Littoral and Limnetic Phytoplankton Distribution and Biodiversity in a Tropical Man-Made Lake, Malaysia

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Abstract

The distribution of the phytoplankton community in different zones of Putrajaya Lake, Malaysia was analyzed from October 2009 to September 2010 to examine the zonal-distribution relationship. Three stations representing three different lake zones namely Station 1 (littoral zone), Station 2 (sub-littoral zone) and Station 3 (limnetic zone) were selected. Water transparency, temperature, pH, dissolved oxygen and conductivity were found to be important factors characterizing each zone. A total of 148 species from 77 genera were recorded throughout the sampling duration from October 2009 until September 2010. During this period, Chlorophyta was the most abundant group (59% of the total phytoplankton), followed by Pyrrophyta (15%), Cyanobacteria (11%), Bacillariophyceae (9%), Chrysophyceae (3%), Cryptophyta (2%) and Euglenophyta (1%). The highest mean density of phytoplankton was recorded in the limnetic zone (433.94 ± 18.29 cells ml⁻¹), followed by sub-littoral (292.94 ± 18.61 cells ml⁻¹) and littoral zone (199.58 ± 13.56 cells ml⁻¹). There was a significant difference in the Shannon-Wiener diversity index for phytoplankton diversity and abundance in all three zones (p<0.05) with limnetic zone demonstrating the highest species diversity.
Species commonly found in the sub-littoral area also dominated both littoral and limnetic phytoplankton communities suggesting that sub-littoral zone acted as an interphase for phytoplankton adaptation and migration between the two different zones. The findings suggest that spatial distribution and diversity of the phytoplankton community can be affected significantly by local lake zonation characterized by environmental variations.

**Keywords:** Phytoplankton community, Species diversity, Tropical lake

### 1. Introduction

The phytoplankton community is known for their spatial and temporal dynamics throughout the water column. They float freely, populating the euphotic zone or upper strata of water bodies by controlling buoyancy by means of gas vacuoles, flagella or metabolic processes [7]. Their dynamics are a function of multiple environmental processes that affect a lake system including climatic, physical and chemical changes [14]. The detailed consideration of the biology of lakes and other water body types begins with the phytoplankton as they form the base line of the aquatic food web. Thus, the dynamics of the rest of the biological community is dependent to a very large extent on these photosynthetic microorganisms. In tropical lakes, variation in the succession and periodical pattern of phytoplankton community is strongly associated to meteorological factor and water stratification mixing process caused by the prevailing wind, in contrast to temperate environment where high temperature fluctuations in accordance to changing seasons exert major influence [36, 38].

Lakes have regions that are well defined by boundaries and physical characteristics which clearly define local communities and their niche [43]. Lake boundaries have different abiotic conditions, resulting in different species that can adapt within the given condition. Nevertheless, phytoplankton possesses the capacity to tolerate and co-occur even though each species may have a specific niche based on its physiological requirements and the constraints of the environment. The variability of morphometric features and physico-chemical parameters affect the development of specific types of aquatic macrophytes, the communities of which in turn play the habitat-making role, changing both the physical and chemical conditions, thus creating the substrate and refuges for aquatic organisms [29].

The phytoplankton community structure has been adopted as an important biological indicator due to its ability to respond rapidly and predictably to a wide range of pollutants and environmental changes [35]. Knowledge on the changes in phytoplankton biomass and species composition across time and space can provide useful early warning signals of degrading conditions and the possible
causes [15]. Nevertheless, the effects of different local regions in a lake towards the dynamics of phytoplankton population are rarely studied and understood. There have been few published studies focusing on the effect of different lake zones on the phytoplankton community structure within a single lake body. Understanding how the in-lake factors affect the dynamics of phytoplankton community as the primary producer may help in future lake management. The objective of this study was to examine the zonal-distribution relationship of phytoplankton community in terms of their density and diversity in littoral and limnetic areas in Putrajaya Lake, Malaysia.

