Phytoplankton community and relationship to water quality in the permanent area of Lake Tempe, South Sulawesi, Indonesia

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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 aimed to describe the phytoplankton abundance and relationship to water quality in the permanent areas of Lake Tempe. Observations were conducted from March to May 2016 in the permanent areas of Lake Tempe at five locations. The observed parameters were phytoplankton abundance and water quality. The phytoplankton community structure was analyzed by the Diversity Index, Evenness Index and Dominance Index. Total nitrogen, total phosphorus and Chlorophyll values were relatively high in April and May 2016 compared to those in March 2016. A total of five phyla and 53 species of phytoplankton were found in Lake Tempe, comprising Chlorophyta, Bacillariophyta, Cyanophyta, Euglenophyta and Dinophyta. The abundance of phytoplankton ranged between 540 and 1,448,100 individuals L^{-1}. Phytoplankton abundance was high, with relatively low taxa richness, in April and May 2016, compared to March 2016. Low to moderate community (0.089–3.155) and low uniformity (0.004–0.323) among species in the phytoplankton community were found in Lake Tempe. The dominant species were found especially in April and May 2016, as seen from the high dominance index value (0.648–0.983). This study concludes that the connectivity of main rivers and water levels is the basis in the management of Lake Tempe to increase biodiversity.
Key Words: abundance, diversity, species richness, nutrient, phytoplankton.

Introduction. Floodplain lakes are mainly characterized by very high water level fluctuations. These extreme conditions are greatly influenced by the main rivers which make them have unique characteristics. Junk et al (1989) and Bonnet et al (2008) stated that the height of water in the main river greatly determines the characteristics of lake flooding exposures such as flooded areas, duration of submergence, connectivity between lakes, and residence time of water. This is certainly very influential on energy and nutrient input between rivers and lakes due to flooding exposure, also affecting the structure, diversity, and productivity of the resident biota, including phytoplankton. Casali et al (2011) found in their research that extreme water level fluctuations cause changes in the structure and diversity of the phytoplankton community, such as the number of species and their taxonomic composition. In their study, Nabout et al (2006) also found that the difference between high and low water in a lake exposed to flooding is observed in the abiotic aspects as well as in the composition and dynamics of the phytoplankton community. The number of phytoplankton types in a lake exposed to flooding is directly related to the level of connectivity to its main channel (Bortolini et al 2014). Many other studies also show that water level changes affect the structure of phytoplankton communities (Ibanez 1998; Junk et al 1989; Nabout et al 2006).

The abundance of phytoplankton and taxa richness in floodplain lakes is influenced by hydrological conditions and water quality parameters (Grabowska et al 2014; Bhat et al 2015). The morphometric characteristics of Lake Camaleao and its relationship to the main river greatly affect the dynamics of phytoplankton (Ibanez 1998). Meanwhile, a two-year observation of Bhat et al (2015) in Bhoj wetland showed that in the first year taxa richness and phytoplankton abundance were lower in the wet season than in the dry season. In contrast, the second year higher taxa richness and phytoplankton abundance were observed during the wet season than during the dry season. This was influenced by hydrologic changes in these waters.

It is very interesting to study the presence of phytoplankton in floodplain lakes such as Lake Tempe as one of the biological variables that can be used to assess the condition of Lake Tempe. This lake has a very important role in South Sulawesi, especially in Wajo, Sidrap and Soppeng Regencies, as the biggest freshwater fish producing areas in the province. On the other hand, there is a continuing decline in fish catches in these waters (Dina et al 2014). Observations conducted by Aisyah & Nomosatryo (2016) showed that Tempe is a productive lake with nitrogen as a limiting factor and the primary producer role of the phytoplankton make it essential to these waters. The aim of the current research was to identify the phytoplankton community structure and its role in the permanent areas of Lake Tempe in relation to the water level fluctuations and quality. The results of these observations will be used as a reference in developing alternative management of Lake Tempe based on the carrying capacity of ecosystems.

