Phytoplankton composition and the occurrence of cyanobacterial bloom in Lake Maninjau, Indonesia

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Abstract. Algae blooms have been recorded in Lake Maninjau in November 2000, October 2011 and recently on April 2018. These blooms were indicated by green scum formation on the lake surface with a very high chlorophyll-a concentration, as high as > 100 µg-L. We determined the characteristics of phytoplankton composition and abundance including environmental conditions during cyanobacterial blooms and non-cyanobacterial blooms in Lake Maninjau. During cyanobacterial blooms, phytoplankton were dominated by Microcystis aeruginosa with a maximum abundance of 24,320 × 10³ individual L⁻¹ (94.4 % of the total assemblage). While during the non-blooming period, cyanobacteria species were more diverse, represented by Cylindrospermopsis raciborskii, Anabaena affinis, Aphanizomeon sp, Planktolyngbya sp. and Chroococcus sp. Diatom (Synedra ulna) generally occurred in all conditions, however, desmids (green algae) disappeared during cyanobacteria blooms. It is highlighted that the occurrence of Microcystis blooms can be related to total phosphorous dynamics in the lake.

1. Introduction
One of the most concerning trends in freshwater systems globally is the increasing distribution of toxic cyanobacteria blooms due to eutrophication and climate change [1]. In Indonesia, the occurrence of Microcystis blooms have been reported in Karangkates Reservoir in 2001 and in Lake Maninjau 2000 [2, 3]. In Lake Maninjau, the occurrence of Microcystis bloom is more frequent, in 2011[4] and April 2018. Most reservoirs and lakes in Indonesia have been heavily impacted by anthropogenic activities and floating fish culture [5]. In Lake Maninjau, organic loads from floating cages was estimated at 111,889.84 tons with an average of 9324.98 tons/year from 2001 to 2013 [6]. With a total of 16,210 units of floating cage, 12,090 tons of fish was harvested from the cage in 2013 [7]. While the trophic state has changed gradually from mesotrophic to eutrophic, succession in phytoplankton assemblage followed [8]. Wastes from the cage contribute to the increased of total phosphorus, ortho-phosphate and nitrogen compounds in the lake [9].

Environmental impact of cyanobacteria bloom to the water would depend on the duration of the bloom, the species producing the bloom, and its cell concentrations. There is a wide range of cell concentration related to the phytoplankton composition of cyanobacteria bloom event. In a lake of Bangladesh at the peak period of phytoplankton blooms, the cell density of Microcystis aeruginosa was 1550 x 10³ cells mL⁻¹ which comprised 96.84 % of the total phytoplankton [10]. In the Hoan Kiem Lake Vietnam the number of Microcystis cells ranged from 27 x 10⁴ to 5 x 10⁸ cells mL⁻¹ [11]. Another approach associated with bloom events criteria is chlorophyll-a concentration per unit volume of water. Specific species such as Microcystis has been used to develop status criteria of cyanobacteria bloom.
For instance, the Commonwealth of Virginia established blooming criteria for *Microcystis aeruginosa* under chlorophyll-a level of 27.5 μg L⁻¹ (27.5 mg.m⁻³) and 50,000 cells. ml⁻¹ due to production of potential toxin [12].

The occurrence of *Microcystis* blooms in fresh water ecosystems has been explained by a series of factors related to species capacity in regulating buoyancy, water column stability, as well as environmental factors such as the availability of light, nutrients, temperature and pH [13,10, 16]. Other studies have attributed the algal blooms occurrence to physical characteristics such as lake morphometry, water column mixing, and temperature stratification [14]. For instance, in Taechung Reservoir Korea, the major factor influencing blue green dominance was a weak monsoon which was directly linked to strong water column stability, high water temperature (>28°C), and reduced silica input. Low N:P ratios were not the determining factors in this lake. Instead, light and pH level seemed to act as secondary factors [15]. In Lo Galindo Lake, Central Chile, bloom of *Microcystis* was generated when the temperature reached its annual peak of 25 °C [16].