2. Materials and methods

2.1. Study site description

The data used in this study were collected from the man-made Putrajaya Lake, located in the heart of the Malaysian federal government administrative center which holds the concept of city-in-a-garden. Putrajaya Lake was created in 1997 by the flooding of two rivers – Chuau river and Bisa river. It was primarily designed to enhance the natural aesthetic appeal of the city besides providing recreational water-based activities. It is an integrated lake with yet the biggest constructed wetlands in the tropics which covers an area of 600 ha. The lake body which occupies some 400 ha and located in the southern part of the wetland receives water inflow from the wetland which acts as a natural filtering system for the lake. The wetland adopts a multi-cell and multi-stage designed system to enhance hydraulic performance and retention of pollutants. The Putrajaya Lake and its associated wetland catchment is a part of the bigger Sungai Langat river basin within the state of Selangor. Average rainfall in Putrajaya Lake ranged from 205.3 mm to 237.0 mm according to lake zones.

2.2. Sampling

Sampling was done monthly from October 2009 until September 2010. Three stations representing different zones of the lake were selected. Station 1 was characterized by dense macrophytes and located close to the dam separating the wetland from the lake; Station 2 was an area at one of the arms of the lake, between the riverine and the lacustrine zones, characterized by lesser submerged aquatic plants; while Station 3 was a region above the main dam, situated in the central part of the lake constituting an open water without vegetation (Fig. 1). Phytoplankton samples were collected from each station using a 2 L Van Dorn water sampler at 0.5 m intervals until photic depth was reached for each station. The 1 L samples were preserved with Lugol’s iodine and subjected to identification and enumeration. Basic environmental parameters such as water temperature, conductivity, pH, and dissolved oxygen were measured in situ during
sampling using the multiparameter water quality meter (YSI 650 MDS). Photic depth was determined from the water transparency readings which were taken using a Secchi disc. Meteorological data was obtained from the Putrajaya Corporation Database Centre.

2.3. Identification and enumeration

Preserved samples were left to settle to the bottom of the measuring cylinder and concentrated to a 100 ml working volume. Identification of phytoplankton was based on related identification keys [2, 10, 19, 21, 23]. Enumeration of phytoplankton was done using an inverted Leitz diavert microscope adopting the method modified by Legendre and Watt [27]. Samples of 1 ml to 4 ml were placed in the counting chamber and left to settle for 4 to 24 h prior to transfer to the microscope stage. Random non-overlapping fields were examined until at least 150 units of the dominant species were counted [26]. Phytoplankton density was calculated using the following formula:

\[
\text{No ml}^{-1} = \frac{(C \times A_t)}{(A_f \times F \times V)} \times \frac{V_1}{V_2}
\]

Where:
- \(C\) = Number of organisms counted
- \(A_t\) = Total bottom area of settling chamber (mm\(^2\))
- \(A_f\) = Area of a field (mm\(^2\))
- \(F\) = Number of field counted
- \(V\) = volume of sample settled (ml)
- \(V_1\) = volume of concentrated sample
- \(V_2\) = volume of lake water

2.4. Statistical analysis

Diversity of phytoplankton abundance was determined using the Shannon-Weiner index (H’) and equitability index (J’) run by PRIMER (Plymouth Routines in Multivariate Ecological Research) version 6. Cluster analysis was performed to examine the percentage similarity of phytoplankton among stations. Statistical differences in determining spatial and temporal significance were tested using the one-way and two-way analysis of variance (ANOVA) (Statistical Package for the Social Sciences, version 20).

3. Results

3.1. Characterization of lake zones

Mean temperature, pH, conductivity, transparency and dissolved oxygen values showed significant differences (p<0.05) amongst stations (Table 1). The
littoral zone showed the lowest water temperature, pH, dissolved oxygen and transparency compared to sub-littoral and limnetic zones. On the other hand, the limnetic station had the highest dissolved oxygen concentration and water transparency.

### 3.2. Phytoplankton composition

There were seven phytoplankton groups in Putrajaya Lake which comprised Bacillariophyceae (diatoms), Chlorophyta (green algae), Cyanobacteria (blue-green algae), Pyrrhophyta (dinoflagellates), Chrysophyceae (golden-brown algae), Cryptophyta (cryptomonads) and Euglenophyta (euglenoids) (Table 2). Chlorophyta dominated the community with a marked 59% of the total phytoplankton density, followed by Pyrrhophyta (15%), Cyanobacteria (11%) and Bacillariophyceae (9%). Chrysophyceae, Cryptophyta and Euglenophyta contributed a small portion to the phytoplankton abundance with 3%, 2% and 1%, respectively. A total of 148 species were recorded from 77 genera for all stations throughout the sampling period (Table 2). The most dominant genus in littoral and sub-littoral zone was *Peridinium* whereas *Staurastrum* dominated the limnetic zone. The genera *Staurastrum* from the Desmidiaceae family and *Scenedesmus* from Scenedesmaceae accounted as the most diverse genera with 11 and 12 species documented, respectively. In this lake, the Desmidiaceae consisted of *Cosmarium*, *Euastrium*, *Spondylosium*, *Staurodesmus*, *Pleurotaenium*, and *Xanthidium* in addition to *Staurastrum*.