Material and Method

Description of the study sites. Lake Tempe is a floodplain lake located in Wajo Regency, Sidrap Regency, and Soppeng Regency, South Sulawesi Province, at positions of 4 ° 00'00 "- 4 ° 15'00" S and 119 ° 52'30 "- 120 ° 07'30 " E. According to Setiawan & Wibowo (2013), the water level fluctuations reach ± 5.6 m. The physical condition of the water catchment area and rainfall greatly affect the water level, inundation area and volume of Lake Tempe. Based on the analysis of the frequency of data monitoring of Lake Tempe elevation for 15 years, the bathymetry map obtained from the Irrigation Agency of South Sulawesi Province, and the fluctuations of average water level elevation in one year (Figure 1), permanent and non-permanent inundation areas of Lake Tempe have been obtained (Harsono 2017). Permanent areas on floodplains, such as the Lake Tempe, are always flooded throughout the year. 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 (KLH 2011).

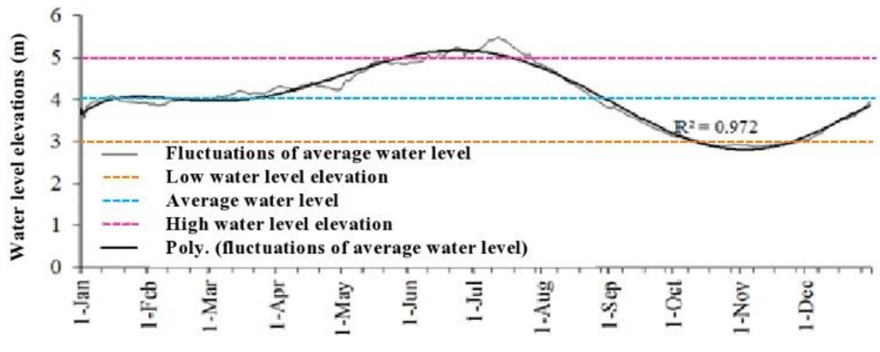

Figure 1. Fluctuations of average water level elevation in Lake Tempe (Harsono 2017).

Data collection. Observations on the phytoplankton community were carried out in March, April, and May 2016, when the water began to rise (Figure 2), at five locations in the permanent areas of Lake Tempe. The sampling map of the observation station is presented in Figure 3. Water samples of 10-20 L were collected at the water surface (APHA 2012), filtered using plankton net no. 25 (net mesh size 53 μm) and preserved using Lugol to a concentration of 1%, until the sample turned brownish yellow (APHA 2012; Wetzel & Likens 2000). Identification was carried out under NIKON Diaphot 300 inverted microscope at 100x, 200x, and 400x magnification, as stated by: Prescott (1951), Scott & Prescott (1961), Mizuno (1979), Gell et al (1999) and Bellinger & Sigee

(2010). Abundance was calculated using the Sedgwick Rafter cell counting method (APHA 2012) and results were recorded in individuals L^{-1}.

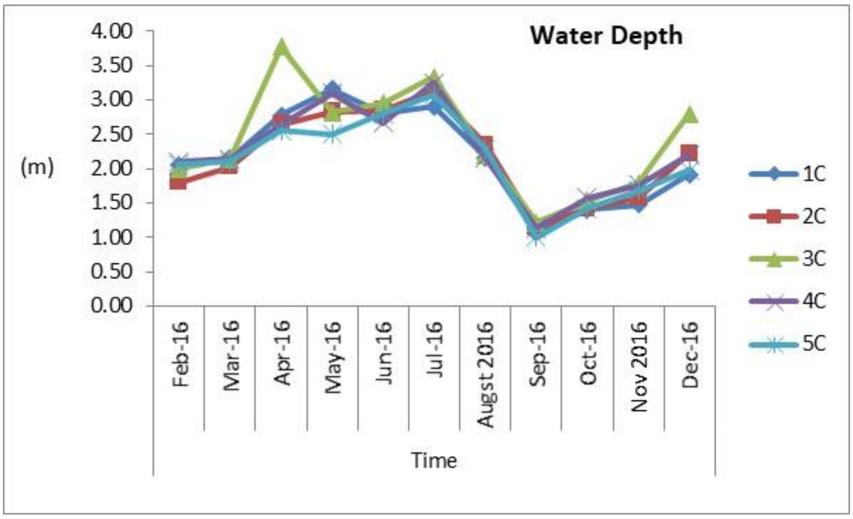

Figure 2. Water depth fluctuations in the permanent areas of Lake Tempe in 2016 (Sulawesty 2016).

