Phytoplankton composition and abundance in the floating treatment wetlands (FTWs) system of Lake Maninjau, Indonesia

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Abstract. Algae blooms have been recorded several times in Lake Maninjau and recently in April 2018. Floating treatment wetlands (FTWs) system was installed in June 2018 in Lake Maninjau as one of the methods to reduce the risk of eutrophication in this lake. The study is to reveal the characteristics of phytoplankton composition and abundance including environmental conditions in the FTWs system in Lake Maninjau. TP concentrations tend to decrease due to nutrient dynamics such as the dilution effect of precipitation which shifting the dominant of phytoplankton composition during observation. There were two different groups separating phytoplankton composition between the inside and outside of the FTWs system. The dominant species of Aphanizomenon gracile and Synedra ulna were related to high conductivity and the TP concentration while Oscillatoria formosa was related to the high temperature. Phytoplankton abundance on the inside of FTWs decreased over time compared to the outside of FTWs, while chlorophyll-a fluctuated with the average value of 6.79 µg.L⁻¹ on the inside of FTWs and 9.54 µg.L⁻¹ on the outside of FTWs. This study suggests that the FTWs could potentially reduce the chlorophyll-a thereby minimizing the risk of eutrophication in a tropical lake.

1. Introduction
The eutrophication of freshwaters has been a major global environmental issue, particularly in tropical lakes. Eutrophication is characterized by high nitrogen and phosphorus concentrations in water bodies, resulting in excessive growth of phytoplankton and other aquatic plants [1]. The potential effect of artificial or cultural eutrophication includes the increase of phytoplankton biomass or macrophyte coverage, a shift to harmful algal bloom (HAB), a decrease of water transparency and increased incidence of fish kill and oxygen decline [2]. In Indonesia, the cyanobacterial bloom has been reported in Karangkates reservoir and Lake Maninjau indicated by the occurrence of Microcystis blooms in 2000 and 2001[3] [4]. Most reservoirs and lakes in Indonesia have been heavily impacted by anthropogenic activities and floating fish culture [5]. Unsurprisingly, the occurrence of Microcystis bloom in Lake Maninjau is more frequent, in 2011[6] and recently April 2018 [7]. Microcystis blooms in Lake Maninjau were indicated by green scum formation on the lake surface with a very high chlorophyll-a concentration, as high as >100 µg.L⁻¹ and maximum Microcystis abundance of 24.320 x 10³ ind.L⁻¹ (94.4% of the total assemblage)[7].
The frequent phytoplankton blooms incidence in Lake Maninjau increases concern to remediate the eutrophication problem in this lake. Floating treatment wetlands (FTWs) was installed in June 2018 in Lake Maninjau as one of the methods to reduce the risk of eutrophication. Floating Treatment Wetlands (FTWs) are an emerging variant of constructed wetland technology which consists of emergent wetland plants growing hydroponically on structures floating on the surface of pond or lake basin [8]. Using FTWs concept, an artificial floating island also has been increasingly applied for mitigation of eutrophication and phytoplankton growth [9]. The coverage of the floating mat of FTWs or floating vegetation minimizes light penetration into the water column, thereby limiting the potential for algae growth [8]. FTWs vegetation also can cause severe underwater light attenuation, inhibiting the photosynthesis process by phytoplankton and finally resulting in the reduction of phytoplankton cell density [9]. This will further affect the Physico-chemical conditions of the water column such as dissolved oxygen and pH which are important factors in nutrients assimilation, such as nitrogen and phosphorus [8] [10]. Poor underwater light determines the dominance of several cyanobacteria functional groups adapted to successfully withstand low-light conditions [11]. The functional group of phytoplankton such as codon S_N, S_1, and S_2 which are characterized by solitary, thin and mainly photosynthetic filaments that thrive in mixed layers, are sensitive to flushing and tolerant of light-deficient conditions [12]. The study is aimed to reveal the characteristics of phytoplankton composition and abundance including environmental conditions in the FTWs system in Lake Maninjau.

