Trophic Status and Phytoplankton Community Structure of Four Small Lakes in Ciliwung Watershed, Indonesia

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Abstract Small lakes are critical freshwater resources to support the quality of human life. Small lakes in the watershed are becoming threatened ecosystems because of increasing land-use changes and anthropogenic activity. We determine the trophic status, phytoplankton community, and environmental factors in Lake Telaga Warna, Lake Cikaret, Lake Sunter, and Lake Cincin. The data was collected from primary and secondary data in 2000, 2007, 2008, 2016, and 2021. There are two groups of lakes based on water quality and trophic status. Lake Telaga Warna and Lake Cikaret, located at the upper and middle watershed, are eutrophic characterized by lower nutrient temperature, pH, conductivity, and Total Dissolved Solids (TDS). Lake Sunter and Lake Cincin, located at lower watersheds, are hypereutrophic characterized by higher nutrients, temperature, pH, conductivity, and TDS. Cyanobacteria dominance was recorded in Lake Telaga Warna and Lake Sunter, where Microcystis aeruginosa; Cylindrospermopsis raciborskii; and Planktothrix agardhii are the dominant species. Hypereutrophic status in Lake Sunter was characterized by the bloom of Planktothrix agardhii with total abundance (1,038 x 103 individual L−1 x 103), chlorophyll-a (431 µgL−1), low diversity index and species richness index. Cyanobacteria dominance in Lake Telaga Warna was under phosphorous limitation, while Cyanobacteria bloom in Lake Sunter was under nitrogen limitation.

1. Introduction
Freshwater small lakes are crucial freshwater resources to support human life [1]. Most lakes ecosystems are facing an environmental problem of eutrophication due to anthropogenic impact. Nutrient enrichment of water bodies is a primary cause of eutrophication [2]. Eutrophication is a global environmental issue that becomes a challenge in freshwater lake management [3]. Eutrophication may have a negative effect on the lake ecosystem and human health [4]. A high organic matter input could increase nutrients and stimulate algal blooms of toxic cyanobacteria, which creates bad odours and tastes in waters [5]. The effect of high algae biomass concentration reduced dissolved oxygen concentration in the waters, cause fish killed, reduce water quality, and potentially risk human health [6,7]. Some genera of cyanobacteria producing toxins material are Microcystis, Planktothrix, Aphanizomenon, Oscillatoria, Lyngbya, Nodularia, Nostoc, Anabaena, Anabaenopsis, Cylindrospermopsis [3,7]. Eutrophication has a wide range of impacts. Not only on a lake and human health but also the economy and social aspects. Eutrophication rose a quite serious social problem and economic loss, as occurred in Lake Maninjau, West Sumatera, Indonesia. Therefore, understanding of the evaluation method and control of eutrophication are needed to have the sustainable use of a lake ecosystem.
Generally, small lakes have small volume, shallower depth (3 to 5 m), unstable hydrological balance, and are sensitive to the increase of nutrients coming from the surrounding area [8]. Therefore, small lakes are susceptible to environmental changes, pollution, and eutrophication. The function of small lakes is not only for flood control but also as water sources, biodiversity conservation, and supporting the socio-economic of the community [9]. It is estimated that there are more than 200 small lakes in West Java, some of which are situated at the Ciliwung watershed. Ciliwung River flows across through the regions within the megacity of Bogor, Depok, and Jakarta. The impact of development in the Ciliwung watershed is risky on water quality and eutrophication at the small lakes in the area. Several urban lakes experienced a significant decrease in volume due to sedimentation and eutrophication [10]. Although Eutrophication has been recognized, control of eutrophication remains the problem in the management of megacity urban lakes. Previous studies reported that the loss and reducing urban lakes in the Jakarta megacity (Jabodetabek) indicated a lack of attention and management [11]. Lack of awareness and understanding of the eutrophication effect on the ecosystem, human health, and economic risks may also cause the policy has not to be fully implemented in resolving the eutrophication problem in urban lakes. To ensure the sustainability of small urban lakes management, a better understanding of eutrophication status, their impact, and efficiency in the assessment are essential. Cyanobacteria bloom characteristics related to the phytoplankton dominant, abundance, and biomass or chlorophyll-a concentration as a threshold of harmful alga bloom are still absent in some lakes of the Ciliwung watershed. This study is aimed to determine the trophic state, phytoplankton composition, cyanobacteria abundance, and the environmental condition of the urban lakes. The results are expected to support the sustainable management of small lakes in the Ciliwung watershed.

