Temporal variation of physico-chemical characteristics and phytoplankton composition of three urban lakes in Cibinong, West Java, Indonesia

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Abstract. Urban lakes are important freshwater resources for securing water supply, flood control, and tourism. There are more than 200 urban lakes in Jabodetabek areas, some of which are experiencing high risk of disappearance due to pollution, eutrophication, and sedimentation. There have been limited basic limnological data on appropriate management practice to protect the integrity of this vulnerable system. The aim of this study is to determine the characteristics and temporal variations of phytoplankton composition, phytoplankton abundance, and water quality in Lake Cibuntu, Lake Dora, and Lake Lotus in Cibinong, West Java in order to support the management strategy of lakes. Phytoplankton sample and water quality data including conductivity, total dissolved solid (TDS), potential of hydrogen (pH), dissolved oxygen (DO), total nitrogen (TN), and total phosphorus (TP) were collected biweekly from July to October 2018. The results revealed that Lake Cibuntu, Lake Dora, and Lake Lotus had different physico-chemical characteristics and phytoplankton dominance and abundance. Lake Cibuntu was characterized by higher temperature, DO, TN, Chlorophyta dominance with phytoplankton abundance ranging from 1,180 to 138,254 individuals L^{-1}; Lake Lotus was characterized by high conductivity, TDS, and Bacillariophyta dominance with phytoplankton abundance ranging from 4,800 to 53,918 individuals L^{-1}, while Lake Dora was characterized by low pH and DO with phytoplankton abundance ranging from 1,926 to 7,287 individuals L^{-1}, and the dominance of phytoplankton changed from Chlorophyta to Chrysophyta in August. Temporally, the variability of the physico-chemical characteristics of those three lakes appeared to be influenced by seasonal monsoon. High nutrients (TN and TP) were found in the lakes which received water source from streams. The variability of phytoplankton dominance and abundance, also temporally, appeared to be related to the dynamics of physico-chemical characteristics of the lakes.
Key Words: anthropogenic , eutrophication, phytoplankton, water quality.

Introduction. Over the past century, urban development has been known to contribute to the decrease of ecological integrity of lakes. Urban lakes in many areas in the world have become a vulnerable system as a result of urbanization or anthropogenic activities. Generally, urban lakes are shallow, have a small size with an average depth of 3 to 5 meters or less, and tend to receive high nitrogen loads. Therefore, urban lakes are sensitive to the pollution and eutrophication (Nasseli-Flores 2008). Agricultural and urban land type uses are recognized as the main sources of nutrient inputs and various contaminants in lakes (Carpenter et al 1998; Carney 2009). In Indonesia, urban lakes in a megacity such as Jakarta have a high risk of disappearance due to land use changes, siltation, sedimentation, eutrophication, and water pollution. Several urban lakes in this area are indicated to have disappeared, and many have also shrunk (Henny & Meutia 2014a). As a consequence, an appropriate management practice is required to protect the integrity of this vulnerable system.

In Indonesia, especially West Java, small lakes, which are commonly called "Situ", have a number of functions as follows: sources of water supply, flood control, recreational areas, sources of irrigation water, and fisheries. In general, small urban lakes in West Java are artificial lakes with an area from 1 to 160 ha and the average of water depth of 0.5 to 2 m (Sudinda 2018). There are over 200 small urban lakes around

Jakarta, Bogor, Depok, Tangerang, and Bekasi (Jabodetabek) areas. In Cibinong, the capital city of Bogor Regency, there are at least 23 small lakes, most of which are situated at the Ciliwung watershed. Bogor Regency is located at the area of the middle stream of the Ciliwung watershed which flows to Jakarta Bay through Jakarta City. It indicates that the small lakes in Cibinong should be managed in order to control water flow (runoff) that flows to Jakarta. Based on the Government Regulation of the Republic of Indonesia Number 42 Year 2008, small lakes function as flood control. However, they also play an important role in conservation of water resources and biodiversity, in microclimate control, and in socio-economic community support. Related to the biodiversity, there are 82 species of aquatic insects found in four urban lakes of Bogor and 20 fish species found in stream of Ciliwung watershed (Hadiaty 2011; Wakhid et al 2020). Therefore, conservation and appropriate management of these small lakes in this area are part of the government program in order to contribute to a better life of urban communities.

Bogor Regency is part of the Jakarta Metropolitan Area (Jabodetabek), which is the largest urban area in Indonesia. Therefore, its urban lakes also have problems such as sedimentation, pollution, and eutrophication. The eutrophication status of urban lakes sometimes proceeds to the state of hyper eutrophic by extremely high biological productivity as indicated by macrophyte and Cyanobacteria blooms. A number of efforts have been made by the local government to maintain the quality of lakes and to improve the degraded lakes by removing sediments, extending inundation areas, and improving water flow connection and riparian zone. Lake Cibuntu and Lake Bojongsari were restored in 1998 and in 2003 respectively (Sulastri 2005).