2. Materials and Methods

2.1. Research location

Lake Maninjau is tectono-vulcanic lake located in West Sumatera, Indonesia, between 100°08′53.84″ E to 100°14′02.39″ E and 0°14′52.50″ S to 0°24′12.17″ S (figure 1) at 462 m above sea level with a surface area of 9,737.50 ha, an average depth of 105.5 m and a maximum depth of 168 m [13]. The volume of water stored in the lake, shoreline and shoreline development is 10.33 billion m³, 52.7 km and 1.51 km/km², respectively [13]. There are two peaks rainy seasons from April to May and October to November. Rainfall is relatively high through the years [14]. In 2018, the higher rainfall occurred in October and November (figure 2).

![Figure 1. Lake Maninjau is located in Sumatra Island of Indonesia. The location of the sampling site is shown by the blue circular (Source: GIS Lab. RC for Limnology LIPI).](image-url)
2.2. Floating Treatment Wetlands (FTWs) design

The FTWs system consisted of several units in alphabet frame inscribed as LIMNOLOGI™ which was assembled using PVC pipe (6-inch Ø) as buoyant material, palm sugar fibers as material mat transplanted onto the woven vinyl rope to hold the fibers. The total area FTWs units of 23.75 m² were planted with *Echinodorus palaefolius*. The FTWs then was placed inside the square metal frame (4 m x 15.5 m) attached to buoyant plastic drums to support the FTWs frame against the wave (figure 3). The floating treatment wetlands (FTWs) system was installed in June 2018 in Lake Maninjau.

2.3. Data collection

Surface water samples were collected at five study sites. Threestations (St1, St2, and St3) were adjacent to the FTWs, one station on the inside of the FTWs (St 4) and one station on the outside of FTWs(St5). The observation was conducted from July to November 2018 including field
measurement to determine Physico-chemical parameters such as temperature, conductivity, dissolved oxygen (DO), pH, total dissolved solids (TDS), total nitrogen (TN) and total phosphorus (TP) and chlorophyll-a-concentration. Phytoplankton samples were collected at the station adjacent FTWs (St 1), on the inside of FTWs (St 4) and the outside of FTW (St 5) (figure 3).

2.4. Physical and chemical measurements
Water temperature, pH, (DO), (TDS) and conductivity data were collected using a water quality checker (Horiba U-10), chlorophyll-α sample was collected by filtering 200 to 500 mL of water sample through a GF/F Whatman glass filter paper and preserved by adding a saturated MgCO₃ solution. The determination of the chlorophyll-α sample is based on APHA [16]. Total Nitrogen (TN) was measured using the persulphate digestion and Brucine methods [16]. Total Phosphorus (TP) was determined using the persulphate digestion and Ascorbic Acid methods [16]. All samples were analyzed at the Research Centre for Limnology, Indonesian Institute of Sciences (LIPI).

2.5. Phytoplankton analysis
Phytoplankton samples were collected at the euphotic zone (surface water and Secchi depth) by filtering 2 L of water through the plankton net (40 μm mesh size). The samples were preserved with 1% Lugol solution for taxonomic study in the laboratory. Phytoplankton species were identified according to Prescott [17], Baker [18], Scott [19] and Gell[20] under magnification of 400x through an inverted microscope. Quantitative analysis of phytoplankton used the Lackey Drop Micro Transect [16]. The functional groups of phytoplankton were classified according to Reynolds[12] and Padi'sak[21]. Direct links between the environmental parameter and the percentage of dominant species of phytoplankton used Canonical Component Analysis (CCA).

3. Results
3.1. Water quality
Higher average value of temperature and pH were observed outside the FTW (St 5), while the higher average value of DO and TDS were found in the adjacent and inside FTWs. The average of conductivity value, TP and TN concentration were not likely distinct between the outside, the inside and the adjacent of FTWs. The lower value of chlorophyll-α was found inside the FTWs (St 4) while the lower phytoplankton abundance was found outside of FTWs (St 5) (table 1).