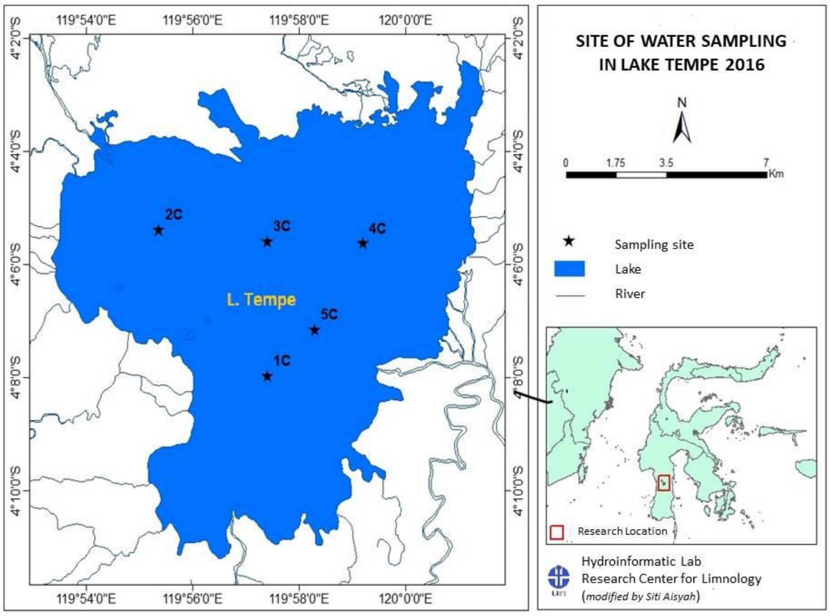

Figure 3. Sampling site in the permanent areas of Lake Tempe in March, April, and May 2016.

Directly measured water quality parameters (with a HORIBA U50 water quality checker) were: pH, dissolved oxygen (DO), temperature, conductivity, total dissolved solids (TDS) and turbidity, while the parameters analysed in the laboratory were: Total Phosphorus/TP (4500-P and 4500-PE methods) and chlorophyll-a (10200 H method), based on APHA (2012); Total Nitrogen/TN (brucine method), based on APHA (1975).

Analysis. Analysis of the phytoplankton community structure can be determined with the Shannon Wiener Diversity Index (H'), the Evenness Index (E) and the Simpson Dominance Index (C), based on Odum (1971). Shannon Wiener index was formulated by the equation:

$$H' = -\sum_{1=1}^{s} \text{Pi} \ln \text{Pi}$$

Where:
H' - the Shannon diversity index;
Pi - ni/N;
ni - 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:

$$D = \sum_{i=1}^{s} \left(\frac{ni}{N}\right)^2$$

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

Results and Discussion

Environmental parameters. Fluctuations in water level in natural lakes are the result of an imbalance in the long-term calculation of the amount of water entering (through inflow, rainfall, runoff and ground water) and the water coming out of the lake (through evaporation and outflow) (Zohary & Ostrovsky 2011). Flooding inundation is a very important environmental parameter in lakes and floods and will determine the productivity and interaction of biota (De Domitrovic 2003). From March to May, the water begins to inundate Lake Tempe (Harsono 2017; Sulawesty 2016). The water depth, ranging from 2.03 to 3.77 m and the water transparency, ranging from 0.42 to 0.94 m, at the time of observation, increased from March to May 2016 (Figure 4).