The status of *Microcystis* bloom in Lake Maninjau together with phytoplankton assemblage, abundance and chlorophyll-a concentration is still absent. Thus, environment factors controlling the occurrence of the bloom have been barely identified. We determined phytoplankton assemblage and environmental factors in Lake Maninjau during cyanobacteria bloom and non-bloom period to support the management strategy in preventing harmful effect of the produced toxin.

2. Materials and methods

2.1. Research location

Lake Maninjau is a tectono-volcanic 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 [17]. The volume of water stored in the lake, shore line and shore line development is 10.33 billion m³, 52.7 km and 1.51 km/km², respectively [17]. There are two peak rainy seasons on April to May and October to November. Rainfall is relatively high through the years and dry season is not so dominant [18].

2.2. Data collection

Surface and subsurface water samples were collected at 9 study sites (figure 1) on April 2009, June 2009, April 2014, August 2015, and March 2016 (non *Microcystis* bloom period) and 6 sites on April 2018 (*Microcystis* bloom period) to determine species composition and abundance of phytoplankton and physico-chemical parameters including Secchi depth, temperature, conductivity, dissolved oxygen (DO), pH, Total Nitrogen (TN) and Total Phosphorus (TP) and Chlorophyll-a concentration. In this study, we used the data of phytoplankton during the period of *Microcystis* bloom from the April 2018 observation. This is because the data of phytoplankton abundance in *Microcystis* bloom in 2000 and 2011 was limited [4]. The physical description of each research location is presented in table 1.

2.3. Physical and Chemical measurements

Water temperature, pH, Dissolved Oxygen (DO), and conductivity data were collected using a water quality checker (Horiba U-10), while water transparency was examined by the measurement of the Secchi depth. We quantified physical indices of the lake, i.e. thermocline depth and Schmidt stability, on the hourly average scale. Thermocline depth (m) was defined as the greatest rate of density change with depth, arrayed from vertical temperature profile recorded by a monitoring station platform. Schmidt stability (J M⁻²), a measure of the resistance to physical mixing, was derived from the profile and lake bathymetric data. Chlorophyll-a 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. Determination of chlorophyll-a sample is based on [19]. Total Nitrogen (TN) was measured using the persulphate digestion and Brucine method [19, 20]. Total Phosphorus (TP) was determined using the
persulphate digestion and Ascorbic Acid method [20]. All samples were analysed at Research Centre for Limnology, Indonesian Institute of Sciences (LIPI).

Figure 1. Lake Maninjau is located in Sumatra Island of Indonesia. The location of sampling site is shown by the blue circular. Source: GIS Lab. RC for Limnology LIPI.

Table 1. Physical description of research stations.

| Name of stations and sampling period                  | Physical description                                                                 |
|-------------------------------------------------------|---------------------------------------------------------------------------------------|
| Apr 09, Jul 09, Apr 14, Aug 15, and Mar 16 (Non-bloom period) Apr 18 (Bloom period) |                                                                                      |
| Bayur                                                 | Area packed with cage fish culture                                                   |
| Tandirih                                              | A few area for fish culture, the surrounding area is human settlement,              |
| Koto Gadang                                           | A few areas for fish culture, the surrounding area is agricultural                  |
| Muko-Muko                                             | Near outlet (Batang Antokan), area for fish culture                                  |
| Sigiran                                               | Area packed with cage fish culture, the surrounding area is human settlement        |
| Pandan                                                | Less area for fish culture and deep lake area                                       |
| Sungai Batang                                         | Area for fish culture, the surrounding area is agricultural                        |
| DM 4                                                  | Central part of lake (145 m depth), no fish culture                                |
| DM 7                                                  | Deepest part of lake (168 m depth), no fish culture                                |

Remark: Apr 09 =April 2009; Apr 14 =April 2014; Aug 15 =August 2015; Jul 09 =July 2009; Mar 18 =March 2018
2.4. Phytoplankton Analysis
Phytoplankton samples were collected at the euphotic zone (surface water and Secchi depth) by filtering 2 L of water through a plankton net (40 μm mesh size). The samples were preserved with 1% lugol solution for taxonomic study in the laboratory. Phytoplankton species was identified according to [21, 22, 23, 24] under magnification of 400 x through an inverted microscope. Quantitative analysis of phytoplankton used the Lackey Drop Micro Transect [25]. Direct links between environmental parameter and the percentage of dominant species of phytoplankton were analysed using Principal Component analysis (PCA) and Pearson’s correlation to identify the environmental factors influencing the cyanobacteria bloom.