Generally, problems of small lakes in urban areas such as Jabodetabek are related to eutrophication (Henny & Meutia 2014b). In Lake Cibuntu, eutrophication often occurs after restoration by removing sediments. In order to maintain the sustainability and integrity of lakes, it is required to understand the physico-chemical and biotic characteristics of them. Artificial small lakes create a variety of morphological types and hydrological characteristics. Some studies have shown that morphological and hydrological characteristics influence water quality and eutrophication in small lakes (Köiv et al 2011; Huang et al 2014). Hydrological regime also regulates phytoplankton growth by regulating thermal condition and nutrient availability (Tolotti et al 2010). The temporal change in the water-column movement pattern (mixing vs. stratification) is one of the main environmental forces which affects on phytoplankton dynamics. Therefore, understanding spatial-temporal water quality related to the hydrological condition (water level and discharge) is important in evaluating eutrophication and providing an inspiration for lake management (Li et al 2016). The objective of this study is to determine the characteristics and temporal variations of water quality (physico-chemical) and phytoplankton composition and abundance in three urban lakes of Cibuntu, Dora, and Lotus in Cibinong and also to support the management strategy in preventing eutrophication.

Material and Method

Research location. Lake Cibuntu, Lake Dora, and Lake Lotus are located at Indonesian Institute of Sciences (LIPI) Complex in Cibinong City, West Java (Figure 1). These areas are surrounded by agricultural land and rural areas. Cibinong is the capital city of Bogor Regency, geographically located between 106º21'-107º13' East and 6º19'- 6º47' South. The climate type in Cibinong has considerably high rainfall over the year (over 60 mm each month). The high amount of rainfall is found in December, January, and February, and the lower one is found in June, July, and August (Perdinan et al 2017). The surface areas of Lake Cibuntu, Lake Dora, and Lake Lotus are 2.11 ha, 1.31 ha, and 0.78 ha respectively, and their maximum depths are 1.20 m, 1.13 m, and 2.0 m respectively. Lake Cibuntu was restored in 1998 owing to eutrophication. Built in 2016, Lake Lotus is a new lake, while Lake Dora was built in 2002. Lake Cibuntu and Lake Lotus receive water source coming from streams that flow through agricultural areas and human settlements, while Lake Dora receives water source coming from groundwater.

Data collection and measurement of physical and chemical parameters. The analyses of surface water samples for total nitrogen (TN) and total phosphorus (TP) were collected every two weeks at four sampling points in Lake Cibuntu and Lake Dora and at three sampling points in Lake Lotus (Figure 1) from July to October 2018. Water temperature, potential of hydrogen (pH), dissolved oxygen (DO), and conductivity parameters were measured every two weeks by using a water quality checker (YSI), while water depth was examined by the measurement of the Secchi depth. TN was analyzed by using the persulfate digestion and Brucine method (APHA 1999). TP was determined using the persulfate digestion and Ascorbic Acid method (APHA 1999). All samples were analyzed at the Research Centre for Limnology, Indonesian Institute of Sciences (LIPI). The primary component analysis was used to classify the physico-chemical characteristics of the lakes.

