Spatial variation of phytoplankton and some physico-chemical variables in Lake Tempe, South Sulawesi

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Abstract. Lake Tempe in South Sulawesi is one of the floodplain lakes in Indonesia that has a unique phytoplankton characteristic. This study aims to see the abundance of phytoplankton and their relationship with physico-chemical parameters in Lake Tempe. Observations were conducted in March and May 2017 in six zones of the lake, consist of 5 zones are non-permanent areas and 1 zone are permanent area. Dissolved oxygen, pH, temperature, turbidity, total dissolved solids, transparency, chlorophyll-a, total nitrogen, and total phosphorus were measured to determine the water quality. Phytoplankton abundance was calculated using the Sedgewick Rafter Method. Phytoplankton community structure was analyzed by Diversity Index, Evenness Index, and Dominance Index. A total of five phyla and 80 species of phytoplankton were found in Lake Tempe, consists of Bacillariophyta, Chlorophyta, Cyanophyta, Dinophyta, and Euglenophyta. The abundance of phytoplankton ranged between 1,133 – 701,390 individual L−1. Moderate to high diversity (1.751 – 3.859) and low uniformity (0.069 – 0.306) among species in the phytoplankton community was found in Lake Tempe. The dominant species was found at two sampling sites (Z.2.1 and Z.2.2), namely Aphanocapsa. The presence of Cyanophyta in Lake Tempe is related to the total phosphorus value.

Keywords: abundance; Indonesia; phytoplankton; taxa richness; water quality

1. Introduction

Lake Tempe is a floodplain lake located in Wajo Regency, Sidrap Regency and Soppeng Regency, South Sulawesi Province, at 4°00'00"-4°15'00" S and 119 ° 52'30"-120°07'30" E. The physical condition of the water catchment area and rainfall greatly affected the water level, inundation area, and volume of Lake Tempe [1]. In the rainy season, the surface area of the water reaches ±12,050 ha with a maximum depth of ±3 m, and in dry season the surface area of the water remains ±2,050 ha with a maximum depth of ±1 m [2]. Floodplain waters have unique characteristics because conditions are very extreme, especially the water level fluctuation and greatly influenced by its main rivers. The extreme water level fluctuations, at times of high water and low water, resulting in changes in the structure and diversity of phytoplankton communities, the number of species, and its taxonomic composition [3]. The number of phytoplankton species in the floodplain lake is directly related to the level of connectivity to the main channel [4], and significantly affect the structure and function of the community of living organisms therein [5]. Hydrological conditions and water quality parameters will affect phytoplankton abundance and taxa richness in floodplain lakes [6,7], and functional changes in phytoplankton communities
resulting from seasonal hydrological variations, mainly due to changes in nitrogen and phosphorus content and chemical speciation along the water year [8].

Floodplain lakes consist of interacting sub-systems, namely the permanent zone (always inundated) and the non-permanent zone (sometimes inundated). The inundation period is very dynamic related to the rainy season and the dry season. During periods of highwater levels, incoming water carries nutrients such as nitrogen and phosphorus derived from the decomposition of macrophytes [9], increased nutrient content (nitrogen and phosphorus) at a highwater level was caused by the entry of nutrients carried by water inflows [10]. These nutrients are used by phytoplankton, zooplankton, benthic organisms, and aquatic plants. This shows how important the non-permanent zone is in supporting the life of aquatic organisms in floodplain lakes.

Based on this, it is very interesting to study the community of phytoplankton in floodplain lakes such as Lake Tempe. Therefore, this research is aimed to study the spatial variation of phytoplankton in Lake Tempe and its relationship with water quality.

2. Methods
The study was conducted in Lake Tempe, South Sulawesi, Indonesia in March and May 2017. Observations on the phytoplankton community were carried out at six zones of the lake, consist of 5 zones are non-permanent areas (Z1, Z2, Z3, Z4, and Z5) and 1 zone are permanent area (Z6) (figure 1). Water samples of two litters were collected at the water surface, concentrated using plankton net no. 25 (net mesh size 53 µm) and preserved using 1% of Lugol solution until the sample turned brownish yellow [11, 12]. Identification was carried out under NIKON Diaphot 300 inverted microscope at 100x, 200x, and 400x magnification [13-17]. Abundance was calculated using the Sedgwick Rafter cell counting method [11] and results were recorded in individuals L\(^{-1}\).