3. Results and Discussion

3.1. Lake stability
Lake stability is one of the environmental factors associated with a buoyancy regulating species, such as Microcystis aeruginosa, bloom. In Lake Maninjau, the calculated Schmidt stability shows a clear annual pattern where the lowest energy is in the early month of the year, reaching its peak in March and September (figure 2). In March to April 2018 Schmidt stability ranged from < 1000 to 4000 (J m⁻²), and it coincided with the occurrence of Microcystis bloom.

3.2. Water quality
Microcystis bloom (April 2018), secchi depth transparency value ranged from 0.3 to 1.25 m (figure 3), while during the non-blooming period Secchi depth could reach 2.98 m (table 2). The highest Secchi depth transparency (2.98 m) was found in March 2016. Based on the long-term monitoring, the lowest of secchi depth transparency (< 1m) was found in the occurrence of Microcystis bloom as in October 2011 and April 2018 (figure 4). Hence, cyanobacteria bloom caused more light attenuation in the lake, in which other autochthonous productivity in the lake may suffer under such condition [27, 28]. There are also some important factors that influence secchi depth such as autochthonous production (plankton), cloud cover and wind action [27, 28].

Conductivity varied during non Microcystis bloom period and Microcystis bloom period (table 2). Conductivity represents ionic concentration in the waters. Higher ionic strength tended to have a higher nutrient concentration [14]. The variability of conductivity may be influenced by nutrient concentration that originated from fish culture waste. Higher pH was found in non Microcystis blooms period ranging from 8.44 to 8.69, while lower pH (7.75) was found in Microcystis blooms period, which was still in alkaline condition. It is likely that the decaying cells of Microcystis reduced the pH. TN and TP ratios were relatively low during the blooming period compared to the non-blooming period (table 2). Chlorophyll-a concentration reached 97.475 μg. L⁻¹ during blooming period in April 2018 (figure 5). Based on the long-term monitoring, the highest concentration of Chlorophyll-a was more than 100 μg. L⁻¹ (figure 6), when the occurrence Microcystis bloom was found in October 2011 [4].

Figure 2. Annual Schmidt Stability of Lake Maninjau [26].
Figure 3. Secchi Depth Transparency in April 2018 (*Microcystis* bloom period).

Table 2. Average value water quality in Lake Maninjau during non *Microystis* bloom and *Microcystis* bloom period.

| Parameters                  | Non-*Microcystis* bloom | *Microcystis* bloom |
|-----------------------------|-------------------------|---------------------|
|                             | Apr 09  | Jul 09  | Apr 14 | Aug 15 | Mar 16 | Apr 18 |
| Secchi depth (m)            | 2.25    | 1.7     | 2.1    | 1.9    | 2.98   | 0.8    |
| Temperature (°C)            | 28.65   | 29.29   | 29.61  | 29.34  | 30.63  | 28.58  |
| Conductivity (mS.cm⁻¹)      | 0.113   | 0.100   | 0.132  | 0.129  | 0.110  | 0.130  |
| pH                          | 8.44    | 8.6     | 8.55   | 8.24   | 8.69   | 7.75   |
| Dissolved Oxygen (DO) (mg. L⁻¹) | 2.88  | 6.00    | 8.21   | 4.35   | 7.76   | 8.71   |
| Total phosphorus (TP) (mg. L⁻¹) | 0.039 | 0.048   | 0.065  | 0.032  | 0.022  | 0.299  |
| Total nitrogen (TN) (mg. L⁻¹) | 1.486 | 0.582   | 1.058  | 0.974  | 0.415  | 1.117  |
| TN:TP                       | 39.7    | 13.3    | 21.5   | 48.2   | 20.2   | 4.7    |
| Chlorophyll-a (µg. L⁻¹)     | 6.21    | 4.55    | 4.00   | 4.80   | 13.67  | 35.31  |