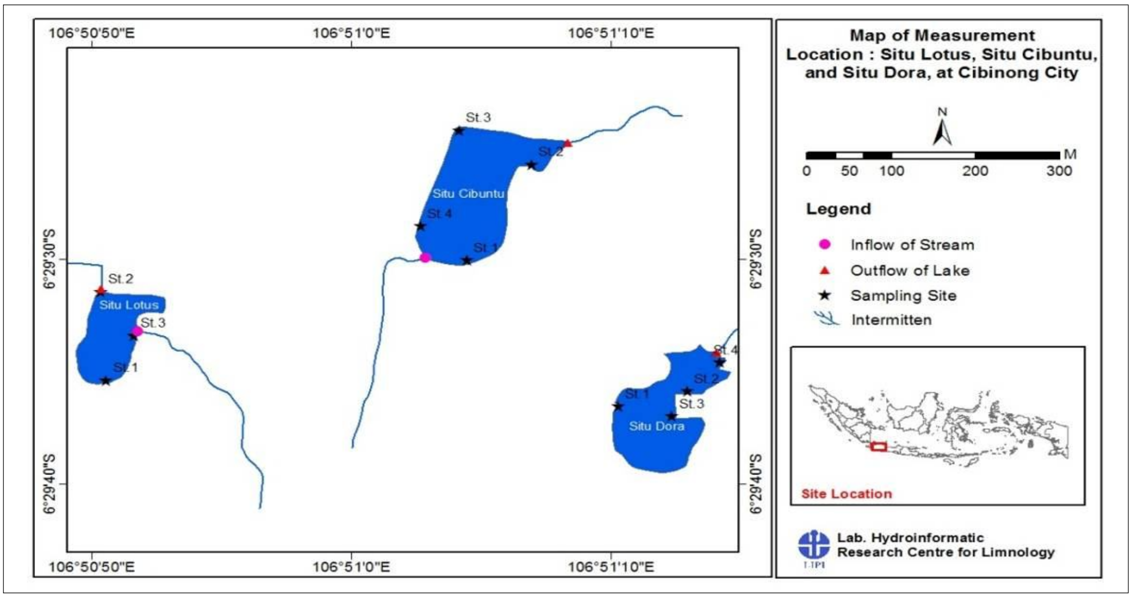

Figure 1. The map of three urban lakes in Cibinong, West Java, Indonesia.

Phytoplankton analysis. Phytoplankton samples were collected biweekly from July to October 2018 by filtering 2 liters of water from the surface water through 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 some references (Prescott 1951; Scott & Prescott 1961; Baker & Fabro 1999; Gell et al 1999) at a magnification of 400X through an inverted microscope. Quantitative analysis phytoplankton used the Lackey Drop Micro Transect (APHA 1999). Phytoplankton functional group was classified according to Reynolds et al (2002) and Padisák et al (2009).

Results

Physico-chemical characteristics. Water depth in Lake Cibuntu, Lake Dora, and Lake Lotus ranged from 20.0 to 75.8 cm, 39.5 to 97.0 cm, and 33.0 to 84.0 cm respectively (Figure 2). Lake Cibuntu and Lake Lotus had a similar pattern of water depth fluctuation with the lowest value found in August. Lake Dora had a different pattern fluctuation compared to that of the two lakes with its lowest value found in October.

Physico-chemical parameter values showed the variability in each Lake (Table 1). Some of physico-chemical parameters such as temperature, DO, pH, conductivity and TDS have been reported by Sulastri et al (2020). High average value of DO was found in Lake Cibuntu and the lowest average was found in Lake Dora. The highest average values of conductivity and TDS were recorded in Lake Lotus. In terms of nutrients, the highest average TN concentration (0.856 mg L^{-1}) was found in Lake Cibuntu, and the lowest one (0.556 mg L^{-1}) was found in Lake Dora, while the highest average TP concentration (0.044 mg L^{-1}) was found in Lake Lotus. The primary component analysis showed that the three lakes had different characteristics of water quality condition. Lake Cibuntu was characterized by high temperature, DO, and TN, while Lake Dora was characterized by low DO and pH. Lake Lotus was characterized by high conductivity and TDS (Figure 3).

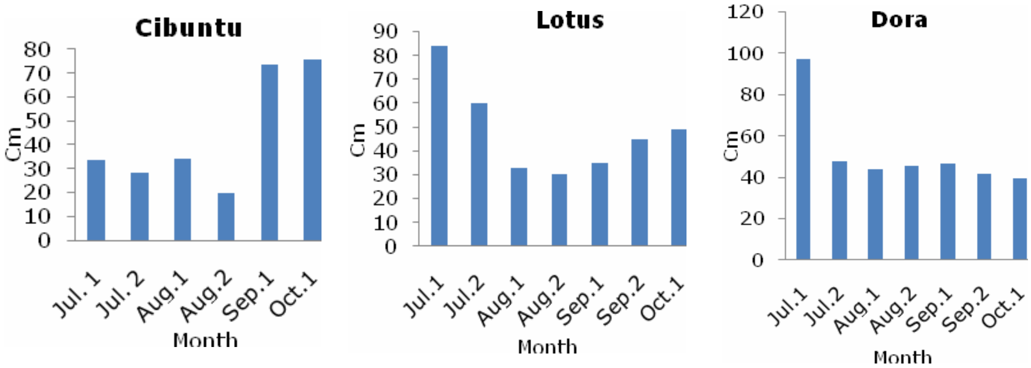

Figure 2. Water depth of three urban lakes in Cibinong, West Java, Indonesia.