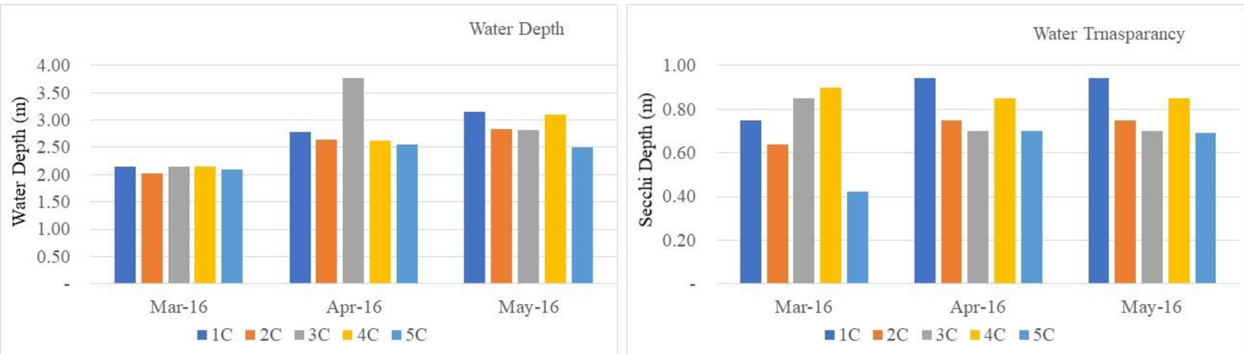

Figure 4. Water depth and transparency in Lake Tempe in March, April, and May 2016.

Turbidity, TDS, and conductivity are presented in Figure 5, with values in the ranges of 7.71 to 42.80 NTU (for turbidity), 11 mg L^{-1} to 107 mg L^{-1} (for TDS), and 0.132 mS cm^{-1} to 1.71 mS cm^{-1} (for conductivity). Water transparency increased with the decrease of turbidity, TDS, and conductivity. Casali et al (2011) observed that the minimum turbidity value occurs when the water is high, and the maximum turbidity value occurs when the water is low. Meanwhile, the water transparency is higher when the water is high and lower when the water is low.

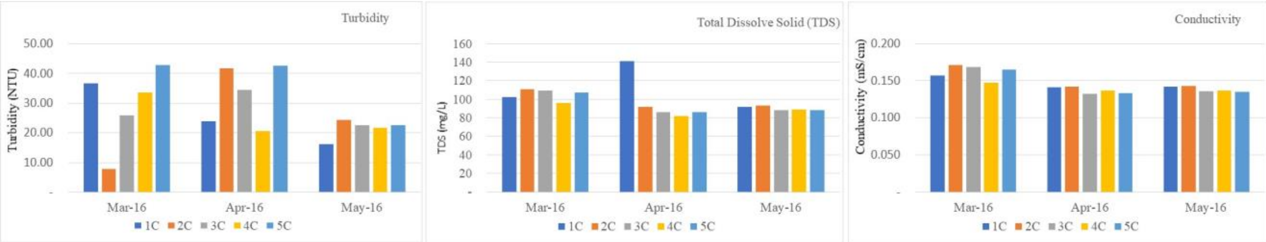

Figure 5. Turbidity, total dissolved solids (TDS), and conductivity in Lake Tempe in March, April, and May 2016.

Dissolved oxygen (DO) is an important environmental parameter for the lake fauna's respiration. During respiration, organisms consume oxygen and give off carbon dioxide while absorbing food molecules to obtain energy for growth and maintenance (Viet et al 2016). The DO value in Lake Tempe increased from 3.12 mg L^{-1} to 9.47 mg L^{-1} during the observation period, as presented in Figure 6. This is presumably due to clearer waters in May (marked by a lower turbidity value), compared to March and April, which intensified photosynthesis processes, resulting in higher DO, as observed by Sharma et al (2016).

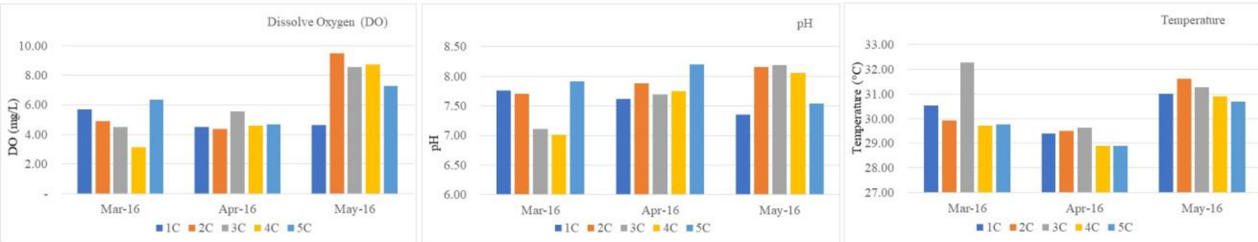

Figure 6. Dissolved oxygen (DO), pH, and temperature in Lake Tempe in March, April, and May 2016.