Figure 1. Sampling sites at Lake Tempe in March and May 2017.
Directly measured water quality parameters included pH, dissolved oxygen (DO), temperature, total dissolved solids (TDS), and turbidity, using the HORIBA U51 water quality checker. The parameters analysed in the laboratory included total phosphorus/TP (4500-P and 4500-PE methods) and chlorophyll-a (10200 H method) [11]; total nitrogen/TN (brucine method) based on [18]. Water transparency was measured using a Secchi disk.

The phytoplankton community structure was determined with the Shannon Wiener Diversity Index (H'), the Evenness Index (E) and the Simpson Dominance Index (C) [19]. Shannon Wiener index was formulated by the equation:

\[
H' = -\sum_{i=1}^{s} p_i \ln p_i
\]

Where:
H': the Shannon diversity index;
p_i: n_i/N;
n_i: number of individuals of taxon i;
N: total number of individuals in the sample;
s: number of species encountered.

Evenness index was formulated by the equation:

\[
E = \frac{H'}{H'_{max}}
\]

Where:
E: Evenness index;
H': Shannon-Wiener Index;
S: number of species encountered;
H'_{max}: the maximum possible value of H' and it is equivalent to ln S.

Simpson Dominance index was formulated by the equation:

\[
D = \sum_{i=1}^{s} \left( \frac{n_i}{N} \right)^2
\]

Where:
D: the Simpson Dominance index;
n_i: number of individuals of taxon i;
N: total number of individuals in the sample;
S: number of species encountered.

3. Results and Discussions
3.1 Result
Water quality data during the observation in Lake Tempe is presented in table 1. It tends to vary in each sampling site. The total phosphorous (TP) values ranged from 0.092-0.178 mg L^{-1}, total nitrogen (TN) ranged from 0.243 - 0.861 mg L^{-1}, and chlorophyll-a ranged from 3,207-33,982 mg m^{-3}. 
Table 1. Average values of physical and chemical parameters at each sampling site.

| Sampling Site | Water Depth (m) | Transparency (m) | DO (mg L⁻¹) | pH | Temperature (°C) | TDS (g L⁻¹) | Turbidity (NTU) | TP (mg L⁻¹) | TN (mg L⁻¹) | Chlorophyll-a (mg m⁻³) |
|---------------|----------------|-----------------|-------------|----|-----------------|-------------|---------------|-------------|-------------|------------------------|
| Z.1.1         | 1.05           | 0.62            | 5.57        | 6.68 | 29.5            | 0.161       | 80            | 0.178       | 0.861       | 3.207                  |
| Z.1.2         | 1.50           | 0.32            | 7.13        | 7.66 | 30.2            | 0.132       | 96            | 0.166       | 0.599       | 4.756                  |
| Z.1.3         | 1.20           | 0.48            | 7.44        | 7.44 | 32.1            | 0.165       | 38            | 0.114       | 0.617       | 29.523                 |
| Z.1.4         | 1.50           | 0.46            | 8.22        | 7.92 | 30.6            | 0.143       | 58            | 0.105       | 0.627       | 13.960                 |
| Z.1.5         | 2.05           | 0.25            | 7.64        | 7.63 | 30.9            | 0.121       | 122           | 0.140       | 0.683       | 8.563                  |
| Z.1.6         | 2.05           | 0.21            | 8.50        | 8.00 | 30.0            | 0.116       | 116           | 0.106       | 0.667       | 5.585                  |
| Z.2.1         | 1.65           | 0.22            | 7.43        | 7.77 | 31.6            | 0.125       | 89            | 0.111       | 0.606       | 47.864                 |
| Z.2.2         | 1.50           | 0.23            | 7.99        | 7.26 | 31.0            | 0.125       | 109           | 0.116       | 0.564       | 33.982                 |
| Z.3.1         | 1.75           | 0.22            | 7.59        | 7.47 | 30.7            | 0.135       | 129           | 0.159       | 0.466       | 31.842                 |
| Z.4.1         | 1.95           | 0.26            | 7.27        | 7.63 | 30.2            | 0.113       | 94            | 0.167       | 0.493       | 27.086                 |
| Z.4.2         | 1.39           | 0.60            | 4.68        | 7.14 | 29.7            | 0.106       | 124           | 0.096       | 0.243       | 9.509                  |
| Z.5.1         | 2.18           | 0.18            | 7.30        | 7.56 | 30.0            | 0.121       | 154           | 0.092       | 0.398       | 16.643                 |
| Z.5.2         | 1.08           | 0.52            | 4.41        | 7.11 | 29.5            | 0.156       | 143           | 0.111       | 0.629       | 27.274                 |
| Z.6.1         | 2.10           | 0.27            | 7.86        | 7.83 | 31.0            | 0.111       | 107           | 0.099       | 0.473       | 6.307                  |
| Z.6.2         | 2.15           | 0.21            | 8.11        | 8.20 | 30.2            | 0.117       | 161           | 0.114       | 0.446       | 7.960                  |
| Z.6.3         | 2.10           | 0.22            | 7.72        | 7.73 | 30.1            | 0.118       | 126           | 0.128       | 0.515       | 17.992                 |
| Z.6.4         | 2.30           | 0.19            | 7.56        | 7.92 | 29.5            | 0.116       | 133           | 0.130       | 0.754       | 9.098                  |
| Z.6.5         | 2.35           | 0.21            | 7.19        | 8.21 | 29.9            | 0.112       | 115           | 0.125       | 0.687       | 19.377                 |