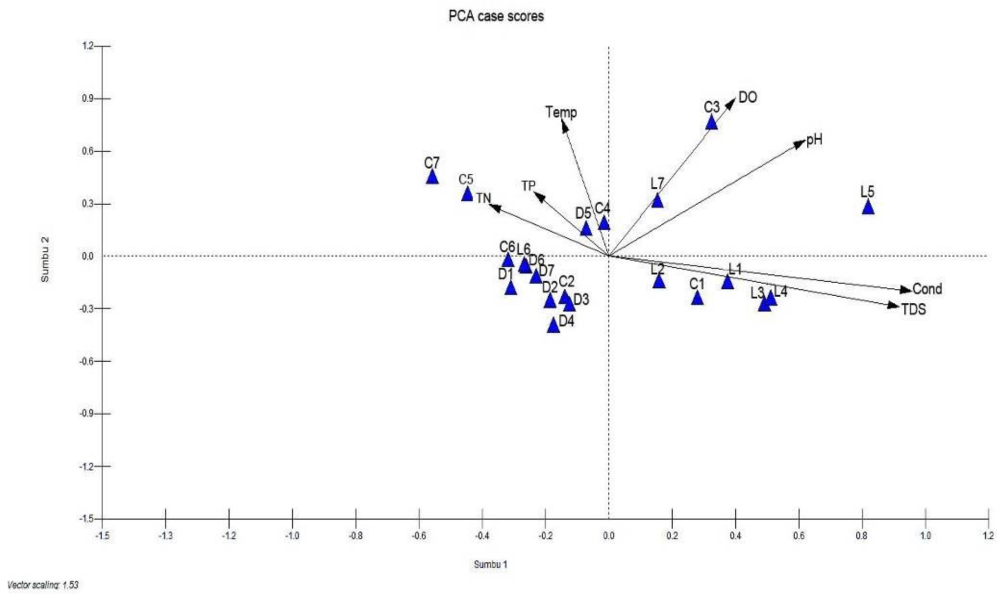

Figure 3. Primary Component Analysis (PCA) of Lake Cibuntu (C), Dora (D) and Lotus (L) based on the temperature (Temp), DO, pH, conductivity (Cond), TDS, TN and TP.

Table 1

Average value of physico-chemical parameter in Lake Cibuntu, Lake Dora and Lake Lotus (Sulastri et al 2020)

Parameters		*Cibuntu*	*Dora*	*Lotus*
Temperature (^oC)	Range	27.33-32.21	26.23- 33.48	27.14-32.07
	Average	29.89	29.31	28.79
DO (mg L^{-1})	Range	6.41-11.23	5.53-7.41	7.11-9.26
	Average	8.35	6.24	7.55
pH	Range	6.32-7.83	5.74-6.54	6.32-7.2
	Average	6.74	6.01	6.69
TDS (mg L^{-1})	Range	21.4-38.03	33.64-48.5	35.25-68.32
	Average	34.37	37.88	55.36
Conductivity (mS cm^{-1})	Range	0.035-0.067	0.055-0.075	0.056-0.122
	Average	0.056	0.061	0.091
TN (mg L^{-1})	Range	0.022-1.486	0.206-1.201	0.520-1.022
	Average	0.856	0.556	0.741
TP (mg L^{-1})	Range	0.010-0.052	0.010-0.083	0.001-0.069
	Average	0.027	0.038	0.044

Temporally, temperature variability was not significantly shown, while DO fluctuated in Lake Cibuntu and Lake Lotus. In Lake Cibuntu, the highest value of DO (> 10 mg L^{-1}) was found in August, while in Lake Lotus, the highest one (> 8 mg L^{-1}) was found in October. In Lake Cibuntu, the value of pH fluctuated with the highest one found in August. A similar pattern of fluctuation of conductivity and TDS in Lake Cibuntu and Lake Lotus was shown. In both lakes, the conductivity and TDS decreased in October. Inversely, in Lake Dora, conductivity and TDS increased in this month (Sulastri et al 2020). In terms of nutrients, fluctuation of TN in Lake Cibuntu and Lake Dora showed a similar pattern, which decreased in August and increased in September and October (Figure 4).

