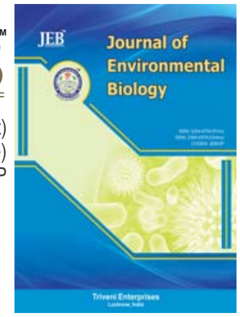
Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in
Journal of Environmental Biology

Original Research

ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

DOI : http://doi.org/10.22438/jeb/38/6/MRN-356



Plankton community characteristics of natural and man-made tropical lakes

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Key words

Lentic ecosystems
Multivariate analyses
Phytoplankton community
Tropical lakes

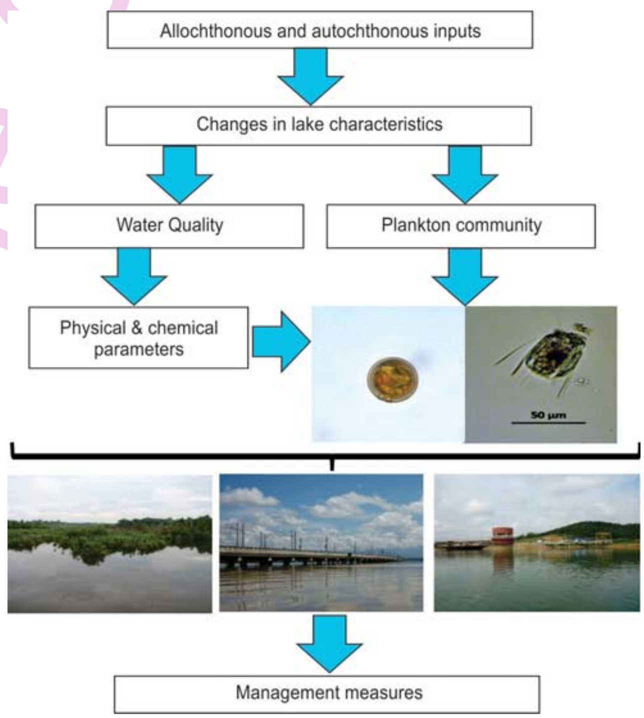
Publication Info

Paper received : 21.05.2016
Revised received : 04.11.2016
Re-revised received : 23.04.2017
Accepted : 22.05.2017

Abstract

Aim : Plankton community assemblages in both natural and man-made lakes are greatly influenced by the environmental variations, which in turn are dependent on the lake morphometric characteristics, edaphic conditions, climatic changes and the surrounding anthropogenic activities. The main objective of the present study was to investigate the pattern of phytoplankton and zooplankton composition and density, and their relationship with the water chemistry in three different lakes of Malaysia.

Methodology : Water quality, phytoplankton and zooplankton abundance were measured in a natural lake and two reservoirs in Malaysia. Multivariate and univariate analyses were performed to compare the differences in community assemblages between a natural lake and a reservoir of same depth, and a shallow and a deep reservoir. -



Results : Marked lake variations were observed in the phytoplankton density. Dominant phytoplankton groups were Cryptophyta and Bacillariophyta in the shallow Bera Lake, Chlorophyta in the shallow Bukit Merah Reservoir and Euglenophyta and Chlorophyta in the deeper Durian Tunggal reservoir. Both man-made lakes had significantly higher ($P < 0.05$) plankton densities compared to the natural lake. The shallower Bukit Merah Reservoir had higher phytoplankton density compared to the deeper Durian Tunggal Reservoir. Dissolved oxygen and pH levels were correlated to the phytoplankton and zooplankton communities in the Bera floodplain, whilst nutrient and chlorophyll-a concentrations were important factors affecting the phytoplankton and zooplankton assemblages, respectively,in the Durian Tunggal and Bukit Merah reservoirs.

Interpretation : Plankton community in shallow tropical lakes have different characteristics and composition compared to the deeper ones, and thus requiring different management measures.

Introduction

Biological communities such as phytoplankton and zooplankton are important components in lakes constituting the basis of the food web that shape the ecological structure and function of water bodies. The assemblages of these phytoplankton and zooplankton communities are dependent on the abiotic factors such as light and mixing, which are influenced by the nutrient, meteorological-climate and water level variations (Barone and Flores, 1994; Wetzel, 2001). Alteration in light regime and nutrient contents in a waterbody leads to a shift in phytoplankton assemblages due to differences in species physiological and morphological adaptation (Reynolds, 1998). Eutrophic or nutrient-rich lakes are usually dominated by large colony forming cyanobacteria whilst mesotrophic lakes are dominated by large colonies of chlorophytes (Naselli-Flores and Barone, 2000).