2. Method

The study was located in some small lakes at the Ciliwung watershed, especially in Lake Telaga Warna, Lake Cikaret, South Lake Sunter, and Lake Cincin (figure 1). Ciliwung watershed, geographically located between 06° 06’ 00” to 6° 46’ 12” S and 106° 48’ 36” to 107° 00’ 00” E. Lake Telaga Warna and Lake Cikaret are located at Bogor Regency where positioned at the upstream and middle part of Ciliwung watershed, respectively. Telaga Warna is a conservation area used for tourism, has a surface area and maximum depth of 5 Ha and 15 m, respectively [12]. Lake Cikaret functioned as a flood control and domestic water source for agriculture and fisheries with an area of 16.90 ha [13]. South Lake Sunter and Lake Cincin are located in Jakarta City, used for flood control and tourism. The area of South Lake Sunter is 26 ha, and the average depth is 3.0 m [14].

The primary and secondary data in 2000, 2007, 2008, 2016, and 2021 were used. The primary data were collected at three or four sampling points on March and June 2021, consisting of phytoplankton community structure, physical, chemical parameters. A water quality checker (Horiba) was used to measure water temperature, pH, conductivity, Total Dissolved Solids (TDS) and salinity. Furthermore, dissolved oxygen (DO) was measured using a YSI DO meter. Total nitrogen (TN) and total phosphor (TP) concentration were measured using spectrometer instruments and analyzed following Brucine and Ascorbic acid method, respectively [18]. Secchi depth was measured using a Secchi disk. Chlorophyll-a sample was collected by filtering 200 mL of surface water using a GF/F Whatman glass filter paper. Subsequently, the samples were preserved with a saturated MgCO3 solution then was ground up and extracted in acetone solution (90%). After centrifugation, the supernatant was measured with a spectrometer [15]. Trophic State Index (TSI) was calculated to classify the trophic status of observed lakes following the [16]. Moreover, phytoplankton samples were collected from 2 L filtered surface waters through plankton net with mesh size 40 μm. Immediately, phytoplankton samples were preserved with 1% Lugol’s solution. Phytoplankton species were identified according to some references [17,18,19] using an inverted microscope with a magnification of 400x. Quantitative analysis used the Lackey Drop Micro Transect method [15]. Species composition data of phytoplankton were analyzed to estimate the diversity indices such as Shannon Wiener (\(H’ = -\sum Pi \ln Pi\)) [20] and Pielou evenness (\(J=H’/\ln S\)) [21]. Lastly, the observed lakes were classified based on environmental factors (independent variable) using a Principal Component Analysis (PCA).
3. Result