Phytoplankton monthly distribution showed that the highest density (p<0.05) at the limnetic zone occurred in the wet months (October to December 2009) and gradually declined until the end of the sampling period in September 2010 (Fig. 2). In October 2009, this station recorded a high density of 883.27 cells ml⁻¹. In the littoral and sub-littoral zones, the phytoplankton densities were highest only in October 2009 (730.99 cells ml⁻¹ in sub-littoral and 545.66 cells ml⁻¹ in littoral zone), but quickly declined to densities lower than 500 cells ml⁻¹ for the rest of the sampling period. Lowest density occurrence was observed in January 2010 for littoral (86.00 cells ml⁻¹) and sub-littoral zones (93.60 cells ml⁻¹). Although all zones exhibited phytoplankton density fluctuations throughout the sampling period, the sub-littoral transition zone showed drastic oscillations compared to adjacent zones which displayed a more gradual change (Fig. 2). Rapid changes of phytoplankton density in the littoral and limnetic can however be observed in the early sampling months from October 2009 until January 2010.

Among all stations, limnetic zone had the highest mean total density (p<0.05) with 433.94 ± 18.29 cells ml⁻¹, followed by sub-littoral (292.94 ± 18.61 cells ml⁻¹) and littoral zone with 199.58 ± 13.56 cells ml⁻¹ (Fig. 3). The dendrogram showed two distinct groups at 83% similarity level consisting of limnetic and littoral + sub-littoral zones (Fig. 4). Limnetic zone showed significantly higher (p<0.05) abundance of chlorophyta compared to the other areas. On the other hand, the
eutrophic indicator groups such as cyanobacteria and euglenophyta were higher (p<0.05) in littoral and sub-littoral zones compared to the open water area (Fig. 5).

3.3. **Phytoplankton diversity**

Shannon-Wiener diversity index (H’) was highest in the limnetic zone followed by sub-littoral and littoral zone (Fig. 6). Species evenness (J’) was highest in limnetic zone and lowest in sub-littoral zone. The differences were significant (p<0.05) across all sampling stations.

4. **Discussion**

All three sampling stations of Putrajaya Lake had different characteristics in terms of location, depth and water quality. The phytoplankton community was dominated by the chlorophytes, which was similar to most phytoplankton community structure in tropical lakes [5, 15, 22, 25]. Domination by specific phytoplankton group depends on the trophic status of a lake [4], which is further determined by the availability of nutrients especially nitrogen and phosphorus [17, 18]. In addition, the tiny sizes and protruding structures of the cells provide competitive advantage to most species of chlorophytes due to high surface volume ratio and increased nutrient diffusion rates [34]. Biswas and Nweze [39] reported that a desmid, *Cosmarium*, was dominant in a shallow African lake. Sharma [4] attributed the dominance of desmids to the low pH, low conductivity and the oligotrophic nature of the water, similar to the characters exhibited in the limnetic zone of Putrajaya lake. Desmids in the limnetic zone were 23.86% of the total phytoplankton as compared to sub-littoral and littoral zones where desmids accounted 10.03% and 8.93%, respectively.

The phytoplankton community abundance can be a useful indicator of the trophic conditions of lake zones based on their relative abundance [14]. The desmid genus *Staurastrum*, and dinoflagellates *Peridinium* which were found dominant in the present study are generally found in oligotrophic waters [35]. The presence of chrysophytes in combination with one or two other algal groups, which can be the cryptophytes, diatoms and/or dinoflagellates indicates oligotrophic or mesotrophic conditions [8]. Malek et al. [42] in their study on the Bacillariophyceae dynamics indicated that Putrajaya Lake trophy interchanged between oligotrophic to mesotrophic.