The pH value ranged from 7.01 to 8.19 (Figure 6). The value in April and May was relatively higher than in March. The pH value during the observation showed quite a high value, illustrating that Tempe is a productive lake. Temperatures tended to be higher in May than in March and April, ranging from 28.90 to 32.27°C (Figure 6). Total nitrogen (TN), total phosphorus (TP), and chlorophyll-a in Lake Tempe from March, April, and May 2016 are presented in Figure 7. TN ranged from 0.051 to 1.143 mg L^{-1}. TP ranged from 0.015 to 0.916 mg L^{-1}, and chlorophyll-a ranged from 0.867-34.388 mg m^{-3}. TN and chlorophyll-a in April and May were higher than in March, while TP values were higher in May. Increased nutrient content (nitrogen and phosphorus) at a high water level was caused by the entry of nutrients carried by water inflows. Also, when the water began to inundate the non-permanent areas of Lake Tempe that are overgrown with macrophytes, it caused decay which increased the nutrients in this region and flowed into the permanent areas of the lake. Nabout et al (2006) mentioned that during periods of high water levels, incoming water carries nutrients such as nitrogen and phosphorus derived from the decomposition of macrophytes.

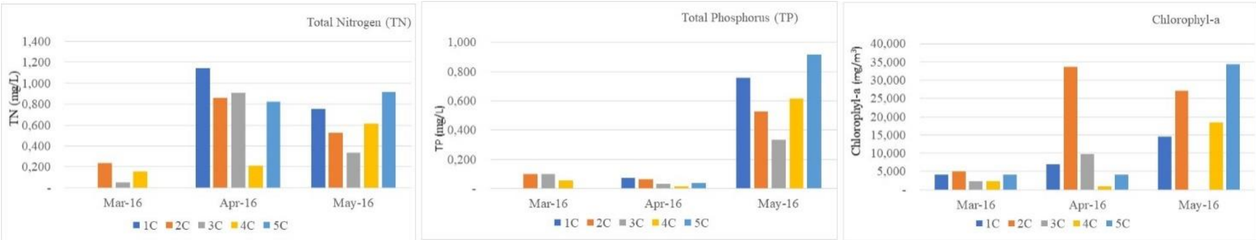

Figure 7. Total nitrogen (TN), total phosphorus (TP), and chlorophyll-a in Lake Tempe in March, April, and May 2016.

Phytoplankton community and relationship with environmental parameters. Extreme water fluctuations in floodplain waters cause changes in the community structure and phytoplankton diversity (Casali et al 2011). Taxa richness and identification of phytoplankton in Lake Tempe showed different values. In March (low water) the species richness was relatively higher than that in April and May (high water) (Table 1), a point also highlighted by Casali et al (2011) and by Grabowska et al (2014). In March, there were 39 species from the phyla Bacillaryophyta, Chlorophyta, Cyanophyta, Dinophyta, and Euglenophyta. In April, there were 26 species from the phyla Bacillaryophyta, Chlorophyta, Cyanophyta, and Euglenophyta, whereas in May, 32 species from the phyla Bacillaryophyta, Chlorophyta, Cyanophyta, Dinophyta, and Euglenophyta (Table 1). The total number of taxa observed was of 53 species, smaller than the number of: 60 species found in the floodplain waters of Lake Sentarum National Park (Sulawesty 2014), 72 species found in the Lower Amazon floodplain waters (Casali et al 2011) and 245 species found in the floodplain lakes of the Biebrza River (Grabowska et al 2014). Chlorophyta taxa richness was higher than other phyla. Large contribution of Chlorophyta to phytoplankton taxa richness was also found in other floodplain waters such as: the Lake Sentarum National Park (Sulawesty 2014), the lakes of the Araguaia River (Nabout et al 2006), the lakes of the Lower Amazon (Casali et al 2011), and the Bhoj wetland area (Bhat et al 2015). The high presence of Chlorophyta is probably due to its cosmopolitan distribution.