Remark: Apr 09= April 2009; Jul 09=July 2009; Aug 15= August 2015; Mar 18=March 2018.
Figure 4. Long term monitoring Secchi depth transparency in Lake Maninjau (Source: Research Centre for Limnology, Indonesian Institute of Sciences Data Base).

Figure 5. Chlorophyll-α concentration in April 2018 (*Microcystis* bloom period).
Figure 6. Long term monitoring Chlorophyll-a concentration in Lake Maninjau (Source: Research Centre for Limnology, Indonesian Institute of Sciences Data Base).

3.3. Phytoplankton composition and abundance

The most dominant assemblage in phytoplankton group in Lake Maninjau is Cyanophyta (blue green algae) (figure 7), except in August 2015 which was dominated by Chrysophyta. Pyrrhophyta also increased, especially Ceratium hirudinella. As reported C. hirudinella was abundant during low phosphate and high TN:TP ratio (42.7) [29]. Our study showed that TN:TP ratio in August 2015 was 48.2 (table 2, table 3). The dominant species found in lake Maninjau was Microcystis aeruginosa, Chroococcus sp., Planktoeyngbya sp., Aphanizomenon sp., Anabaena affinis and Cylindrospermopsis raciborskii, Monallantus sp. and Synedra ulna (figure 8).

The cyanobacteria species found in Lake Maninjau were Microcystis aeruginosa, Chroococcus sp., Planktoeyngbya sp., Aphanizomenon sp., Anabaena affinis and Cylindrospermopsis raciborskii (figure 9). Most of those species are identified as toxin producer species [1, 30]. During the bloom in April 2018 Microcystis aeruginosa was dominant, accounted as much as 94.4 % of total assemblage. In non-cyanobacteria bloom period (March 2016), Chroococcus sp was the dominant species, which accounted to 86.4 % of the total composition (figure 8).

The abundance of Microcystis bloom period in April 2018 ranged from 37.9 to 24,320 x10^3 individual L^-1 (table 3). This dense number of Microcystis cells has also been observed in the other place reaching 1.3 x 10^6 cell. L^-1 [16]. Anabaena affinis and Cylindrospermopsis raciborskii were also abundant during Microcystis bloom period. These two species are commonly found in Lake Maninjau [31]. Chroococcus sp. was abundant during the non-bloom period, ranging from 20.6 to 77.67 x 10^3 individual. L^-1 (table 3). It is likely that Chroococcus prefers environmental condition with high pH, and temperature and relatively better light penetration (table 4). Synedra ulna (diatom) always occurred in Lake Maninjau in every condition. This species is commonly found in eutrophic lake rich in nutrients and alkaline conditions [32].
Figure 7. Phytoplankton composition in Lake Maninjau.
Table 3. Phytoplankton abundance of dominant species.

| Dominant species | Non $Microcystis$ bloom period | $Microcystis$ bloom period |
|------------------|-------------------------------|---------------------------|
|                  | Apr 09  | Jul 09  | Apr 14 | Aug 15 | Mar 16 | Apr 18 |
| Synedra ulna     | 4.95 – 36 | 65 – 88 | 14.2 – 103 | 13.18 | 0.088 – 0.25 | 1.56 – 1040 |
| Monallantus sp   | 0         | 0      | 14 – 27 | 10.8 – 23.25 | 0.05-11.09 | 0 |
| St. playfairi    | 4.5-39.6 | 10.8-65.7 | 0.05 – 0.06 | 1.15 – 0.65 | 0 – 0.025 | 0 |
| Aphanizomenon sp | 17.1-40.5 | 11.3-54.5 | 0         | 0      | 0      | 0.5 – 120 |
| A. affinis       | 4.5-21.6 | 7.2-57.6 | 0 – 0.015 | 0      | 0      | 0      |
| Chroococcus sp.  | 0         | 0      | 0 – 0.02 | 0 – 1.45 | 20.6 – 77.67 | 0 |
| C. raciborskii   | 4.05-6.75 | 16.2 – 81 | 3.55-8.5 | 4.075 | 0      | 0.0050 – 15 |
| M. aeruginosa    | 0-1.8    | 0 – 0.09 | 0.005   | 0      | 0.024-0.01 | 37.9 – 24320 |
| Planktolyngbya sp | 0         | 0      | 144     | 0 – 0.1 | 0      | 0      |
| C. hirudinella   | 0         | 0      | 0       | 0.045-9.987 | 0    | 0      |