In addition to nutrients and light regimes, water body type, size, depth, age, geographical location and habitat connectivity are among other factors that contribute to the variation in plankton community assemblages (De Bie *et al*., 2008; Merrix-Jones *et al*., 2013). De Bie *et al*. (2008) reported that lakes have the highest mean diversity and number of species of zooplankton namely cladoceran communities, compared to other aquatic ecosystems probably due to the favourable conditions associated with the lentic characteristics.In fact, Dodson *et al*. (2007) reported that zooplankton structures were shaped by the size of the lake. Small water bodies were reported to have higher cladoceran abundance and richness than the larger ones (De Bie *et al*., 2008), mainly due to higher availability of nutrients in shallower water bodies compared to the deeper ones. A decrease in phytoplankton and zooplankton densities in lakes in relation to depth are well documented worldwide. Natural lakes differ from man-made lake in terms of connectivity and water level regulation that may affect the light regime and nutrient flushing, which subsequently affect the biological community assemblages. In temperate lakes, Naselli-Flores and Barone (2000) noted that variation of surface mixed layer depth/euphotic depth ratio could trigger the shift in biological assemblage in man-made lakes compared to the natural lakes which were more hydrologically stable. Deeper and cooler zooplankton species such as *Acanthocyclops* spp. and *Cyclops* spp. have been frequently detected in natural lakes (Merrix-Jones *et al*.,2013). Drivers of zooplankton composition in temperate lakes include depth, conductivity, salinity and productivity (Dodson *et al*., 2009; Merrix-Jones *et al*., 2013).

In man-made lakes where water levels are regulated, increase in water level reduces the zooplankton density and biomass, and decreases chlorophyll-a concentration, resulting from hydraulic changes and the associated increased in suspended sediments (Mac Donagh *et al*., 2009). Low water level and high temperature during summers, contribute to higher total phosphorus, dissolved inorganic nitrogen, soluble reactive phosphate ratio and chlorophyll-a, subsequently increasing the dominance of cyanobacterial biomass in Estonian lakes (Haldna *et al*., 2008). In contrast, increasing biomass of diatoms and decreasing biomasses of cyanobacteria were observed during lower water levels in a deep high-altitude tropical reservoir (Valeriano-Riveros *et al*., 2014). The influence of age on zooplankton assemblages were observed to be apparent in man-made lakes with pristine watersheds (Alfonso *et al*., 2010) whereas, the effect of age on zooplankton composition in artificial lakes with heavily disturbed catchment may be compounded by the anthropogenic activities in watersheds (Alfonso *et al*., 2010). Differences in plankton assemblages between natural and man-made lakes in tropical region are limited.

In view of the above, the present study was carried out to investigate the pattern of plankton composition and density, and their relationship to water chemistry in three different lakes in Malaysia to enable a better understanding of plankton community structure in natural and man-made lakes at different depths.

Materials and Methods

Three lakes in Peninsular Malaysia namely Bera lake, Pahang, Bukit Merah reservoir, Perak and Durian Tunggal reservoir, Melaka were selected as study area (Fig. 1). Bera lake is a natural floodplain lake with a total surface area of 6 km^2, mean depth of ~2.8m. It is a dystrophic wetland designated as an important RAMSAR site, due to its diverse freshwater biodiversity of many endemic species. The water body is known as the largest and among the oldest freshwater lake in the country with organic and peat deposits originating 4500-5500 years ago (Morley, 1981). Bera lake is largely fed by Tembagau river throughout the year and acts as a discharge outlet to the Pahang river, which becomes a major inflow into the lake during the wet season. Bukit Merah reservoir is one of the oldest artificial lakes in Malaysia created in 1906 for irrigation and flood mitigation purposes. In addition, the reservoir also stores water for drinking and domestic purposes, and a sanctuary for the endemic *Scleropages formosus* of the golden arowana variety. It is a large lentic water body (surface area of 33 km^2) but very shallow (mean depth of ~2.5m) and is mostly fed by Kurau river and Merah river, and discharged into Terusan and Selingsing dams. Durian Tunggal reservoir is an important reservoir that was created in 1974 for water supply. It is the youngest lake created (<50 yr) compared to Bera lake (>4500 yr) and Bukit Merah reservoir (>100 yr) for this study. The reservoir has a surface area of 5.8 km^2 and mean depth of ~6m. The lake is heavily regulated and dependent on inter-water transfer scheme namely water pumping from Muar River in Johor.

The water and plankton samples were collected from three lakes during wet season (December) and dry season (May). Sites were selected both in the pelagic and littoral areas. Water quality was estimated based on *in situ* measurements using a multi-parameter probe, YSI 6600 (YSI Inc., Yellow Springs. OH, USA) and laboratory analyses of water samples collected from each lake. Water samples were collected using a Van Dorn sampler and was preserved in cooler boxes at 4 °C and transported to laboratory for analysis of chlorophyll-a (Chla), nitrate (NO_3-N), soluble reactive phosphorus (PO_4-P), dissolved organic carbon (DOC), total suspended solids (TSS), and total phosphorus (TP). Measurements were performed at three depths in the pelagic region (depth exceeded 2m) and measured at 0.5 m near littoral zone.