Temporaly, the water quality parameters fluctuated (figure 4). Low values of temperature and pH were found in October, while low DO concentration was found in September. This coincides with the low concentration of chlorophyll-α in the same month. The lower value of conductivity was found in October and November and the lower value of total dissolved solids (TDS) was found in August. Total nitrogen (TN) and total phosphor (TP) also fluctuated. Higher concentrations of TN and TP were found in July. TP concentration declined below our detection limit measurement(<0.01 mg.L⁻¹) in October and November.

3.2. Phytoplankton composition and abundance
The dominant phytoplankton composition changed during survey periods (figure 5A). Bacillariophyta was dominant in July with the percentage of composition ranging from 44.06% to 77.31% then continually decreased by the end of the survey period. The dominant phytoplankton in August was Cyanophyta (Cyanobacteria) with the percentage ranging from 43.96% to 56.55%. The percentage of Pyrrophyta (Dinoflagellata) and Chlorophyta increased in September with the range from 26.13% to 29.51% and 25.71% to 38.07%, respectively. Cyanophyta (Cyanobacteria) was dominant again in October and November with the percentage range from 38.66% to 55.87% and 69.68% to 82.2% respectively.

Spatially, the higher percentage of Cyanobacteria was found on the outside of FTWs (St 5) and the lower percentage of Cyanobacteria was found on the adjacent station of FTWs (St 1) and the inside of FTWs (St 4). The percentage of Chlorophyta and Bacillariophyta composition was also higher on the adjacent station (St 1) and the inside of FTWs (St 4) than on the outside of FTWs (St 5). Based on the
similarity matrix of phytoplankton composition there were two different groups separating phytoplankton composition between on the inside and outside of the FTWs system. The first group were St1 and St 4 with the similarity value 94.43% and the second group was St 5 with the similarity value 85%.

**Table 1.** The average value of environmental parameters for the survey at adjacent, inside and outside of FTWs.

| Parameter          | Adjacent FTWs | In site FTWs | Out site FTWs |
|-------------------|---------------|--------------|---------------|
|                   | St 1          | St 2         | St 3          | St 4          | St 5          |
| Temperature (°C)  | Range 28.2 – 29.3, 28.5 – 29.3, 28.1 – 29.5, 28.1 – 29.5, 28.2 – 30.1 | Average 28.76, 28.82, 28.86, 28.84, 29.03 | Average 29.03 |
| pH                | Range 6.87 – 9.00, 6.87 – 9.00, 6.87 – 9.02, 6.58 – 9.01, 7.41 – 8.83 | Average 8.29, 8.35, 8.37, 8.33, 8.41 | Average 8.41 |
| DO (mg.L⁻¹)       | Range 6.86 – 10.19, 6.60 – 10.07, 7.01 – 10.23, 6.44 – 10.25, 7.03 – 9.76 | Average 9.27, 9.23, 9.31, 8.7, 8.5 | Average 8.5 |
| Conductivity (mS/cm) | Range 0.113 – 0.134, 0.122 – 0.133, 0.122 – 0.133, 0.122 – 0.134, 0.123-0.131 | Average 0.125, 0.127, 0.125, 0.127, 0.126 | Average 0.126 |
| TDS (g.L⁻¹)       | Range 73.6 – 87.0, 73.3 – 87.0, 73.5 – 86.0, 45.0 – 87.0, 44.0 – 85.0 | Average 80.44, 80.56, 80.22, 74.46, 72.92 | Average 72.92 |
| TN (mg.L⁻¹)       | Range 0.166 – 0.569, 0.076 – 0.558, 0.260 – 0.752, 0.115 – 0.467, 0.275 – 0.477 | Average 0.371, 0.287, 0.454, 0.319, 0.368 | Average 0.368 |
| TP (mg.L⁻¹)       | Range 0.001 – 0.44, 0.001 – 0.049, 0.001 – 0.044, 0.011 – 0.49, 0.001 – 0.044 | Average 0.022, 0.032, 0.024, 0.024, 0.023 | Average 0.023 |
| Chlorophyll-a (μg.L⁻¹) | Range 5.13 – 9.41, 3.56 – 11.62, 5.46 – 9.82, 3.68 – 9.86, 4.44 – 20.95 | Average 7.6, 8.52, 7.26, 6.79, 9.54 | Average 9.54 |
| Phytoplankton (x10⁶.ind.L⁻¹) | Range 12.975 – 67.150, 8.600 – 54.600, 14.325 – 55.325 | Average 31.120, 31.070, 29.085 | Average 29.085 |