Phytoplankton group composition in Putrajaya Lake is comparatively similar to Lake Chini, Pahang, Malaysia [3] and Banglang Reservoir, Pattani in Southern Thailand [5]. Both studies documented 135 phytoplankton species and had *Staurastrum* amongst the most dominant and diverse genus recorded. Other reports on diversity in lakes across Malaysia showed a high variation depending
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on the type, size, and history of the water bodies; e.g. 19 and 33 genera were recorded from a study in small urban water bodies, Lake Aman and Lake Titiwangsa, respectively [14], 43 genera were identified in a highly stained (dystrophic) swamp, Paya Bungor, Pahang [16], and 56 species were documented from a study in a newly formed Kenyir reservoir, Terengganu [15]. From other tropical reservoirs such as the Barra Bonita reservoir, Brazil, 131 taxa were recognized [31].

In contrast to studies by Khuantraitrong and Traichaiyaporn [44], and Ghosh et al. [40], phytoplankton in Putrajaya Lake exhibited high densities in the wet season. The Botryococcus braunii bloom in the early sampling months near the littoral zone may have contributed to the high phytoplankton density during this period (personal observation). The bloom of the same species was also recorded in the Banglang reservoir coinciding with high concentration of total phosphorus, ammonium and nitrate [5]. At the same time, high turbidity caused by heavy rain which led to light limitation and low water transparency in shallow water bodies might be among the leading factors that inhibited phytoplankton growth to be lower in the littoral and sub-littoral zones compared to limnetic zone [11, 44]. This was in accordance to the case in Bera lake [25] which demonstrated peak abundance of phytoplankton density in the early northeast monsoon (September until October 1971) in each station sampled, with the open water region having the highest density (739.4 cells L⁻¹) followed by littoral region (440.4 cells L⁻¹) and swamp-forest region (124.4 cells L⁻¹). Furtado and Mori [25] discussed that dominant peak in phytoplankton abundance could be due to increased nutrient influx favouring temporal development of certain taxa or caused by the translocation of littoral and sub-littoral phytoplankton to limnetic area by monsoonal rainfall.

Despite Hutchinson’s [20] statement on non-existing correlation between lake area and number of phytoplankton species, more recent studies by Jankowski and Weyhenmeyer [43] including the present study found that larger and deeper lake areas are associated with higher diversity and species richness. The high species density and evenness for limnetic zone thus may be closely attributed to the wider area of the lake represented by the relevant station (Station 3). Study in the Banglang reservoir also recorded the highest phytoplankton density in the lacustrine zone and the outflow zone was lower than both lacustrine and transition zones for phytoplankton densities which ranged from zero to 2.1x10⁹ cells m⁻³ [5]. Large ecosystems are likely to harbour more species due to higher immigration rates and lower extinction rates [30]. The optimal depth of distribution for phytoplankton is in the first 3-5 m of the water column [33]. This supports the fact that limnetic zone has a deeper sampling depth with highest water transparency recorded, thus penetration of light was optimum for the growth of phytoplankton as manifested in the high reading of dissolved oxygen within the water column.
On the other hand, the dense growing macrophytes in the littoral zone might have practically prevented sunlight from penetrating the water column, impeding growth and flourishing of algae [9]. Density of aquatic macrophytes largely determines the diversity and abundance of littoral plankton, as discussed in the study of the plankton community in different habitat conditions of an oxbow lake [1]. In addition, the presence of macrophytes tends to inhibit the growth of phytoplankton as demonstrated by the clear water wherever macrophytes dominate. This study demonstrated significantly higher (p< 0.05) algal diversity and evenness values in the open water area (3.48 and 0.85, respectively), compared to areas overgrown with submerged macrophytes (3.24 and 0.83, respectively), and another area with less vegetation cover (3.32 and 0.82, respectively). The lesser macrophytes in sub-littoral zone allowed the phytoplankton to grow more intense with less competition for light source compared to the littoral zone. Studies on the secondary productivity in Temenggor reservoir, Perak [32] also showed the same result where Shannon-Wiener diversity and evenness indices of zooplankton in the limnetic zone were 1.98 and 0.42, respectively, while the littoral zone recorded 1.91 and 0.01, respectively.