3.1. Water quality

The lower temperature (20.0 to 21.0°C) was recorded in Lake Telaga Warna, located upstream of the Ciliwung watershed (1,097-1,400 above sea level) (table 1). Lake Sunter and Lake Cincin have a wide range of DO concentrations. The highest DO was recorded in Lake Cikaret in 2016 and Lake Sunter in 2000 (table 1). In Telaga Warna, the pH value showed acidic to neutral (5.0-7.15), and in Lake Cinicin was neutral to alkali (7.23-8.61) (table 1). High conductivity and TDS were recorded in Lake Sunter and Lake Cincin, ranging from 0.453 to 0.723 mgL⁻¹ and 0.753 to 1.83 mgL⁻¹, respectively. Telaga Warna has wide range of TDS (40-238 mgL⁻¹) in 2007 (table 1). In terms of lakes nutrients, such as N-NO₃, TN, and TP concentration, showed a gradient distribution based on their position in the Ciliwung watershed (table 1). A lower concentration of nutrient (TP) (0.013-0.070 mgL⁻¹), TN (0.162-2.416) and Chlorophyll-a (7.0-16.48 µgL⁻¹) was found Lake Telaga Warna. Higher nutrient concentration of TP (0.649-1.327 mgL⁻¹ and 0.893-1.722 mgL⁻¹), TN (4.281-5.277 mgL⁻¹ and 4.203-4.801 mgL⁻¹) and Chlorophyll-a (88.99-431 µgL⁻¹ and 20.05-378 µgL⁻¹) was found in Lake Sunter and Lake Cincin (table 1). Based on chlorophyll-a and TP concentration, the observed lake’s status was eutrophic to hypereutrophic. The standard value for chlorophyll-a and TP concentration for eutrophic lake range from 7.3 – 20 µgL⁻¹ and 24 – 48 µgL⁻¹ respectively, while the standard value of chlorophyll-a and TP for hypereutrophic lake range from 56-55 µgL⁻¹ and 96 – 192 µgL⁻¹ respectively [16]. In Lake Telaga Warna, TN/TP ratio >12 means that phosphorus is a limiting nutrient for algae growth, while in Lake
Cikaret wide range of TN/TP ratio was found. In Lake Sunter and Lake Cincin, nitrogen is a limiting nutrient for algae growth with a TN/TP ratio of < 12 [22].

The lower temperature (20.0 to 21.0°C) was recorded in Lake Telaga. Principle component analysis showed there are two groups of lakes based on the water quality conditions. The first group is Lake Telaga Warna and Lake Cilakret with higher Secchi depth and lower temperature, pH, conductivity, TDS, salinity, TN and TP. The second group is Lake Sunter and Lake Cincin that have higher water temperature, pH, conductivity TDS, TN and TP (figure 2).

Table 1. Water quality characteristic of observed lakes.

| Parameters | Telaga Warna | Cikaret | Sunter | Cincin |
|------------|--------------|---------|--------|--------|
|            | 2007a | 2021 | 2016b | 2021 | 2000c | 2008d | 2021 | 2021 |
| Depth      | m    | 6.5 | 1-1.5 | 4.0-5.0 | 1-1.5 | 1 |
| Secchi depth | cm    | 10-142 | 100 | 72 | 100-150 | 24-33 | 14-16 | 30 | 30 |
| Temperature | °C    | 20.0-21.0 | 20.3-20.5 | 27.0-28.0 | 29.3-30.2 | 29.0-31.0 | 28.5-32.0 | 28.1-30.4 | 28.87-33.5 |
| TSS         | mgL⁻¹ | 5.0-47 | 6.0-7.0 | 10.0-12.0 | 1.0-30 | 53-117 | 86 |
| Conductivity | cmS m⁻¹ | 0.033-064 | 0.163 | 0.453-0.723 | 0.753-1.83 |
| TDS         | mgL⁻¹ | 40-238 | 24-37 | 85-86 | 297-723 | 482-1170 |
| pH          | mgL⁻¹ | 6.0 | 7.15-7.67 | 6.0-7.0 | 6.75-7.84 | 6.96-7.04 | 8.0 | 7.37-7.91 | 7.23-8.61 |
| DO          | ppt | 7.2 | 6.51-7.15 | 12.1 | 7.55-7.78 | 1.32-7.15 | 1.48-7.23 | 0.23-9.07 |
| Salinity    | ppt | 0 | 0.1 | 0.1-0.2 | 0.1-0.7 |
| N-NO3       | mgL⁻¹ | 0.005-0.033 | 0.001-0.034 | 0.034-1.122 |
| P-PO4       | mgL⁻¹ | 0.162-2.416 | 0.783-3.793 | 4.281-5.277 | 4.203-4.801 |
| TN          | mgL⁻¹ | 0.013-0.070 | 0.263 | 0.649-1.327 | 0.893-1.722 |
| TP          | mgL⁻¹ | 13.0-111.0 | 3.0-44.0 | 5.0-8.0 | 2.0-5.0 |
| Chlorophyll | µgL⁻¹ | 7.40-16.48 | 18.05-39.93 | 88.99-431 | 20.05-378 |

Reference: a: [23]; b: [24]; c: [25]; d: [26]
Figure 2. Principle Component Analysis (PCA) of Lake Telaga Warna, Lake Cikaret, Lake Sunter, and Lake Cincin, based on physical-chemical parameters.

