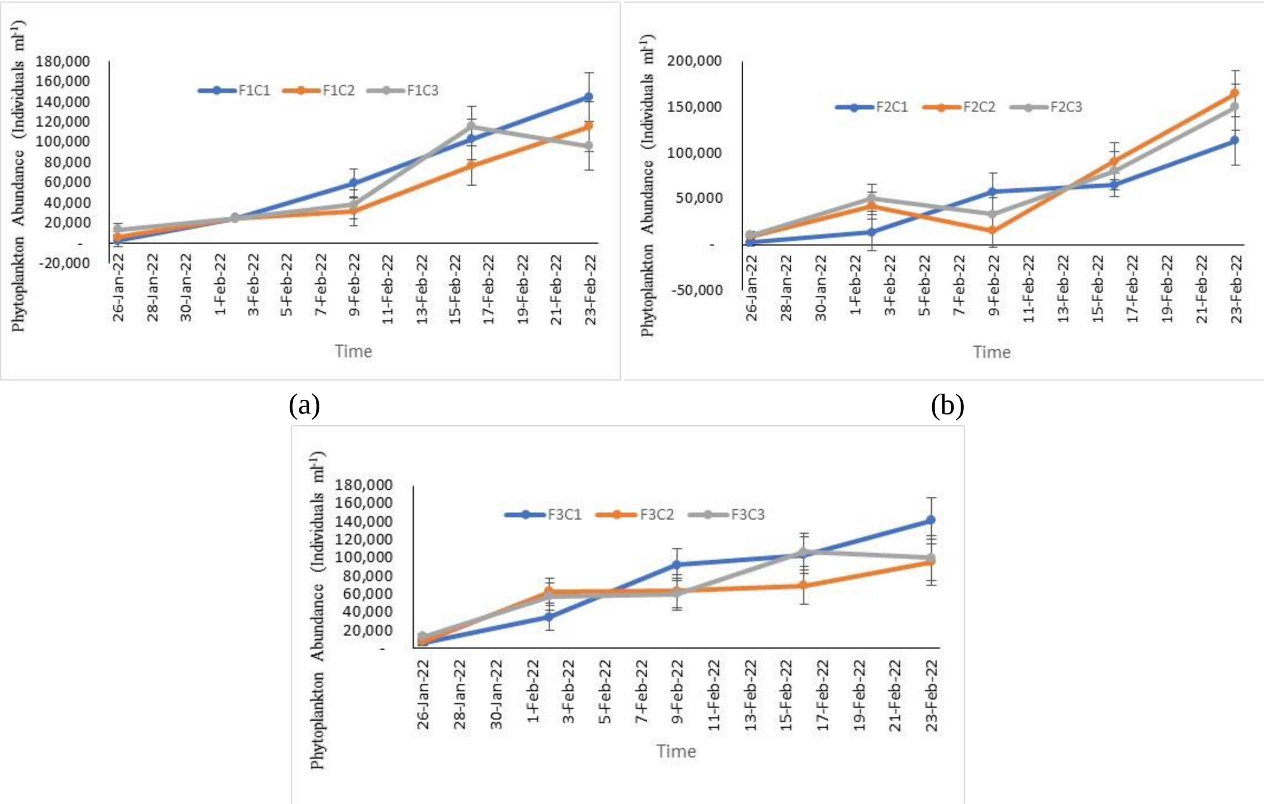
Figure 1 The abundance of phytoplankton during observation

Table 4 Two-way analysis of variance (ANOVA) result from the abundance of phytoplankton on the addition of phosphorus was 0.03 mg/L (a), 0.09 mg/L (b), and 0.15 mg/L (c) with different light intensities

Tests of Between-Subjects Effects					
Dependent Variable:					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Model	175993705884.000[a]	9	19554856209.333	8.058	0.000
Fosfor	725625887.511	2	362812943.756	0.149	0.862
Cahaya	304473592.178	2	152236796.089	0.063	0.939
Fosfor * Cahaya	1669247711.956	4	417311927.989	0.172	0.951
Error	87367782864.000	36	2426882857.333		
Total	263361488748.000	45			

a. R Squared = .668 (Adjusted R Squared = .585)