The composition of phytoplankton in Lake Tempe based on abundance (figure 2a) was dominated by Cyanophyta of 60% (701,390 individuals L⁻¹), while Dinophyta had the lowest abundance of 0.1% (1.133 individuals L⁻¹). Species in high abundance were Mougeotia (Chlorophyta), Aulacoseira granulate (Bacillariophyta), Anabaena spiroides, Aphanocapsa, and Microcystis (Cyanophyta). Phytoplankton consisted of five phyla (figure 2b), the high number of species was Chlorophyta (51%) and the lowest number of species was Dinophyta (2%). Chlorophyta consisted of 42 species, Bacillariophyta (23 species), Cyanophyta (8 species), Euglenophyta (5 species), and Dinophyta (2 species).

![Figure 2a](image1.png)  ![Figure 2b](image2.png)

**Figure 2.** Composition of phytoplankton groups based on (a) total abundance and (b) number of species.

The abundance of phytoplankton at each sampling site during observations ranged from 1,268-419,798 individuals L⁻¹. The lowest abundance was found at Z.6.1 and the highest abundance was found at Z.2.1 (table 2). Table 2 showed phytoplankton composition based on the number of species and abundance at each station.
Table 2. Number of species and abundance of phytoplankton in each sampling site.

| Sampling Site | Number of Species | Abundance (Individuals L⁻¹) |
|---------------|-------------------|----------------------------|
| Z.1.1         | 33                | 8,059                      |
| Z.1.2         | 31                | 53,291                     |
| Z.1.3         | 34                | 64,249                     |
| Z.1.4         | 31                | 96,938                     |
| Z.1.5         | 22                | 40,286                     |
| Z.1.6         | 20                | 32,048                     |
| Z.2.1         | 24                | 419,798                    |
| Z.2.2         | 27                | 267,852                    |
| Z.3.1         | 28                | 24,045                     |
| Z.4.1         | 26                | 35,175                     |
| Z.4.2         | 29                | 4,043                      |
| Z.5.1         | 25                | 10,365                     |
| Z.5.2         | 31                | 26,243                     |
| Z.6.1         | 17                | 1,268                      |
| Z.6.2         | 15                | 23,966                     |
| Z.6.3         | 15                | 40,470                     |
| Z.6.4         | 18                | 7,886                      |
| Z.6.5         | 20                | 21,064                     |

The index value of diversity, evenness, and dominance can be used to assess the stability of phytoplankton community. The value of diversity index (H') in Lake Tempe was ranged from 1.216 to 3.589, the evenness index value (E) ranged from 0.069 to 0.306, and the dominance index value (C) ranged from 0.111 to 0.620 (table 3).