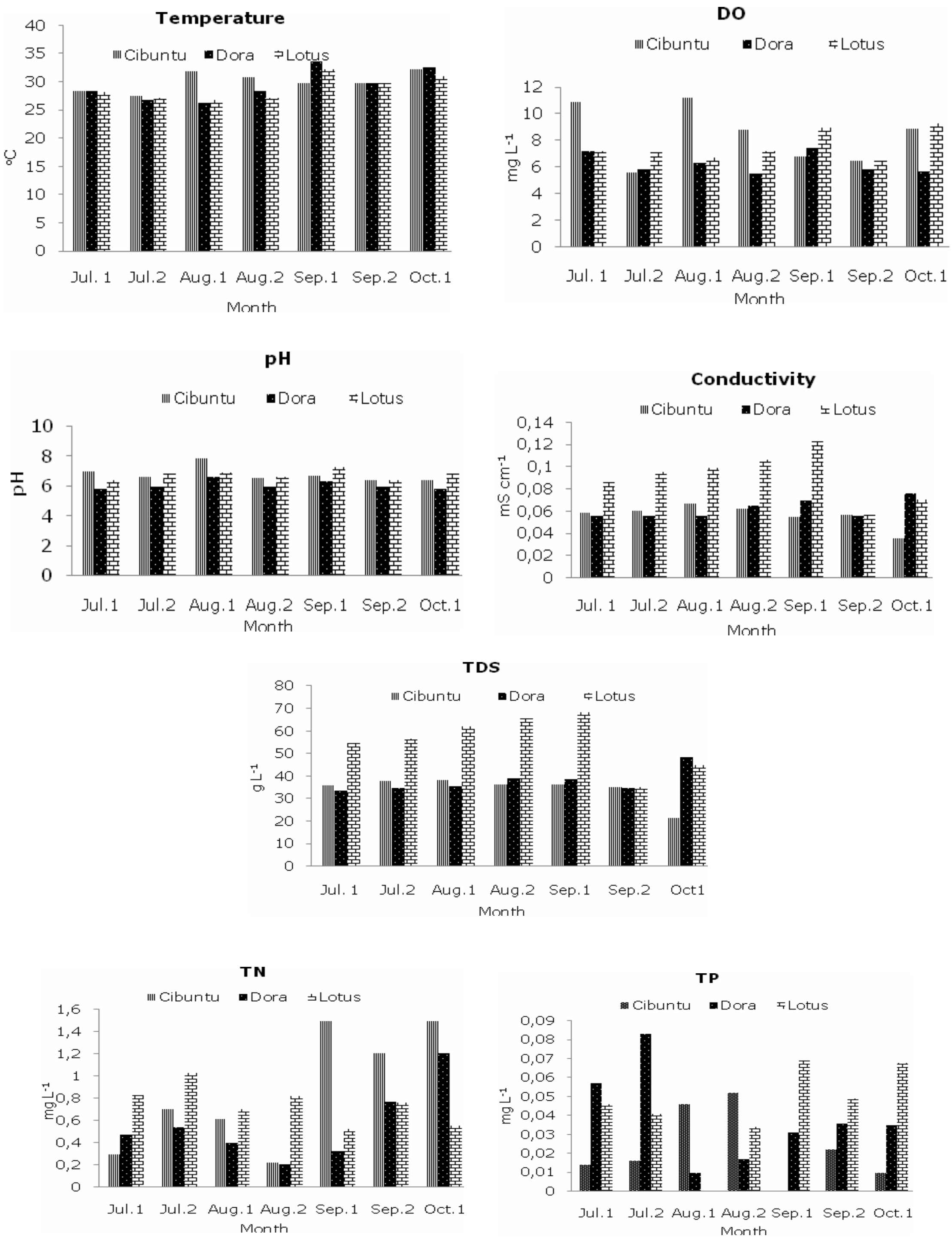

Figure 4. Temporal variation of physico-chemical distribution based on every two weeks observations in three urban lakes of Cibinong, West Java, Indonesia.

Temporally, TN concentration in Lake Lotus did not indicate significant variability during the study period, while TP concentration in both Lake Cibuntu and Lake Lotus showed different fluctuations. In Lake Cibuntu, TP increased in August and decreased in September and in October. Contrastingly, TP in Lake Lotus decreased in August and increased in September and in October. In Lake Dora, low TP concentration was also found in August (dry season).

Phytoplankton composition and abundance. Chlorophyta was the most dominant phytoplankton in Lake Cibuntu, while Bacillariophyta was dominant in Lake Lotus. Chlorophyta was also dominant in Lake Dora; however, this dominant Chlorophyta was replaced by Chrysophyta in August with its peak reaching 79.75%. In Lake Cibuntu, Chlorophyta reached its peak (98.2%) in September. Also in the same month, Bacillariophyta reached its peak (98.2%) in Lake Lotus (Figure 5). Phytoplankton abundance was found in Lake Cibuntu, ranging from 1,623 to 138,254 individuals L^{-1}, and in Lake Lotus, ranging between 4,700 and 53,918 individuals L^{-1}. In Lake Dora, phytoplankton abundance ranged between 1,162 and 7,287 individuals L^{-1}, which made it lower compared to that in Lake Cibuntu and Lake Lotus.

Temporally, the highest abundance of phytoplankton was found in August, while in Lake Lotus, it was found in September. Phytoplankton abundance in Lake Dora did not significantly indicate variability during the observation periods.