Although the result of the statistical analysis was insignificant (Table 4), there were differences in the response of phytoplankton to the addition of phosphorus and varied light levels. At the end of the observation, the addition of 0.09 mg/L phosphorus with 50% light level (5,005 - 91,190 Lux) resulted in the highest abundance of phytoplankton compared to other treatments, followed by the addition of 0.09 mg/L phosphorus with 100% light level (10,010 - 182,380 Lux), 0,03 mg/L phosphorus with 30% light level (3,003 - 54,714 Lux), and 0.15 mg/L phosphor with 30% light level (3,003 - 54,714 Lux) (Figure 2). These results indicated that the supply of phosphorus into the waters would trigger the growth of phytoplankton. The abundance of phytoplankton is also influenced by the intensity of light entering the waters.



(a) (b)

(c)

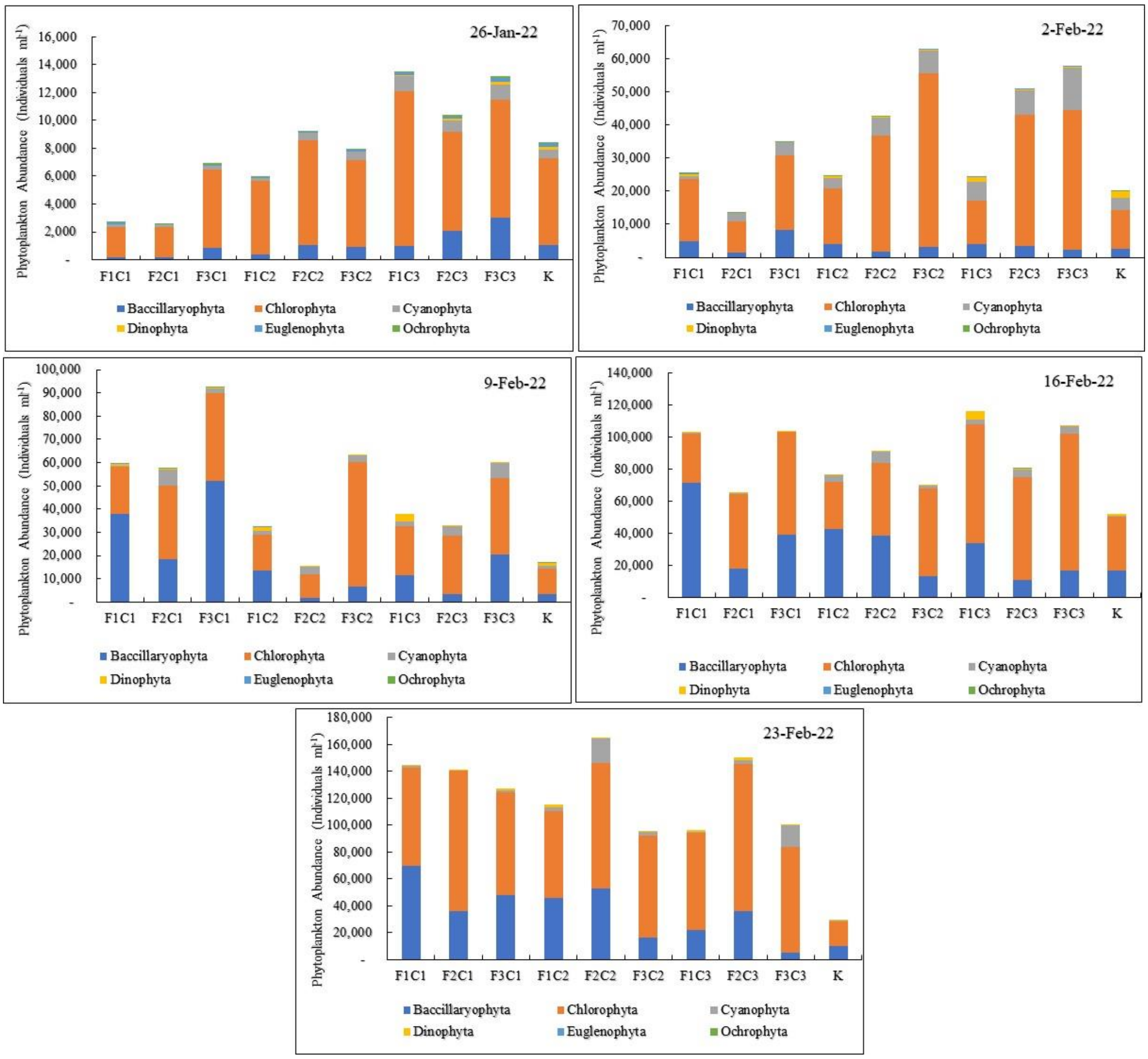
Description:

F1 = 0.03 mg/L P	F3 = 0.15 mg/L P	C2 = 50% light
F2 = 0.09 mg/L P	C1 = 30% light	C3 = 100% light

Figure 2 The abundance of phytoplankton on the addition of phosphorus was 0.03 mg/L (a), 0.09 mg/L (b), and 0.15 mg/L (c) with different light intensities

The addition of 0.03 mg/L phosphorus and 30% light level (3,003 - 54,714 Lux) produced the highest phytoplankton abundance compared to other light levels, while at 100% light level, there was a decrease in phytoplankton abundance at the end of the observation (Figure 3a). The addition of 0.09 mg/L phosphorus produced the highest phytoplankton abundance at 50% light level (5,005 - 91,190 Lux), followed by 100% light level (10,010 - 182,380 Lux) (Figure 3b). The addition of 0.15 mg/L phosphorus with 30% light level (3,003 - 54,714 Lux) produced the highest phytoplankton abundance. At 100% light intensity (10,010 - 182,380 Lux) phytoplankton abundance decreased at the end of the observation (Figure 3c). According to Cymbola et al. (2008), Lichment (1998), Marzetz et al. (2020), and Yuan et al. (2021), besides nutrients, light also greatly affects the abundance, composition, and dynamics of phytoplankton in the waters. The combination of these two parameters will determine the structure of the phytoplankton community in the waters.

Sixty-four genera of phytoplankton were identified and distributed in six phyla. During the experiment, Chlorophyta had the highest number of taxa, followed by Bacillariophyta and Cyanophyta, while for Dinophyta, Euglenophyta, and Ochrophyta, there were only 1 - 3 genera found. The high number of phytoplankton species from the phylum Chlorophyta, Bacillariophyta, and Cyanophyta was also reported by Sulastri et al. (1994), Sulawesty et al. (2002), and Sulawesty et al. (2012) to be found in Lake Cikaret, Lake Cibuntu, and Lake Rawa Kalong. From Figure 3, it can be seen that in the first week of observation (February 2, 2022), the addition of 0.15 mg/L phosphorus with 50% light level (F3C2) produced the highest abundance of Chlorophyta, followed by the addition of 0.15 mg/L phosphorus with 100% light level (F3C3).