3.2 Trophic Status
Based on the Trophic Status Index (TSI), Lake Telaga Warna and Lake Cikaret is a eutrophic lake, while Lake Sunter and Lake Cincin are hypereutrophic lakes (figure 3). In Telaga Warna, TSI (Chl-a) < TSI (TP) = TSI (SD) indicate algae dominate light attenuation and other factors such as zooplankton grazing that limit alga biomass (figure 3). In Lake Sunter and Lake Cincin, TSI (Chl a) > TSI (SD) indicates large particulates of phytoplankton dominate light attenuation in waters [16].

Figure 3. Trophic State Index (TSI) of observed lakes.

3.3. Phytoplankton community and diversity
Cyanophyta or Cyanobacteria is the dominant phytoplankton assemblage in Lake Telaga Warna, which contribute up to 70% and 71% of total abundance (figure 4). Cyanobacteria almost contribute 100% of phytoplankton abundance in Lake Sunter indicates the algae is in bloom condition. It seems Lake Sunter has experienced algae bloom since 2000. Cyanobacteria contribute 7-22% in Lake Cikaret and 24% in Lake Cincin. In Lake Cikaret, a high percentage of phytoplankton are Cryptophysa (34%) and each group of Chlorophyta and Euglenophyta contributes 24%. Bacillariophyta is the dominant
phytoplankton assemblage in Lake Cincin, contributing 53% of total abundance. The occurrence of algae blooms in Lake Sunter was also characterized by a low number of species with Shannon diversity index 0.04 - 0.87, Evenness 0.013, and Margalef Richness index 0.288, and high phytoplankton abundance 104.461 – 1920.5 x 103 individual L⁻¹ (table 2). It indicates, Lake Sunter has low ecological stability for the phytoplankton community. The value of the Shannon diversity index and Margalef Richness index for good environmental conditions ranges from 2.5 to 3.5 [27]. The highest number of species, Shannon diversity index, Evenness, and Margalef Richness index was recorded in Lake Cikaret (table 2). The lower phytoplankton abundance was in Lake Telaga Warna 4.045 x 103 individual L⁻¹ in 2007 and Lake Cikaret 7.717 x 103 individual L⁻¹ in 2021.

Table 2. Number genera or species, diversity index (H'), Evenness (J), uniformity index (E), Margalef's Richness index (D_M), and total abundance of phytoplankton.

| Biodiversity index/abundance | Telaga Warna 2007a | Cikaret 2016b | 2021 | 2000c | Sunter 2008d | 2021 | Cincin 2021 |
|-----------------------------|--------------------|--------------|------|-------|-------------|------|------------|
| Genera/Species              | 26                 | 19           | 39   | 6     | 10          | 6    | 25         |
| H'                          | 1.27               | 2.227        | 0.56 | 0.87  | 0.024       | 1.764|            |
| J                           | 0.399              | 0.608        |      | 0.013 | 0.548       |      |            |
| E                           |                    |              |      |       |             | 0.32 |            |
| D_M                         | 2.481              | 3.128        |      | 0.288 | 2.377       |      |            |
| Total abundance             | 4.045              | 10.604       | 7.717| 1,920.5| 104.461     | 1,044.2| 24.243    |

(x10^3 Individual L⁻¹)

Reference: a: [23]; b: [24]; c: [25]; d: [26]
Figure 4. Phytoplankton composition of observed lakes.