For phytoplankton, one litre of lake water samples were collected below the surface of water column, mid-depth and near bottom of the lake and samples were fixed *in situ* with Lugol's iodine to achieve 1% final solution. The samples were identified and counted under an inverted microscope to the lowest taxa possible. Densities were calculated in terms of number of cells/ml in the sample. Zooplankton samples were collected in vertical hauls using a 63 µm plankton net by lowering the net to near lake bottom to the surface. The samples were poured into 500ml bottles and fixed *in situ* with buffered formalin to provide 5% final solution. Samples were collected in each site with at least two replicates for each season. The samples were identified and counted to the lowest taxa using an inverted microscope and a compound microscope. Densities were calculated to the number of individuals per litre of water sample.

All analyses in the laboratory were based on standard methods for the examination of water and wastewater (APHA, 2012): Chla–fluorometric method; NO_3-N – automated hydrazine method; NH_3N - automated phenate method; DOC – wet oxidation method; TSS – gravimetric technique; PO_4 – molybdate method; TP – persulphate digestion and automated ascorbic acid reduction method.

Environmental variables were transformed and analysed using principal component analysis (PCA). Univariate analysis was performed to examine the differences in three lakes. Plankton communities were examined based on non-multidimensional scaling (NMDS) and cluster analysis to detect similarities/differences of the plankton assemblages as described in Sharip *et al*., (2012). PERMANOVA was used to estimate the components of variation in phytoplankton and zooplankton community compositions at the spatial scale of lake and depth, while principal coordinate analysis (PCoA) was used to correlate environmental variables with the ordination axes based on Pearson Correlation (Anderson and Willis, 2003; Sharip *et al*., 2012). T-test and SIMPER were used to analyse the differences in phytoplankton and zooplankton assemblages between the following: the natural and shallower man-made lake and the shallower and deeper man-made lakes. All multivariate analyses were performed using PRIMER 6 (Plymouth Marine Laboratory, Plymouth, UK), while univariates were analysed using SPSS. The alpha level of significance was set at 0.05.

Results and Discussion

Durian Tunggal reservoir had the highest clarity followed by Bera and Bukit Merah lakes (Table 1). Surface DO levels were lowest in Bera lake whilst chlorophyll-a concentrations were highest in Bukit Merah reservoir. Mean PCA of the environmental variables, derived by employing Euclidean distance, indicated marked differences between lakes. The first three eigenvalues of the principal components explained 65.1% of the variance; the first component corresponded to 37% variance and the second component explained 17% of the variance (Fig. 2). The first component along axis 1 was correlated with transparency, nitrate, phosphate and conductivity; the component along axis 2 was correlated with chlorophyll-a, DO, pH and DOC. Univariate analysis indicated significant differences in water quality between

Table 1: Mean variation of environmental variables between lakes.