3.2. Discussion
The water depth in March and May ranges from 0.90 to 2.40 m, at this time it is a period of inundation in Lake Tempe. In March the water depth begins to rise in Lake Tempe, and will reach its peak in July [1, 2]. The low transparency in Lake Tempe in 2017 was relatively similar within 2011, 2013, and 2019 [2, 21, 22]. High sedimentation is the cause of the low transparency in Lake Tempe. Sedimentation in Lake Tempe comes from the erosion of land cover in the form of agricultural land and pasture in the upstream area [1], rainwater inputs that bring agricultural runoff and soil erosion in Lake Tempe cause lower transparency values [22].

Dissolved oxygen shows a value that supports the life of aquatic organisms. The pH value showed quite a high value, this shows that Lake Tempe is productive water and this is common in eutrophic waters [20]. The temperature in Lake Tempe is relatively high around 29.5-32.1°C, this high value is the same as the results observed by [2, 21, 22]. This is due to the position of Lake Tempe in the latitude equator area [22].

Turbidity will affect the penetration of light entering the water and will disrupt the life of phytoplankton. The turbidity value ranges from 38-161 NTU, this value is higher than the turbidity in 2016 [2]. TDS values range from 0.106 to 0.165g L⁻¹, TDS describes the inorganic material in the waters. The value of TN and TP in Lake Tempe is quite high, based on the Regulation of the Minister of Environment of the Republic of Indonesia No. 28/2009, the value of TN is in the eutrophic category and TP is in the hypereutrophic category. The high nutrient content is due to the entry of nutrients carried by water inflow and also the decomposition of aquatic plants when the water begins to submerge. Incoming water carries nutrients such as nitrogen and phosphorus derived from the decomposition of
aquatic plants, during periods of high water-levels [10]. The chlorophyll-a content also shows that Tempe Lake is included in the category of eutrophic water.

Table 3. Diversity Index, Evenness Index, and Dominance Index in each sampling site

| Sampling Site | Diversity Index | Evenness Index | Dominance Index |
|---------------|-----------------|----------------|-----------------|
| Z.1.1         | 3.859           | 0.306          | 0.111           |
| Z.1.2         | 3.314           | 0.215          | 0.167           |
| Z.1.3         | 3.123           | 0.198          | 0.197           |
| Z.1.4         | 2.594           | 0.157          | 0.268           |
| Z.1.5         | 2.023           | 0.132          | 0.325           |
| Z.1.6         | 2.567           | 0.210          | 0.264           |
| Range Z1      | 2.023–3.859     | 0.132–0.306    | 0.111–0.325     |
| Z.2.1         | 1.216           | 0.069          | 0.620           |
| Z.2.2         | 1.759           | 0.100          | 0.549           |
| Range Z2      | 1.216–1.759     | 0.069–0.100    | 0.549–0.620     |
| Z.3.1         | 3.250           | 0.233          | 0.174           |
| Z.4.1         | 2.370           | 0.156          | 0.399           |
| Z.4.2         | 3.723           | 0.351          | 0.120           |
| Range Z4      | 2.370–3.723     | 0.156–0.351    | 0.120–0.399     |
| Z.5.1         | 3.119           | 0.294          | 0.204           |
| Z.5.2         | 3.061           | 0.245          | 0.226           |
| Range Z5      | 3.061–3.119     | 0.245–0.294    | 0.204–0.226     |
| Z.6.1         | 2.886           | 0.281          | 0.196           |
| Z.6.2         | 1.765           | 0.171          | 0.506           |
| Z.6.3         | 1.751           | 0.126          | 0.443           |
| Z.6.4         | 2.666           | 0.240          | 0.316           |
| Z.6.5         | 2.501           | 0.200          | 0.361           |
| Range Z6      | 1.751–2.886     | 0.126–0.280    | 0.196–0.506     |