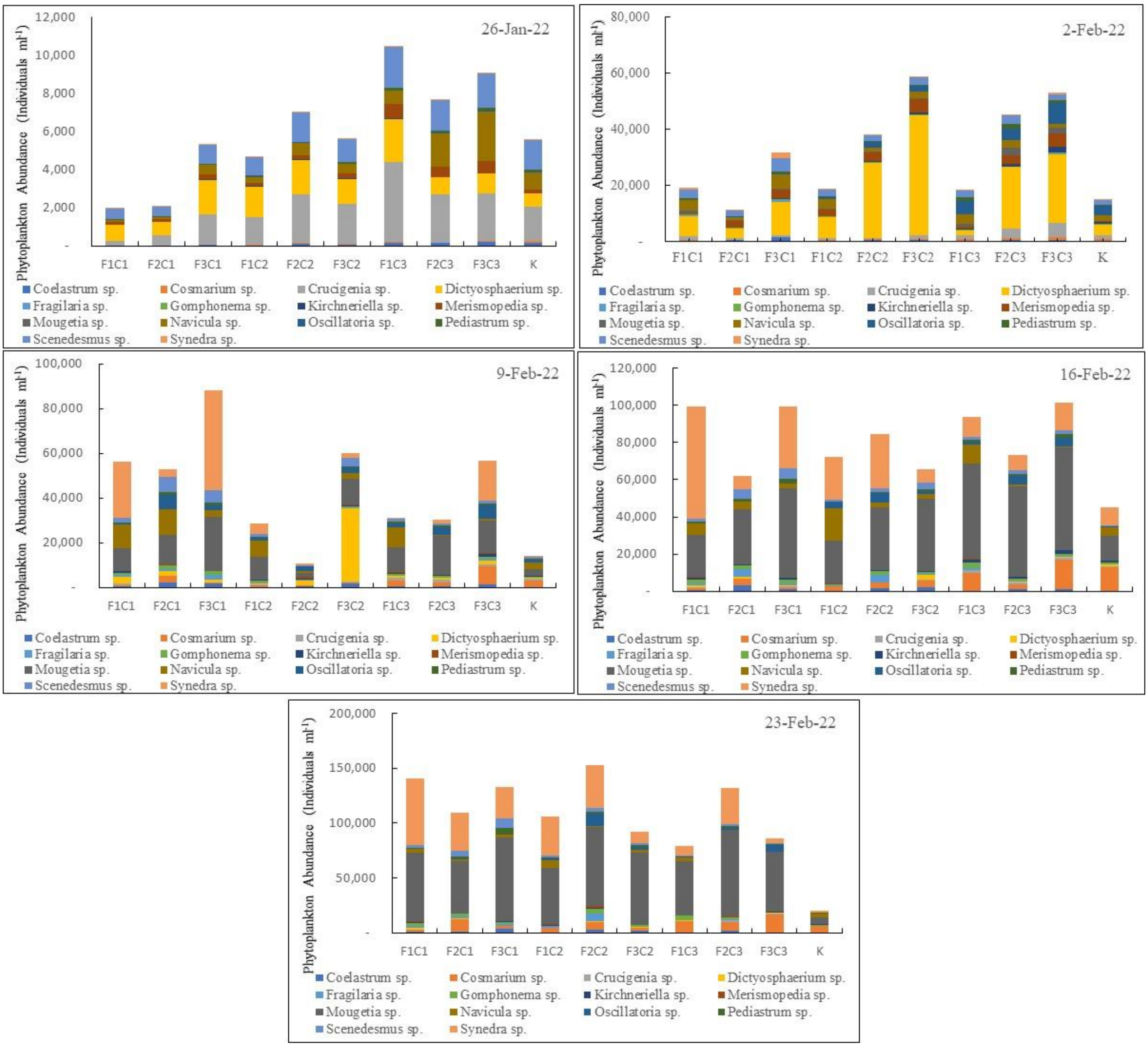
Description:

F1 = 0.03 mg/L P	F3 = 0.15 mg/L P	C2 = 50% light	K = Control
F2 = 0.09 mg/L P	C1 = 30% light	C3 = 100% light	

Figure 3 The abundance of phytoplankton in each phylum during observation

In the second week of observation (February 9, 2022), the highest abundance of phytoplankton was from the phylum Chlorophyta at the addition of 0.15 mg/L of phosphorus and 50% light level (F3C2), followed by the phylum Bacillariophyta at the addition of 0.15 mg/L phosphorus and 30% light level (F3C1). On the third week of observation (February 16, 2022), the highest abundance of phytoplankton was from the phylum Chlorophyta at the addition of 0.15 mg/L phosphorus with 100% light level (F3C3), followed by the addition of 0.03 mg/L phosphorus with 100% light level (F1C3), and followed by the phylum Bacillariophyta at the addition of 0.03 mg/L phosphorus with 30% light level (F1C1). Lastly, in the fourth week of observation (February 23, 2022), the phylum Chlorophyta had the highest abundance consecutively on the addition of 0.09 mg/L phosphorus with 100% light level (F2C3), the addition of 0.09 mg/L phosphorus with 30% light level (F2C1), and the addition of 0.09 mg/L phosphorus with 50% light level (F2C2).