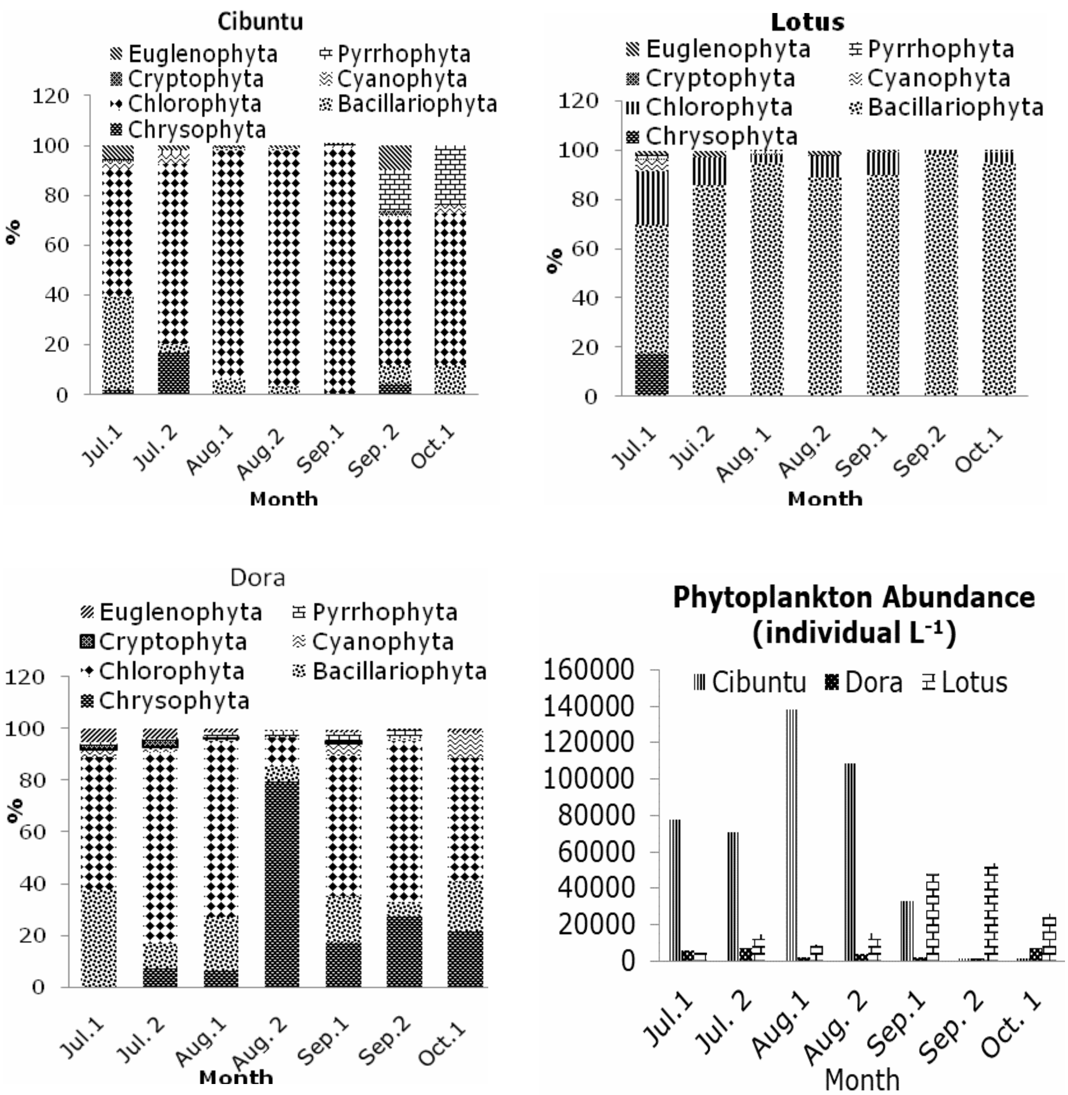

Figure 5. Phytoplankton composition and abundance of three urban lakes in Cibinong, West Java, Indonesia.

***Functional group of phytoplankton**.* The phytoplankton functional group approach was identified by alpha-numeric codes according to Reynold et al (2002) and Padisák et al (2009). Functional group of phytoplankton was classified based on the similarity of habitat, ability of adaptation, and sensitivity to environmental factors (Table 2). Phytoplankton functional group provides important information on understanding the dynamics of pelagic communities of phytoplankton and analysis of ecological status of lakes (Boric et al 2012). Lake Cibuntu, Lake Lotus, and Lake Dora have similarities in the functional group of phytoplankton. We identified 15 phytoplankton functional group (D, E, N, P, MP, F, J, Lo, Tc, T, M, SN, X1, W1 and W2) (Table 2). However, they had a difference in representative species dominance. Phytoplankton functional group P was the most dominant assemblage in Lake Cibuntu and Lake Lotus with differences in species dominance. *Staurastrum* sp., the representative of functional group P, was found dominant in Lake Cibuntu, while *Aulacoseira granulata,* the representative of functional group P, was found dominant in Lake Lotus. *Dinobryon* sp., the representative of functional E, was found dominant in Lake Dora in August. *Cosmarium* spp., the representative of functional group N (isiodiometric desmid), was often found in Lake Dora.