The abundance of phytoplankton in Lake Tempe is quite high. Cyanophyta is the group with the highest abundance, reaching 60%, followed by Chlorophyta (24%), and Bacillarilyphyta (16%). This result differs from that obtained by [2] in the permanent zone of Lake Tempe, where Bacillarilyphyta is highly abundant. Many factors cause changes in the abundance and composition of phytoplankton. In floodplains lakes, the abundance of phytoplankton and the number of species were influenced by hydrological conditions and water quality parameters [6, 7], increased Diatoms (Bacillarilyphyta) in floodplains lake caused the decline of Cyanophyta [4]. In Lake Tempe, the abundance of Bacillarilyphyta decreased replaced by Cyanophyta.

The high Cyanophyta in Lake Tempe is related to the high nutrient content in the waters, according to Kraus et al. [8], nutrient input in the water causes high Cyanobacteria in floodplains, it was also mentioned by Sulastri et al. and Sulawesty et al. [23, 24] that the dominance of Cyanophyta in Lake Maninjau is characterized by high levels of nutrients such as TN, TP, and nitrates, and phylum Cyanophyta is more influenced by the concentration of phosphorus, chlorophyll-a, turbidity, and organic
matter [23]. The observations show that chlorophyll-a, TP, and turbidity in Lake Tempe is high (table 1). The input of nutrients into the waters leads to the dominance of cyanobacteria, this plays an important role in supporting the stability of the phytoplankton-nutrient relationship during the hydrological cycle [8].

Anabaena spiroides, Anabaena, Aphanocapsa, and Microcystis are species that are in high abundance and are always found during observation, from the Chlorophyta group is Mougeotia, and from the Bacillaryophyta group is Aulacoseira granulata. These species are commonly found in eutrophic, alkaline, and nutrient-rich waters [17, 26], such as Lake Tempe. The number of species of Chlorophyta was higher than other phyla reaching 51% of the species found. Large contributions from Chlorophyta are also found in several floodplain lakes such as the lakes of the Lower Amazon [3], the lakes of the Araguaia River [10], and the Bhoj wetland area [7], as well as observations in Lake Tempe [2]. The high number of species of Chlorophyta in the waters is due to its cosmopolitan distribution.

The distribution of the abundance of phytoplankton at each sampling site shows a variable value, its distribution pattern is similar to that of chlorophyll-a. For example, Z.2.1 and Z.2.2 have a high abundance of phytoplankton, the chlorophyll-a content also has a higher value than other sampling sites. This shows that chlorophyll-a can describe the abundance of phytoplankton in the water, as mentioned by Darchambeau et al. [25] that the biomass of phytoplankton can be described by mg / m3 of chlorophyll-a. The high abundance in Z.2.1 and Z.2.2 is due to the high abundance of Cyanophyta of the Aphanocapsa species. This species is typical of open wetland waters [17] such as Z.2.

Diversity, evenness, and dominance index can describe the stability of the phytoplankton community in waters. The diversity index value in Lake Tempe shows moderate to high values, the evenness index value is close to zero indicating low evenness, indicating a tendency to dominate certain species. The results showed that there were two sampling sites with a dominance index value, namely Z.2.1 and Z.2.2, with the dominant species is Aphanocapsa. Z.2.1 and Z.2.2 are part of the non-permanent zone which is strongly influenced by water fluctuation, which causes the community to be unstable. The presence of dominating species indicates an unstable community structure due to ecological pressure [19].

Phytoplankton spread throughout Lake Tempe, its abundance is relatively higher. The abundance distribution pattern was almost the same as the chlorophyll-a content. The community structure is relatively stable with moderate to high diversity.

4. Conclusion
Nutrient content in Lake Tempe influences the structure of phytoplankton communities quantitively and qualitatively, especially total phosphorous (TP) influences the presence of Cyanophyta. The phytoplankton community structure is stable with moderate to high diversity values, although two sampling sites have unstable communities with a tendency to dominate species.

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