The drastic changes in the sub-littoral zone may be due to the movement and adaptation of sub-littoral species between littoral and limnetic zones, the need for increased competition on the part of macrophytes, and the more diversified environmental condition which enabled the coexistence of algal species with different life strategies [1]. Norizam and Ali [32] observed that zooplankton of Temenggor reservoir migrated to the limnetic zone in certain period of the day. Based on this fact, it is regarded that the sub-littoral zone may act as an interphase for the community to coexist with other communities of different zones or a life strategy medium. This observation is consistent with the theory on the coexistence and avoidance of phytoplankton species which postulates that different species coexist by being constrained by different resources (equilibrium theory of competition) and that environmental variability permits the coexistence of species competing for the same resource [44], or as Hutchinson [20] described it as the paradoxical nature of the phytoplankton.

The relative predominance of flagellated groups (Pyrrhophyta, Chrysophyceae, Cryptophyta and Euglenophyta) in littoral and sub-littoral zones compared to the limnetic zone may be associated to their ability to move best in lighted water layers especially in shallow lakes [34]. Denser species from the eutrophic indicator group found in littoral zone suggested the zone was moderately polluted as euglenoids indicates the effects of organic pollution [41]. Disregarding the Chlorophyta group, Pyrrhophyta (dinoflagellates) exhibited the highest density in all zones. Distribution of dinoflagellates is often associated with chemical characteristics in water, indicating they are widely tolerant and ubiquitous, especially among genera of Ceratium and Peridinium but with restriction to certain ranges of pH and dissolved organic matter [12].
Dinoflagellates typically form a minor component in freshwater phytoplankton communities and they co-occur with their prey, often the diatoms [13], consistent with the observation in the present study. As for cryptophytes, they normally present in low numbers and occur in most lakes regardless of trophic state [12, 28].

5. Conclusion

Findings from this study in 2009 and 2010 indicated that the dynamics and community structure of the phytoplankton community in Putrajaya Lake were influenced by varying factors that contributed to the different conditions of the zones at different times of the year. Although the littoral, sublittoral and limnetic zones looked contiguous, their environmental parameters were dissimilar, resulting in different phytoplankton abundance and diversity. Apparently, habitat characteristics were important factors that determined the composition of species in the community, their life strategies, growth and development. Phytoplankton richness and diversity were lower in the littoral zone probably due to higher turbidity, lower light availability and higher abundance of macrophytes compared to the limnetic area. In addition, the littoral zone was more likely to be subjected to environmental disturbance from the adjacent land-based activities. Limnetic zone of the lake, on the other hand, seemed to have a more stable and suitable environmental conditions for mesotrophic phytoplankton growth, thereby showing higher species diversity compared to the littoral zone.

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Table 1: Mean values ± SE and range of environmental variables of Putrajaya Lake at different stations. Values in rows having different superscripts are significantly different at p<0.05. Number of samples (n) of each zone is given in parentheses.

<table>
<thead>
<tr>
<th>Physico-chemical parameters</th>
<th>Zones</th>
<th>Littoral (n=92)</th>
<th>Sublittoral (n=112)</th>
<th>Limnetic (n=168)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean±SE</td>
<td>Range</td>
<td>Mean±SE</td>
<td>Range</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>30.94±0.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.66-34.30</td>
<td>31.85±0.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>29.92-34.01</td>
</tr>
<tr>
<td>pH</td>
<td>6.67±0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.61-7.18</td>
<td>7.07±0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.11-7.74</td>
</tr>
<tr>
<td>Conductivity (µS cm&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>81.54±1.38&lt;sup&gt;b&lt;/sup&gt;</td>
<td>65.00-134.00</td>
<td>84.54±0.66&lt;sup&gt;c&lt;/sup&gt;</td>
<td>70.00-98.00</td>
</tr>
<tr>
<td>Transparency (m)</td>
<td>1.05±0.03&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.40-1.80</td>
<td>1.21±0.04&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.30-1.80</td>
</tr>
<tr>
<td>Dissolved oxygen (mg l&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>7.00±0.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.10-8.90</td>
<td>7.79±0.08&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.60-9.07</td>
</tr>
</tbody>
</table>
Table 2: Mean densities (cells ml\(^{-1}\) ± SE) and percentages (%) of dominant phytoplankton genera in different zones of Putrajaya Lake during September 2009 to October 2010.