Table 2

Trait-separated functional groups of phytopkankton in Lake Cibuntu, Lake Lotus and Lake Dora

Division	*Observed species*	*FG*	*Lakes*		
			Cibuntu	*Dora*	*Lotus*
Chrysophyta	*Dinobryon* sp.	E	*	***	*
	Aualacoseira granulata	P	*	*	***
	Fragilaria spp.	P	*	*	*
Chlorophyta	*Staurastrum* spp.	P	***	*	*
Chlorophyta	*Cosmarium* spp.	N	*	**	*
Bacillariophyta	*Amphora* sp.	Mp		*	*
	Cymbella sp.	Mp	*	*	*
	Navicula cuspidata	Mp	*	*	
	Navicula spp.	Mp	*	*	*
	Surirella spp.	Mp	*	*	*
	Nitzchia spp.	D	*		*
	Synedra sp.	D	*	*	*
	Synedra ulna	D	*	*	*
Chlorophyta	*Ankistrodesmus* spp.	J	*	*	*
	Actinastrum sp.	J	*	*	
	Coelastrum spp.	J	*	*	*
	Coelastrum microporum	J	*	*	*
	Dictyosphaerium sp.	J	*	*	*
	Pediastrum spp.	J	*	*	*
	Scenedesmus spp.	J	*	*	*
	Sphaerocystis sp.	J	*	*	*
	Tetraedron sp.	J	*	*	
	Kirchneriela lunaris	F	*	*	*
	Oocystis spp.	F	*	*	*
Cyanophyta	*Cylindrospermopsis raciborskii*	SN	*	*	
	Microcystis aeruginosa	M	*		*
	Meugeota sp.	T		*	
	Oscillatoria spp.	Tc	*	*	*
	Chrooccoccus sp.	Lo	*	*	
Pyrrhophyta	*Peridinium* spp.	Lo	*	*	*
Euglenophyta	*Euglena* spp.	W1	*	*	*
	Phacus spp.	W1			*
	Trachelomonas spp.	W2	*	*	*
	Strombomonas spp.	W2			*

Remark: *** dominant in Lakes Cibuntu and Lotus; *** dominant in Lake Dora in August; ** often found in Lake Dora, *found in Lakes Cibuntu, Dora and Lotus.

Discussion. The variability of water depth in Lake Cibuntu and Lake Lotus might be related to the seasonal monsoon of the year. It was influenced by rainfall through water inflows from inlets. In Cibinong, the dry season started in August, while the rainy season started in October. In tropical countries like Indonesia, water level and water volume depend on precipitation. The decreasing water depth in Lake Dora or in the rainy season might be related to the input of water mainly from the groundwater into this lake. In the start of the rainy season, rainfall did not directly flow into the lake but was absorbed into the soil. The water quality differences in Lake Cibuntu, Lake Lotus, and Lake Dora could be attributed to the differences in morphological features, water sources, and land use types on those lakes. Lake Cibuntu and Lake Lotus received water source coming from the streams flowing through agricultural areas and human settlements, while Lake Dora received water source from groundwater. Some studies suggest that morphological and hydrological characteristics influence water quality and eutrophication in small lakes (Köiv et al 2011; Huang et al 2014). Water chemistry in open water is also linked with source of water either from groundwater or from atmospheric precipitation (Dodson et al 2005). As reported, small lakes receive water source coming from streams that flow through forest areas as shown by their low level of TP concentration. And small lakes receive water source coming from streams that flow through agricultural areas, and it is characterized by high concentration of TN and nitrate level, lower number of taxa richness, and high abundance of Cyanophyta (Sulastri et al 2008). Fertilizers from agricultural areas can increase the ion in streams which increases conductivity and TDS in lakes (Bhateria & Jain 2016). Groundwater inflows can have effects on the conductivity in lakes depending on the bedrock they flow through (Bhateria & Jain 2016).