Table 1

Phytoplankton species richness at the phyla taxonomic level for Lake Tempe in March, April and May 2016

Phylum	*Taxa*			
	Mar-16	*Apr-16*	*May-16*	*Total*
Baccillaryophyta	8	6	2	12
Chlorophyta	22	12	20	30
Cyanophyta	4	5	6	6
Dinophyta	1	0	1	1
Euglenophyta	4	3	3	4
Total	39	26	32	53

The abundance of phytoplankton ranged from 540 to 1571 individuals L^{-1} in March, from 192,750 to 1,448.100 individuals L^{-1} in April, and from 104,787 to 313,350 individuals L^{-1} in May (Table 2). The value in April and May was higher than in March. The high abundance of phytoplankton in April and May was due to the increase in nutrients entering the permanent areas of Lake Tempe (Figure 7). Nutrients began to enter Lake Tempe along with the increasing water carrying nutrients, which triggered the growth of phytoplankton, causing very high abundance in April and May. The alternating periods of high water and low water increase the nutrient cycle, which in turn stimulates the biodiversity and productivity of shallow water bodies. When water is high, changes in the chemical composition of the sediment, water column and supply from the catchment area support the growth of phytoplankton (Grabowska et al 2014).

Table 2

The abundance of phytoplankton in Lake Tempe in March, April, and May 2016

Time	*Sampling site*				
	1C	*2C*	*3C*	*4C*	*5C*
March 2016	900	1,571	983	874	540
April 2016	192,750	1,448.100	898,275	271,388	535,125
May 2016	207,660	313,350	219,810	194,550	104,787

High phytoplankton abundance (Table 2) was also characterized by high chlorophyll-a in April and May (Figure 7). The strong positive correlation of chlorophyll-a content with the density of phytoplankton indicates that phytoplankton biomass can be expressed as mg chlorophyll-a m^{-3} or mg chlorophyll-a m^{-2}, by integrating chlorophyll-a measurements at different sampling depths throughout the mixolimnion (0-65 m) (Darchambeaua et al 2014).

The highest average phytoplankton abundance was from the phylum Bacillaryophyta (Figure 8), especially in April and May (Figure 9), while in March the highest percentage of phytoplankton abundance was from the Chlorophyta *phylum* (Figure 9). The high abundance of Diatoms/Bacillaryophyta (especially *Asterionelia* spp., *Fragilaria crotenensis*, *Synedra*, *Stephanodiscus*, and *Melosira granulata*) in lakes is a characteristic of eutrophic waters, usually alkaline with nutrient enrichment (Sellers & Markland 1987). The nutrient content (TN and TP) in Lake Tempe was quite high especially in April and May (Figure 7), and he pH value also showed that the Lake Tempe water was alkaline (Figure 6), both parameters causing the high abundance of Bacillaryophyta in April and May.

There were no species with high abundance in March (low water). On the contrary, in April and May (high water) there were species with higher abundance, namely *Aulacoseira granulata*, formerly *Melosira* (Gomez et al 1995) and Bacillaryophyta. The dominance of biovolume from filamentous Bacillariophyceae during periods of high water occurred because, at certain times, this phytoplankton can form an inoculum consisting of vegetative cells, which are stored in sediments and resuspended in the water column when turbulence occurs as mentioned by Nabout et al (2006). Observations of the latter study also showed that, at a high water period, the largest phytoplankton biovolume is of filamentous species such as *Aulacoseira italica* and *Aulacoseira herzogii*.