The cyanobacteria species observed inside the FTWs and outside the FTWs were *Aphanizomenon gracile*, *Cylindrospermopsis raciborskii*, *Oscillatoria formosa*, *Anabaena spiroides*, *Microcystis aeruginosa*, *Chroococcus*, and *Merismopedia*. *Aphanizomenon gracile* and *Oscillatoria formosa* were the dominant species during the survey period (figure 5B). Another dominant species of phytoplankton were *Synedra ulna*, *Peridinium* and *Staurastrum playfairii* (figure 5B).

*Oscillatoria formosa* was dominant in August accounted as much as 40.6% to 52.6% of total assemblage of phytoplankton. *Aphanizomenon gracile* was dominant in October and November accounted as much as 29.2% to 72.4% of total assembly respectively (figure 5B). The highest dominant species of *Aphanizomenon gracile* was found in St 5 (outside the FTWs). The percentage of *Peridinium* increase in September accounted for as much as 23.3% in St 5 (outside the FTWs) and 24.7% in St 1 (adjacent to FTWs).

Total Phytoplankton abundance ranges from 12.975 x 10³ to 67.150 x 10³ ind.L⁻¹ and tends to decrease during the survey period (figure 5C). The highest abundance of phytoplankton was found in August at St 1 (adjacent of FTWs) and the lowest value of total abundance was found in November at St 1. The average value of total abundance in St 1, St 2 and St 3 were 31.120 x 10³, 31.070 x 10³ and 29.085 x 10³ ind.L⁻¹, respectively.

The functional groups represented by the phytoplankton encountered in the FTWs system and open area were codon D, F, J, L0, H1, M, N0, S0, T0 (table 2). Group D was commonly found in the
shallow enriched nutrient and turbid waters. In this study group D represented by *Synedra ulna* was abundant in Lake Maninjau. This species was dominant and important contributions to the total abundance of phytoplankton in July.

**Figure 4.** Temporal variation of temperature, pH, DO, conductivity, TDS, Chlorophyll-*a*, TN and TP.
Figure 5. Temporal composition of phytoplankton (A), dominant species (B) and phytoplankton abundance (C).
Group S_N represented by *Cylindrospermopsis raciborskii* which was tolerant to low nutrient, low light and sensitive to flushing was frequently recorded in the study period, while Group S_N represented by *Aphanizomenon gracile* was dominant in October and November. Group H_I represented by *Anabaena spiroides* was occasionally found in FTWs system and outside of FTWs. Group T_C represented by *Oscillatoria formosa* was dominant in August. Group F which can develop in low nutrient to high turbidity and group W_1 mostly found in pond rich inorganic mater were rarely recorded in the in FTWs and open area of Lake Maninjau. Group L_0 represented by *Peridinium sp*, *Ceratium hirudinella*, *Merismopedia sp*, and *Chroococcus sp* and *Peridinium sp* has a higher abundance in September. Group M represented by *Microcystis aeruginosa* was not dominant in species and abundant during the study period. Group J belonged to a small cell of Chlorophyta.