In Telaga Warna, phytoplankton was dominated by Cyanophyta with *Cylindrospermopsis raciborskii*, *Microcystis aruginosa*, *Colesphaerium* sp. as dominant species. In Lake Cikaret, phytoplankton was dominated by Cryptophyta, where *Cryptomonas* sp. was the dominant species. *Scenedesmus* spp. *Euglena* spp. and *Trachelomonas* spp. are frequently found in this lake. In Lake Sunter, species *Planktothrix agardhii* (Syn. *Oscillatoria*) and *Arthosphira* sp. were dominant, while in Lake Cincin, phytoplankton was dominated by species of *Fragilaria* sp. belong to Bacillariophyta and *Coelosphaerium* sp. belong to Cyanophyta.

4. Discussion
The surrounding area condition and watershed of the observed lakes could influence the water quality status. Land-use type at the catchment basin affects the water quality in lake waters [28]. Ciliwung River flows across the interconnected regions within the urban area of Bogor, Depok, and Jakarta. Land-cover of the Ciliwung watershed is dominated by the buildings, only a small portion of forest area is found at the upper watershed or around Lake Telaga Warna (figure 1). Therefore, Lake Sunter and Lake Cincin, located in Jakarta city and situated at the lower part of the Ciliwung watershed, was characterized by higher pH, conductivity, TDS, TN, TP, and Chlorophyll-a. A crowded urban area like Jakarta City could affect the water quality in lakes. Urban areas play an important role in increasing the level of nitrate and phosphate in waters and then could stimulate eutrophication [28]. Nutrient sources of urban areas are cities sewage, industrial wastewater, erosion, and runoff [4]. The accumulation of pollution materials coming from the upper river system also influences water quality in the lower river system. The higher conductivity and TDS in Lake Sunter and Lake Cincin indicate high dissolved ions concentration. High
ions concentration in a lake could be input from agriculture, domestic, and industry activities in the surrounding area and the watershed [29]. Total Dissolved Solids and conductivity value could also be correlated to the salinity [30]. The TDS value for freshwater lakes ranges from 50 to 250 mgL$^{-1}$ [29]. A wide range of DO in Lake Sunter and Lake Cincin could be related to the hypereutrophic condition of lakes. Hypereutrophic lake was characterized by rich organic matters in the water overlying sediment, so the factor that influences oxygen reduction in a hypereutrophic lake may be oxygen consumption by bacterial to decompose rich organic material in this water column [31]. In shallow lakes such as Lake Sunter and Lake Cincin, windy conditions could stimulate water turbulence cause low DO in water overlaying sediment ascend to the surface waters. TN and TP ratio is an important role in preventing cyanobacteria bloom. A Low TN/TP ratio is often found in the cyanobacteria bloom condition. In Lake Maninjau, the bloom of Microcystis aeruginosa occurred in low the TN: TP ratio (4.7) [32]. A low TN: TP ratio in Lake Sunter and Lake Cincin indicate high phosphorus concentration and nitrogen become the limiting factor for phytoplankton growth. Therefore, phosphorus is a major factor to stimulate algae bloom in those lakes. Phosphate concentration ranges from 0.03 to 0.1 mg L$^{-1}$ or higher could stimulate algae blooms in the lake [4].

Most observed lakes have a high chlorophyll-$a$ concentration, with the highest concentration of 431 µgL$^{-1}$ was recorded in Lake Sunter. Cyanobacteria bloom in Lake Maninjau was characterized by high chlorophyll-$a$ concentration (> 100 µgL$^{-1}$) in 2011 and (97.475 µgL$^{-1}$) in 2018 [32]. WHO has defined Chlorophyll-$a$ of 10 µgL$^{-1}$ as a threshold effect for drinking water and chlorophyll-$a$ of 50 µgL$^{-1}$ as a threshold effect for recreational water use [33]. Differentiation of percentage abundance of phytoplankton composition among observed lakes could be influenced by hydrological, physical and chemical factors such as temperature, light intensity, nutrient, and pH [34]. In Lake Maninjau, Indonesia Microcystis aeruginosa bloom was recorded in a higher water column stability period and low TN: TP ratio [32].