Remark * = Phytoplankton calculation in colony. Ap-09=April 2009; Jul-09=July 2009; Apr 14=April 2014; Aug15=August 2015; Mar16=March 2016; Apr18=April 2018.

3.4. Link between environmental factors and dominant phytoplankton.

Principal Component Analysis between phytoplankton and environmental factors showed that there were three components (figure 10). The first component was $Microcystis$ aeruginosa and Monnalantus sp which was related to the environmental factor of temperature, pH, TN and TP for their dominance while the second component, was Aphanizomenon sp, Anabaena affinis, Cylindrospermopsis raciborskii, Synedra ulna which was related to conductivity and DO parameter for their dominance, the third group was Ceratium hirudinella which was related to TN:TP ratio for their dominance (figure 10, table 5). Pearson’s correlation analysis showed that $Microcystis$ had a positive correlation with TP, negative correlation with TN:TP ratios and Secchi depth transparency (table 5). It is indicated that increasing total phosphorus and lower TN:TP ratios create favourable condition for $Microcystis$ aeruginosa bloom in Lake Maninjau. Among the physical and chemical factors, high TP concentration and low TN:TP ratio are most often used as indicators of cyanobacteria bloom. For instance, in Steilacoom Lake in Washington, blooms of $Microcystis$ aeruginosa occurred when there was higher total phosphorus, decreased water transparency, high water column stability, high surface water temperature and pH [33]. And the success of $Microcystis$ over other cyanobacteria was also associated with low nitrogen to phosphorus ratios [34]. In Lake Maninjau, water temperature and pH did not show a positive correlation with $Microcystis$ bloom, however the average temperature (28.58 °C) and pH (7.75) are still in the range for $Microcystis$ growth. In Bangladesh Lake, the initiation and persistence of $Microcystis$ natural blooms was determined by relatively high water temperatures with the range of 28 to 30 °C [12]. Other study also reported that neutral and weakly alkaline conditions support the rapid growth of $M$. aeruginosa [35]. Based on this phenomenon, phosphorus was apparently the primary factors control $Microcystis$ bloom in Lake Maninjau.
Figure 8. Photomicrographs of dominant species of phytoplankton in Lake Maninjau (a) *Anabaena affinis*, (b) *Aphanizomenon* sp., (c) *Monallantus* sp., (d) *Chroococcus* sp., (e) *Microcystis aeruginosa*, (f) *Staurastrum playfairii*, (g) *Ceratium hirudinella*, (h) *Synedra ulna*, (i) *Planktolyngbya* sp., (j) *Cylindrospermopsis raciborskii*.

Figure 9. The percentage of phytoplankton composition of dominant species. Remarks: Cerat = *Ceratium hirudinella*, Plank = *Planktolyngbya* sp.; Micro = *Microcystis aeruginosa*; Cylin = *Cylindrospermopsis raciborskii*; Chroo = *Chroococcus* sp.; Apha = *Aphanizomenon* sp.; Anab = *Anabaena affinis*; Staur = *Staurastrum playfairii*; Mol = *Monallantus* sp.; Syn = *Synedra ulna* sp.