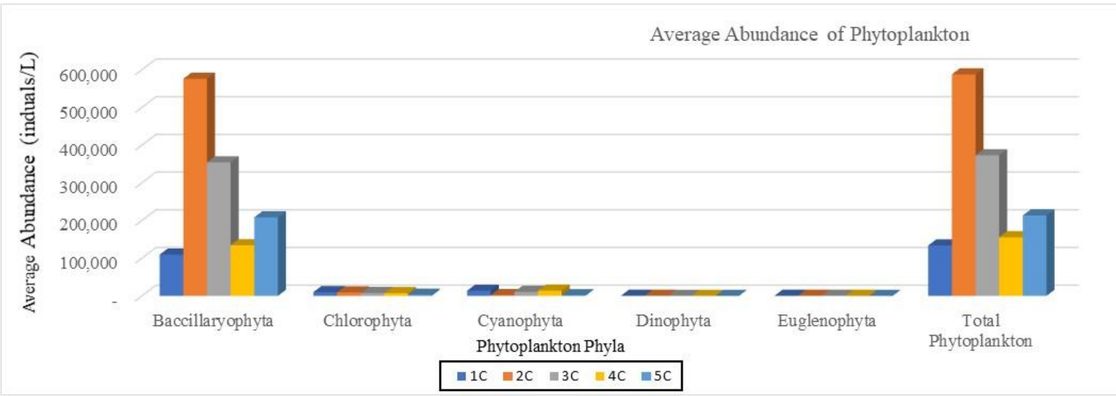

Figure 8. The average abundance of phytoplankton at different study sites in Lake Tempe in March, April, and May 2016.

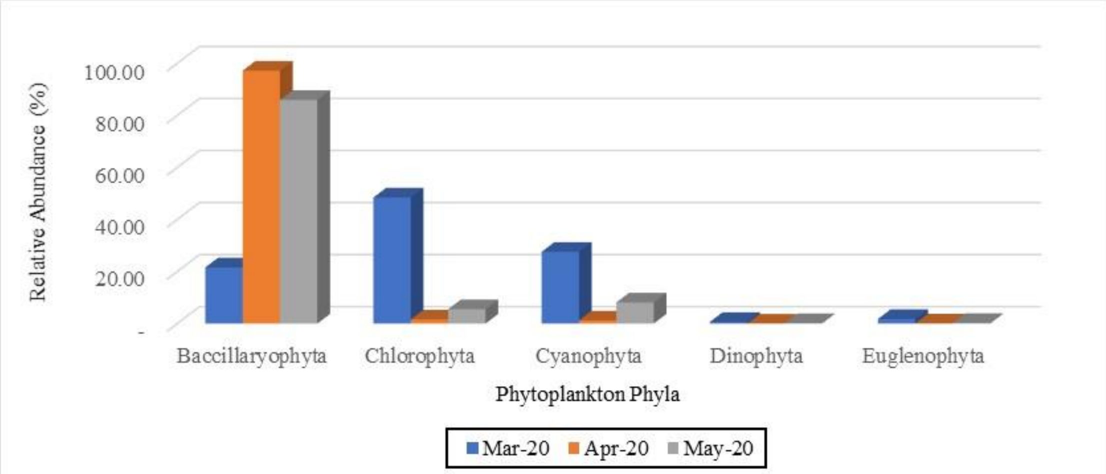

Figure 9. The relative abundance of phytoplankton in Lake Tempe in March, April, and May 2016.

Phytoplankton index. Diversity Index, Evenness Index, and Dominance Index of phytoplankton in Lake Tempe during this study are presented in Table 3. According to Odum (1971), moderate diversity index values in March was shown, while April and May showed low values. Evenness index values close to zero in April and May indicate the low uniformity of the phytoplankton community. There is a tendency of dominance by certain species. The dominance index approaching one in April and May shows the dominance type. Observations in April and May showed that there is a dominant species, namely *Aulacoseira granulata*. The presence of species dominating in waters indicates an unstable community structure due to ecological pressure (Odum 1971). Phytoplankton community structure in the permanent area of Lake Tempe is more stable in March (low water) than April and May (high water), which could be due to the water rises (April and May) and to the nutrients carried by the incoming waters, while in March entering water volumes are moderate.

Table 3

Diversity index (H’), evenness index (E), and dominance index (C) of phytoplankton in Lake Tempe in March, April, and May 2016

Time	*Ecology index*		
	H’	*E*	*C*
March 2016	2.458	0.249	0.293
April 2016	0.411	0.023	0.887
May 2016	0.976	0.055	0.747

Conclusions. The variability of physical and chemical conditions of floodplain lakes, which is strongly influenced by the main river, will affect the structure of the phytoplankton community quantitatively and qualitatively. Based on the observation of the permanent areas of Lake Tempe, it is noticeable that taxa richness and phytoplankton diversity are higher when the water is low, whereas phytoplankton abundance is higher when water is high, being accompanied by the dominance of certain species. This study concludes that the connectivity of main rivers and water levels are the basis in the Lake Tempe biodiversity management.

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