The results of the observations indicated that Chlorophyta needed higher light intensity (at 50% and 100%) for its growth, while lower light intensity (at 30%) could already spur the growth of Bacillariophyta. These results are in accordance with the statement from Marzetz et al. (2020) that the effect of phosphorus concentration and light intensity on phytoplankton biomass will be different; Chlorophyta generally requires higher light intensity for growth. Cymbola et al. (2008) stated that in treatments of low light intensity, diatoms (Bacillariophyta) would dominate—diatoms (Bacillariophyta) would be the dominating group particularly at low average light intensity, while Chlorophyta would dominate in low to high light intensity (Lichment 1998).



Description:

F1 = 0.03 mg/L P	F3 = 0.15 mg/L P	C2 = 50% light	K = Control
F2 = 0.09 mg/L P	C1 = 30% light	C3 = 100% light	

Figure 4 The abundance of phytoplankton in each dominant genus during observation

There are 14 genera whose abundance is quite high and is always found during the observations (Figure 4). At the beginning of the observation (January 26, 2022), *Crucigenia* sp., *Dictyosphaerium* sp., and *Scenedesmus* sp. (Chlorophyta) were highly abundant. In the first week of observation (February 2, 2022), *Dictyosphaerium* sp. was still high in abundance, as well as *Navicula* sp. (Bacillariophyta), *Scenedesmus* sp. (Chlorophyta), and *Oscillatoria* sp. (Cyanophyta). In the second week of observation, (February 9, 2022), *Mougetia* sp. (Chlorophyta) and *Synedra* sp. (Bacillaryophyta) started to show higher abundance among other species. Other species such as *Gomphonema* sp., *Fragillaria* sp., and *Navicula* sp. (Bacillariophyta), *Coelastrum* sp., *Cosmarium* sp., *Crucigenia* sp., *Dictyosphaerium* sp., *Kirchneriella* sp., *Pediastrum* sp., and *Scenedesmus* sp. (Chlorophyta), *Merismopedia* sp. and *Oscillatoria* sp. (Cyanophyta) are still commonly found. In the third week of observation (February 16, 2022), *Mougeotia* sp. and *Synedra* sp. were still high in abundance.

In the fourth week of observation (February 23, 2022), *Mougeotia* sp. still had the highest abundance. *Mougeotia* sp. is a filamentous phytoplankton, that can photosynthesize at 16,200 - 124,200 Lux and tolerate pH 3 - 9 (Bellinger and Sigee 2010). *Synedra* sp. is known as a species that can tolerate high nutrient content in the waters (Bellinger and Sigee 2010). This study showed that the abundance of *Synedra* sp. is higher at low light intensity (3,003 - 54,714 Lux), while *Mougeotia* sp. is high at all light intensity. Although it is non-toxic, the high abundance of *Mougeotia* sp. in the waters would have implications for ecosystem function and water management. It is known that this species is not favored by zooplankton and can accumulate in waters. The accumulation will increase the cost of water management (especially if the water is a raw water source) and can also cause blockages in fishing nets (Tapolczai et al. 2014).

CONCLUSION

The results showed that the addition of phosphorus (0.03 mg/L, 0.09 mg/L, and 0.15 mg/L) into Lake Cikaret at a light intensity of 30% (3,003 - 54,714 Lux), 50% (5,005 - 91,190 Lux), and 100% (10,020 - 182,380 Lux) caused an increase in the abundance of phytoplankton; the value was higher than the control (without the addition of phosphorus). This study also showed that the addition of phosphorus at different light levels would affect the structure of the phytoplankton community in the waters, their composition, and their abundance. The entry of phosphorus into Lake Cikaret plays a significant role in increasing the abundance of phytoplankton. Hence, it is necessary to reduce the entry of phosphorus into the waters to prevent the phytoplankton from being fertilized as it would decrease the quality of the waters.

ACKNOWLEDGEMENTS

This research is financed by the National Innovation Research Agency, Republic of Indonesia through the National Research Priority for Micro and Macro Marine Algae Strains of Indonesia in the year 2021 program. Thank you to Environmental Management Study Program, Graduate School, Pakuan University Bogor, for the guidance during the research. In this paper, all the authors are the main contributors.

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