**Table 2.** Species composition of phytoplankton based on the functional group in the study site.

| Codon | Habitat | Typical representatives | Tolerances | Sensitivities |
|-------|---------|-------------------------|------------|--------------|
| D     | Shallow, enriched turbidwaters, including rivers | *Synedra ulna*<br>*Synedrasp* | Flushing | Nutrient depletion |
| F     | Clear, deeply mixed Meso-eutrophic | *Oocyst parva*<br>*Kircheneriellalunarisi* | Low nutrient high turbidity | CO₂ deficiency |
| J     | Shallow, enriched lakes, ponds and rivers | *Pediastrum duplex*<br>*Ankistrodesmus sp*<br>*Actinastrum sp*<br>*Coelastrum microphorum*<br>*Scenedesmus sp*<br>*Dictyosphaerium sp*<br>*Tetraedron sp* | Setting into low light | |
| L_0   | Summer epilimnia in deep and shallow, oligo to eutrophic, medium to large lakes. | *Peridinium sp*<br>*Ceratium hirudinella*<br>*Chroococcus sp*<br>*Merismopedia sp* | Segregated nutrients | Prolonged or deep mixing |
| N_A   | Oligo-mesotrophic, atelomictic environments | *Stauastrum sp*<br>*Cosmarium sp* | High insolation | Flushing, low total light At lower latitudes with species sensitive to destratification |
| S_N   | Warm mixed layers | *Cylindrospermopsis raciborskii*<br>*Aphanizomenon gracile* | Light and nitrogen-deficient | Flushing |
| H_I   | Eutrophic, both stratified and shallow lakes with low nitrogen content. | *Anabaena sp* | Low nitrogen | Poor light, low phosphorous. |
| T_C   | Eutrophic standing waters or slowing rivers with emergent macrophytes. | *Oscillatoria formosa*<br>*Oscillatoria acutissima* | | |
| W_1   | Ponds, even temporary, rich inorganic mater | *Euglena sp* | high BOD | Grazing |
3.3. Relationship between phytoplankton and physicochemical parameters

CCA analysis showed that the dominant of Bacillariophyta was related to the high value of conductivity, DO and pH, while the dominant of Cyanophyta was related to low total phosphorus (TP). Chlorophyta was related to TN and TP while Pirrhophyta or Dinoflagelata related to total dissolved solids (TDS) (figure 7A). The relationship of the dominant species and environmental parameters was presented in figure 7B. The dominant of Synedra ulna was related to the high value of conductivity, DO and TP concentration. The dominant of Oscillatoria formosa was related to the high value of temperature, while the dominant of Aphanizomenon gracile was related to low total phosphor (TP). The dominant of Peridinium sp related to the high value of TDS, while the dominant of Staurastrum playfairy was related to the high value of TN.

4. Discussion

The lower temperature found in the stations adjacent to the FTWs (St1) and inside the FTWs (St4) indicated that the coverage of floating wetland inhibited the solar radiation and reduced the water temperature in the water. The coverage of floating wetlands could also reduce the light intensity and inhibit phytoplankton growth as indicated by the low concentration of chlorophyll-a in those sites. Inversely, outside the FTWs which was not affected by the coverage of floating wetland had the highest of chlorophyll-a concentration. A study also reported that floating plant coverage can cause severe underwater light attenuation, inhibit the photosynthesis of phytoplankton and finally resulting in the reduction of phytoplankton growth [9].

The higher pH outside of the FTWs also corresponded to high concentration of chlorophyll-a in this site. The higher DO concentration in the wetland system was probably because of assimilation activity from floating wetland roots and the lake waves induced by the wind.

The average value of conductivity, nutrient (TN and TP) was not so distinct between site observation (adjacent site of FTWs, inside of FTWs and outside of FTW). It was probably because of nutrient assimilation competition between floating aquatic plants in the FTWs system and phytoplankton outside the FTWs. The high TDS in the adjacent station and inside the FTWs might be related to the function of floating aquatic plant which absorbed the suspended solids.

In terms of phytoplankton abundance, the lower average abundance of phytoplankton was found outside FTWs although the chlorophyll-a was the highest in this site. Pigment concentration of phytoplankton is very different between species and within species concerning external factors such as light intensity, temperature and nutrient availability [22].