Table 4. Pearson’s correlation between phytoplankton and environmental factors.

| Species            | Temp | SD   | pH   | Con   | DO   | TN   | TP   | TN : TP |
|--------------------|------|------|------|-------|------|------|------|---------|
| Synedra ulna       |      |      |      |       |      | -0.12| -0.149| 0.106   |
| Monallantus        | **0.603** | **0.513** | 0.246 | 0.342 | 0.35 | **-0.606** | -0.322 | 0.253   |
| Staurastrum        | 0.021 | 0.028 | 0.14 | -0.413 |      | **-0.583** | -0.048 | -0.317 | -0.018 |
| Anabaena           | -0.123 | -0.203 | 0.017 | **-0.665** | -0.264 | 0.082 | -0.046 | -0.28   |
| Aphanizomenon      | -0.341 | -0.199 | 0.133 | -0.457 | **-0.713** | 0.597 | -0.287 | 0.428   |
| Chroococcus        | **0.721** | **0.73** | **0.516** | -0.369 | 0.342 | -0.185 | -0.33 | 0.244   |
| C. raciborskii     | -0.082 | -0.157 | 0.098 | **-0.638** | -0.172 | -0.042 | -0.128 | -0.236  |
| Microcystis        | -0.492 | **-0.572** | **-0.725** | 0.381 | 0.157 | 0.475 | **0.87** | **-0.53** |
| Planktolyngbya     | -0.222 | -0.07 | 0.131 | 0.421 | 0.495 | **-0.523** | 0.009 | -0.192  |
| C. hirudinella     | **0.291** | 0.166 | **-0.074** | **0.345** | **-0.311** | **-0.049** | **-0.248** | **0.461** |
Figure 10. Component plot in rotated space from Principal Component Analysis between dominant species (*Anabaena*, *Aphanizomenon*, *Ceratium Chroococcus* *Cylindrospermopsis*, *Microcystis*, *Monallantu* *Planktolyngbia*, *Staurastrum*, *Synedra* and environmental factors) and environmental factors (Temperature, Secchi depth, Conductivity, DO, pH, TN, TP and TN:TP).

Table 5. Component matrix of dominant species and environmental factors.

| Component Matrix $^a$ | Component 1 | Component 2 | Component 3 | Component 4 | Component 5 | Component 6 |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| SD                     | 0.899       | -0.312      |             |             |             |             |
| Temp                   | 0.895       | -0.216      | 0.334       |             |             |             |
| TP                     | -0.789      | -0.475      | -0.135      | -0.158      | 0.16        |             |
| pH                     | 0.753       | 0.295       | -0.164      | -0.269      |             |             |
| Micro                  | -0.728      | -0.412      | -0.392      | 0.234       |             |             |
| Molla                  | 0.659       | -0.429      | 0.109       | 0.359       | 0.294       |             |
| TN                     | -0.587      | 0.288       | 0.551       | -0.375      | 0.281       |             |
| Anap                   | -0.213      | 0.786       | 0.317       | -0.353      | 0.193       |             |
| Con                    | -0.279      | -0.782      | 0.338       | 0.37        | -0.124      |             |
| Anab                   | -0.267      | 0.752       | -0.465      | 0.279       |             |             |
| Cyl                    | -0.172      | 0.731       | -0.515      | 0.244       | 0.277       | 0.101       |
| DO                     | 0.155       | -0.679      | -0.633      |             | 0.302       |             |
| Syn                    | 0.658       |             |             | 0.503       | 0.228       | 0.391       |
| TN:TP                  | 0.529       | 0.298       | 0.681       | -0.155      | -0.195      |             |
| Cer                    | 0.284       | -0.111      | 0.617       | 0.392       | 0.481       | -0.103      |
| Croc                   | 0.657       | -0.144      | -0.101      | -0.66       | 0.176       |             |
| Plank                  | -0.42       | -0.338      | 0.534       | -0.589      |             |             |
| Staur                  | -0.338      |             |             | -0.124      | -0.774      |             |

$^a$: Extraction Methods Principal Component Analysis

*a*: 6 component extract
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