High DO concentrations in Lake Cibuntu and Lake Lotus coincided with high phytoplankton abundance in these two lakes (Figure 5). Photosynthesis activities of phytoplankton produced oxygen and contributed to the DO concentrations in the waters. Higher amount of DO in Lake Cibuntu and Lake Lotus in October might also be related to the increase of water circulation as an effect of discharge which increased in October, the start of the rainy season. Higher pH in Lake Cibuntu and Lake Lotus coincided with high DO in these two lakes (Figure 5). Richness of major ions in Lake Lotus was indicated by high conductivity and TDS in this lake. TDS has a significant correlation with HCO_3^- and Ca^{2+}, while conductivity correlates significantly with anion HCO_3^-, SO_4^-, and Cl^- (Harris 1986). Conductivity in waters is affected by the geology of the area through which the water flows. High content of TDS coincides with high level of conductivity (Bhateria & Jain 2016). Low conductivity and TDS in Lake Cibuntu and Lake Lotus in October were related to the dilution of precipitation. Inversely, in Lake Dora, its conductivity increased and it was likely related to evaporation as it coincided with the decrease of water depth (Figure 2) in this month. As stated, the changes of conductivity could be related to precipitation, evaporation, air temperature, and hydrological conditions (Makhlough 2008; Pal et al 2015).

High TN in Lake Cibuntu and high TP in Lake Lotus in the start of the rainy season (September and October) indicated that nutrient concentrations in these two lakes were highly influenced by those from the watershed input (Figure 4). Lake Cibuntu and Lake Lotus received water source coming from the streams flowing through agricultural areas and human settlements. Input of nutrients into the lake depends on nutrient availability in the watershed (Fraterrigo & Downing 2008). Rainfall stimulates nutrient loads in waters from terrestrial runoff (Wantzen et al 2008). High TP in Lake Cibuntu found in August might be due to the accumulation of TP indicated by low water depth. On the other hand, in small and shallow tropical lakes, water quality is also strongly affected by wind-induced sediment resuspension which results in significant changes on their water chemistry including TP (Tammeorg et al 2013). This phenomenon is in line with the morphological condition of Lake Cibuntu which was shallower than that of Lake Lotus. The increase of TN in Lake Dora in October and September was due to the accumulation of TN concentrations as it coincided with low water depth.

The difference in phytoplankton composition in Lake Cibuntu, Lake Dora, and Lake Lotus is in line with the differences in water quality of the three lakes (Figure 5). TDS and conductivity influence diatom structure community (Bacillariophyta) (Kivrak & Uygun 2012) and water column stability, while nutrient availability influences the variability of phytoplankton composition (Reynolds 1980). In Lake Dora, the dominance of Chrysophyta in August was related to the limited TN and TP availability in this month (Figure 4). Chrysophyta in this observation was dominated by *Dinobryon* sp. that was adapted to low nutrient concentration (Table 2).

High percentage of Chlorophyta and Bacillariophyta in Lake Cibuntu and Lake Lotus found in September and October could be related to the increase of water circulation due to water input from inlet in the start of the rainy season. Chlorophyta in Lake Cibuntu was dominated by *Staurastrum* spp., while Bacillariophyta in Lake Lotus was dominated by *A. granulata* (Table 2). *Staurastrum* spp. and *A. granulata* were functional groups representing Codon P that were sensitive to water column stratification or their habitat in waters with continuous or semi continuous mixed layer and higher trophic level (Reynolds et al 2002; Padisák et al 2009). This type of habitat can be found in small shallow lakes such as Lake Cibuntu and Lake Lotus which acquire inflows from a tributary. *Aulacoseira* spp. is able to adapt to water turbulence and its life cycle is closely related to the regime of the water-column mixing (Lund 1965).

The highest phytoplankton abundance was recorded in Lake Cibuntu in August with low water depth and high TP concentrations. In lakes, nitrogen (N) or phosphorus (P) are the limiting factors for phytoplankton growth. The concentrations and balance of N and P ratio affect phytoplankton growth rate and abundance (Jørgensen 1980; Wetzel 2001). The fluctuation of phytoplankton abundance in Lake Cibuntu and Lake Lotus apparently was also affected by water inflow fluctuation. Low phytoplankton abundance in Lake Cibuntu in September and in October (the start of the rainy season) was indicated by higher water depth condition as a result of phytoplankton flushing out from the lake. High volume inflows during rain events can reduce algae biomass owing to high flushing rates (Figueredo & Giani 2009).

Conclusions. Lake Cibuntu, Lake Dora, and Lake Lotus have different physico-chemical characteristics, phytoplankton composition, and abundance. Temporally, those three lakes show the variability of physico-chemical characteristics which is influenced by seasonal monsoon. High nutrients (TN, TP) found in the lakes receive the water source from the stream. High inflow volume in the rainy season causes disruption of phytoplankton abundance in Lake Cibuntu and Lake Lotus. Based on the functional group, Codon P is dominant in Lake Cibuntu and Lake Lotus, indicating that these two lakes are eutrophic with continuous or semi continuous mixed layer. During the dry period, Lake Dora is in poor condition, and it is dominated by functional groups of Codon E. However, functional groups of Codon N are often found in this lake in the other period of mesotrophic waters.

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