Temporally some water qualities fluctuated during the survey period. The lower DO in September coincided with chlorophyll-a concentration. The lower temperature, pH and conductivity, found in
October and November could be influenced by the rainy season. Rainfall showed a remarkable seasonal variation in Lake Maninjau region during the studied period (figure 2). In tropical areas, seasonal changes in climate especially related to precipitation induce modifications in the physical and chemical characteristics of the waters[23]. Therefore reduction in TP concentration during the rainy season (October and November) can be corresponded to the dilution effect due to atmospheric precipitation and influx of surface runoff. The lower Concentration of TN and TP in August may be related to the assimilation of TN and TP by phytoplankton which indicated by the highest total abundance of phytoplankton this month (figure 4).

Temporally, the change of dominant Bacillariophyta to Cyanophyta was related to the change of environmental factors. Remarkable seasonal variation in rainfall in Lake Maninjau region is an important factor to explain the changes in environmental factors and the phytoplankton dynamics in the lake [24]. For instance, the dominant Bacillariophyta found in July was related to the high conductivity, DO and temperature, while the dominant of Cyanophyta (Cyanobacteria) was related to the condition of low TP and TN concentration. Synedra ulna was a dominant species belong to Bacillariophyta and was also related to the high value of conductivity, DO and TP concentration. This species is commonly found in enriched waters and sensitive to nutrient depletion (table 2). Other studies reported that the distribution of Bacillariophyta and Synedra was greatly influenced by conductivity and dissolved oxygen (DO) [25][26].

Oscillatoriaformosa is a species belong to Cyanobacteria found dominant in August. The dominant of O. formosa was related to the condition of high temperature and low nitrogen concentration. Oscillatoria spp. was also classified as SN species (for nitrogen-fixing species) therefore this species was tolerant and adaptive to the low nitrogen concentration [12]. Aphanizomenongracile was species belong to Cyanobacteria found dominant in October and November. The dominant of this species was related to the condition of low conductivity and low TP concentration. The dominant of Aphanizomenon in low TP concentration and conductivity can be explained by distinctive physiological features of Aphanizomenon which produces akinetes in its life cycle. These akinetes arise from normal vegetative cells in response to environmental stresses, such as low phosphorus concentration, declines in temperature, low light intensity and to promote survival this species in periods of unfavorable growth conditions [27] [28]. Based on the functional group, Aphanizomenongracile is also classified in the SN species group which is tolerant and adaptive to the low nitrogen concentration and low light intensity [21].
Figure 7. CCA analysis between phytoplankton taxonomic group and physicochemical parameters (A) and between species dominant and physicochemical parameters (B).

The coverage of FTWs system appears to influence the composition and similarity of phytoplankton as indicated by more dominant of Cyanobacteria outside the FTWs, more diverse phytoplankton composition in the FTWs system (St 1 and St 4) than in the St 5 and the difference of phytoplankton similarity between the inside of FTWs system and the outside of FTWs system.
coverage effect of FTWs system in St5 caused higher water temperature in this site which gave an optimal temperature for Cyanobacteria growth. The optimum temperature for maximum Cyanobacteria growth was higher than Chlorophyta (green algae) and Bacillariophyta (diatom)[29].

5. Conclusion
Floating Treatment Wetlands (FTWs) system could reduce the temperature, chlorophyll-a and the percentage of Cyanobacteria in the eutrophic Lake Maninjau. Phytoplankton composition inside the FTWs system was more diverse than phytoplankton composition outside the FTWs. The change of phytoplankton dominancy from Bacillariophyta to Cyanophyta was related to environmental factors. Species dominant was change from sensitive species to nutrient depletion (Syndra ulna) to more adaptive species to low nutrient concentration and low light intensity (Oscillatoriaformosa and Aphanizomenon gracile).

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Acknowledgments
This research is funded by the State Budget of the Indonesian Government (National Priority
Research) through Research Center for Limnology, Indonesian Institute of Sciences. We acknowledge
RC for Limnology in providing the research facility in Lake Maninjau. The authors thank Mrs.Rosidah
and other teams for their assistance in the field survey.