<table>
<thead>
<tr>
<th>Genera</th>
<th>Phyla/Family</th>
<th>Number of species</th>
<th>Littoral zone</th>
<th>Sublittoral zone</th>
<th>Limnetic zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean±SE</td>
<td>%</td>
<td>Mean±SE</td>
</tr>
<tr>
<td>Peridinium</td>
<td>Pyrrhophyta</td>
<td>5</td>
<td>29.6±3.76</td>
<td>14.86</td>
<td>46.8±3.92</td>
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<tr>
<td>Chroococcus</td>
<td>Cyanobacteria</td>
<td>5</td>
<td>15.6±2.24</td>
<td>7.86</td>
<td>25.2±3.93</td>
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<td>Scenedesmus</td>
<td>Chlorophyta</td>
<td>12</td>
<td>13.8±1.57</td>
<td>6.92</td>
<td>20.2±1.86</td>
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<tr>
<td>Crucigenia</td>
<td>Chlorophyta</td>
<td>4</td>
<td>13.6±1.23</td>
<td>6.85</td>
<td>21.0±2.18</td>
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<td>Staurostrum</td>
<td>Chlorophyta</td>
<td>11</td>
<td>10.8±2.17</td>
<td>5.44</td>
<td>14.7±1.52</td>
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<td>Cryptomonas</td>
<td>Cryptophyta</td>
<td>1</td>
<td>10.0±2.78</td>
<td>5.02</td>
<td>4.8±1.19</td>
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<td>Selenastrum</td>
<td>Chlorophyta</td>
<td>2</td>
<td>9.5±1.30</td>
<td>4.80</td>
<td>24.8±2.95</td>
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<td>Botryococcus</td>
<td>Chlorophyta</td>
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<td>8.36±0.81</td>
<td>4.19</td>
<td>7.25±0.61</td>
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<td>Tetraedron</td>
<td>Chlorophyta</td>
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<td>6.5±1.00</td>
<td>3.30</td>
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<td>Dinobryon</td>
<td>Chrysophyceae</td>
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<td>6.16±0.54</td>
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<td>9.26±1.23</td>
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<td>Chlorophyta</td>
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<td>2.96</td>
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<td>Bacillariophyceae</td>
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<td>7.22±0.75</td>
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<td>Chlorophyta</td>
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<td>5.33±0.54</td>
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<td>8.69±0.90</td>
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<td>Oscillatoria</td>
<td>Cyanobacteria</td>
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<td>4.06±0.46</td>
<td>2.03</td>
<td>3.36±0.63</td>
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<td>Ankistrodesmus</td>
<td>Chlorophyta</td>
<td>4</td>
<td>3.85±0.57</td>
<td>1.93</td>
<td>5.05±0.79</td>
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<tr>
<td>Chlorrella</td>
<td>Chlorophyta</td>
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<td>3.81±1.16</td>
<td>1.91</td>
<td>3.45±0.84</td>
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<td>Staurodesmus</td>
<td>Chlorophyta</td>
<td>2</td>
<td>3.50±0.94</td>
<td>1.75</td>
<td>4.85±0.88</td>
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<td>Gleocystis</td>
<td>Chlorophyta</td>
<td>2</td>
<td>3.43±0.39</td>
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<td>7.59±1.05</td>
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<tr>
<td>Achmanthes</td>
<td>Bacillariophyceae</td>
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<td>3.14±0.43</td>
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<td>Euglenophyta</td>
<td>6</td>
<td>2.90±0.50</td>
<td>1.46</td>
<td>2.40±0.55</td>
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<td>1.17</td>
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<td>Others</td>
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Figure 1: Geographical location of the study area and sampling stations in Putrajaya Lake, Peninsular Malaysia.
Figure 2: Changes of monthly mean total density (cells ml\(^{-1}\) ± SE) of phytoplankton community in different zones of Putrajaya Lake.
Figure 3: Mean total densities (cells ml\(^{-1}\) ± SE) of phytoplankton community in different zones of Putrajaya Lake. Mean values with different superscripts indicate significant difference at p<0.05.
Figure 4: Dendrogram of phytoplankton mean total density (cells ml$^{-1}$) according to zones in Putrajaya Lake.
Littoral and limnetic phytoplankton distribution and biodiversity

Figure 5: Mean density percentages (%) of phytoplankton groups in different zones of Putrajaya Lake.
Figure 6: Shannon-Wiener diversity index ($H'$) and species evenness ($J'$) of different zones in Putrajaya Lake. $S$ is number of species.