The dominance of Cyanobacteria in Lake Telaga Warna and Lake Sunter could be related to the preference of environmental conditions of the dominant species. Cylindrospermopsis raciborskii, Microcystis aeruginosa, and Planktothrix agardhii are sensitive to flushing. Cylindrospermopsis raciborskii adapted to low light, and Planktothrix agardhii adapted two high light deficient [35]. Cylindrospermopsis raciborskii is also dominant under low and extreme N: P ratios (122:1) [36]. The highest TN: TP ratio was also recorded in Lake Telaga Warna. Cylindrospermopsis raciborskii and P. agardhii were preferred to grow in nutrient-rich waters but those two species have a different preference of environmental conditions. Planktothrix agardhii was positively correlated to TP and PO43-, while C. raciborskii was positively correlated to NH4+ [37]. Those studies support our findings that Cylindrospermopsis raciborskii was dominant in Lake Telaga Warna, characterized under phosphorous limitation. Planktothrix agardhii is preferred to grow in Lake Sunter, characterized by high phosphorus concentration or under nitrogen limitation.

The low dominance of cyanobacteria in Lake Cikaret may be related to unbalance hydrological condition which is indicated by a variability water discharge during the season of the year [16]. Cyanobacteria has a preference for higher water column stability of lakes [32]. Hydrological factors influence thermal stratification and nutrient availability, an important factor in stimulating algae growth [38]. The dominant assemblage of phytoplankton in Lake Cikaret was Cryptophyta constituted 34% of the total phytoplankton abundance. Cryptophyta was represented by Cryptomonas sp. which is found in small shallow enriched lakes [35]. Euglenophyta contributes 24% of the total phytoplankton abundance and was represented by some species of Euglena, Trachelomonas, Phacus, and Strombomonas. Those genera were commonly found in rich inorganic matter waters [35]. The dominant of Bacillariophyta in Lake Cincin was represented by Fragilaria sp. Fragilaria spp. This species is commonly live in a habitat with continuous or semi continued mixed layers of shallow eutrophic lakes, or sensitive to stratification and to silicate depletion in the lake [35].

Cyanobacteria in Lake Sunter dominated by Planktothrix (Syn. Oscillatoria) with the abundance (104.461 to 1,920.5 x 103 individual L$^{-1}$) and Telaga Warna dominated Cylindrospermopsis raciborskii and Mycrocystis aeruginosa with (5,750 x individualL$^{-1}$ and 2,293 individualL$^{-1}$) is lower
The differentiation of trophic status of those lakes coincided with the thresholds level of cyanobacteria bloom for minor, moderate, and severe blooms category are 4,000; 10,000 and 100,000 cyanobacterial cells mL⁻¹ [39]. Some species of cyanobacteria found observed lake as Microcystis spp. Planktothrix (syn. Oscillatoria) agardhii, Cylindrospermopsis raciborskii have the capacity to produce toxins [7]. Low Shannon diversity index, Evenness, and Margalef Richness index of phytoplankton in Lake Sunter could be related to the high Cyanobacteria bloom in this lake. Low phytoplankton richness is related to the high cyanobacteria density.

5. Conclusion
The trophic state of observed lakes is eutrophic to hypereutrophic category. Lake Telaga Warna and Lake Cikaret were classified as eutrophic lakes, while Lake Sunter and Lake Cincin were classified as hypereutrophic lakes. The differentiation of trophic status of those lakes coincided with the physicochemical characteristic of lakes. The hypereutrophic status of lakes was characterized by high chlorophyll-a, abundant phytoplankton, higher temperature, conductivity, pH, TDS, nutrient, and lower Secchi depth. Cyanobacteria dominance was recorded in Lake Telaga Warna and Lake Sunter. Eutrophic status in Lake Telaga Warna characterized by Microcystis aeruginosa and Cylindrospermopsis raciborskii as a dominant species and phosphorus as limiting factor for alga growth. Hypereutrophic status in Lake Sunter characterized by Cyanobacteria bloom, dominated by Planktotrix Agardhii. High phosphorus concentration is a factor stimulating for Cyanobacteria bloom in this lake. Some species of cyanobacteria found in observed lakes have the capacity to produce toxins. In Lake Sunter, both under conditions of cyanobacterial dominance and high chlorophyll-a concentration increase probability toxin impact for health.

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