Lake	Bera		Bukit Merah		Durian Tunggal	
Season	Wet	Dry	Wet	Dry	Wet	Dry
Temperature (°C)	27.7±0.5^{a}	30.2±0.4^{b}	29.6±0.8^{c}	29.8±0.8^{c}	29.2±0.6^{e}	30.7±0.6^{e}
Conductivity (µS cm^{-1})	50.2±1.6^{a}	56.9±1.7^{b}	23.4±4.1^{c}	30.8±5.2^{d}	87.4±2.3^{e}	144.4±4.1^{f}
pH	4.62±0.43^{a}	5.43±0.42^{b}	6.32±0.38^{c}	6.50±0.94^{c}	6.69±0.41^{e}	6.38±0.30^{e}
Dissolved oxygen (mg l^{-1})	3.02±0.74^{a}	3.19±1.07^{a}	6.83±0.75^{c}	6.98±0.65^{c}	5.29±2.47^{e}	5.29±1.92^{e}
Depth (m)	5.9±1.7^{a}	5.0±1.6^{a}	2.8±0.5^{c}	2.5±0.5^{c}	8.7±4.4^{e}	6.9±4.3^{e}
Secchi disk transparency (m)	0.8±0.3^{a}	1.4±0.2^{b}	0.8±0.2^{c}	0.6±0.2^{c}	2.4±0.4^{e}	2.4±0.3^{e}
Turbidity (NTU)	22.1±11.1^{a}	2.7±0.7^{b}	12.9±19.3^{c}	20.6±12.9^{d}	21.9±16.8^{e}	3.1±5.2b^{f}
Dissolved organic carbon (mg l^{-1})	9.1±0.2^{a}	10.0±1.8^{a}	4.5±1.0^{c}	4.9±0.9^{c}	3.7±0.5^{e}	3.1±0.1^{f}
Total phosphorus (mg l^{-1})	0.072±0.179^{a}	0.046±0.019^{a}	0.076±0.174^{c}	0.026±0.027^{c}	0.016±0.009^{e}	0.069±0.091^{e}
PO_4-P(mg l-1)	0.002±0.002^{a}	0.017±0.006^{b}	ND^{c}	0.006±0.009^{c}	0.013±0.004^{e}	0.026±0.004^{f}
Chlorophyll-a (µg l^{-1})	2.09±2.24^{a}	3.29±4.96^{a}	12.89±4.83^{c}	10.2±9.8^{c}	5.59±2.10^{e}	3.01±3.23^{e}
NH_4-N(mg l^{-1})	0.017±0.037^{a}	0.189±0.549^{a}	0.023±0.049^{c}	0.099±0.114^{d}	ND^{e}	0.126±0.079^{f}
NO_3-N(mg l^{-1})	0.155±0.04^{a}	ND^{b}	0.034±0.038^{c}	0.060±0.110^{c}	1.325±0.323^{e}	1.658±0.982^{e}
TSS (mg l^{-1})	9.36±20.15^{a}	6.45±10.81^{a}	5.09±2.58^{c}	9.36±7.07^{c}	2.27±2.68^{e}	1.45±0.69^{e}
TSI (Chla)	37.8	42.2	55.7	53.4	47.4	41.4

Values are mean±SD (n=11); Values (in rows) with different letters superscripts are significantly different (P < 0.05); ND- non detectible

Fig. 1 : Location of study areas in various lakes and the sampling locations (stars)

lakes f(54)=44.96, P<0.001. Significant differences between lakes were observed in terms of temperature, specific conductivity, pH, dissolved oxygen, depth, transparency, chlorophyll-a, nitrate, phosphate and TSS. These differences showed significant impacts on phytoplankton communities.

The t-test for environmental variables between the natural Bera lake and the created Bukit Merah reservoir indicated marked differences between lakes in terms of temperature, specific conductivity, pH, chlorophyll-a, DO, salinity and DOC (P<0.05). T-test analysis for Bukit Merah and Durian Tunggal reservoirs showed marked differences were observed in temperature, specific conductivity, salinity, DO, transparency, Chla, TSS, NO_3N, PO_4-P (P<0.001), pH and turbidity (P<0.05). Bukit Merah reservoir had higher Chla, DO, TSS and turbidity whilst Durian Tunggal reservoir has higher conductivity, salinity, transparency and nitrate concentrations. Bera lake and Durian Tunggal reservoir had higher turbidity during wet period possibly due to influxes of turbid water from Bera river and Muar river, respectively as our qualitative observation.In Durian Tunggal reservoir, water in the lake was characterized by lower levels of nutrients including ammonium and higher levels of turbidity during the wet season and higher conductivity, and ammonium levels during dry season. Both Bera and Durian Tunggal could be categorized as mesotrophic during the two study periods.

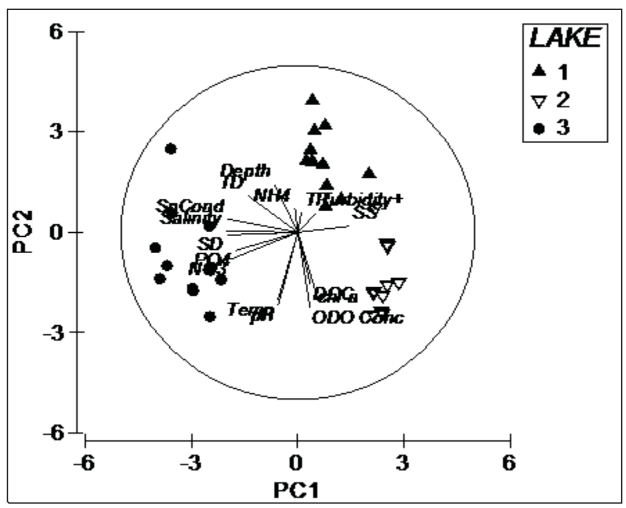


Fig. 2 : PCA biplots of mean values of the environmental variables in different lakes and reservoirs. Number indicates lake; 1 – Bera, 2 – Durian Tunggal; 3 – Bukit Merah

Phytoplankton assemblages were clearly different between Bera lake and Durian Tunggal reservoir (Fig. 3). In Bera lake, Cryptophyta and Cholorophyta were the dominant groups during the wet season and dry seasons. Bacillariophyceae and

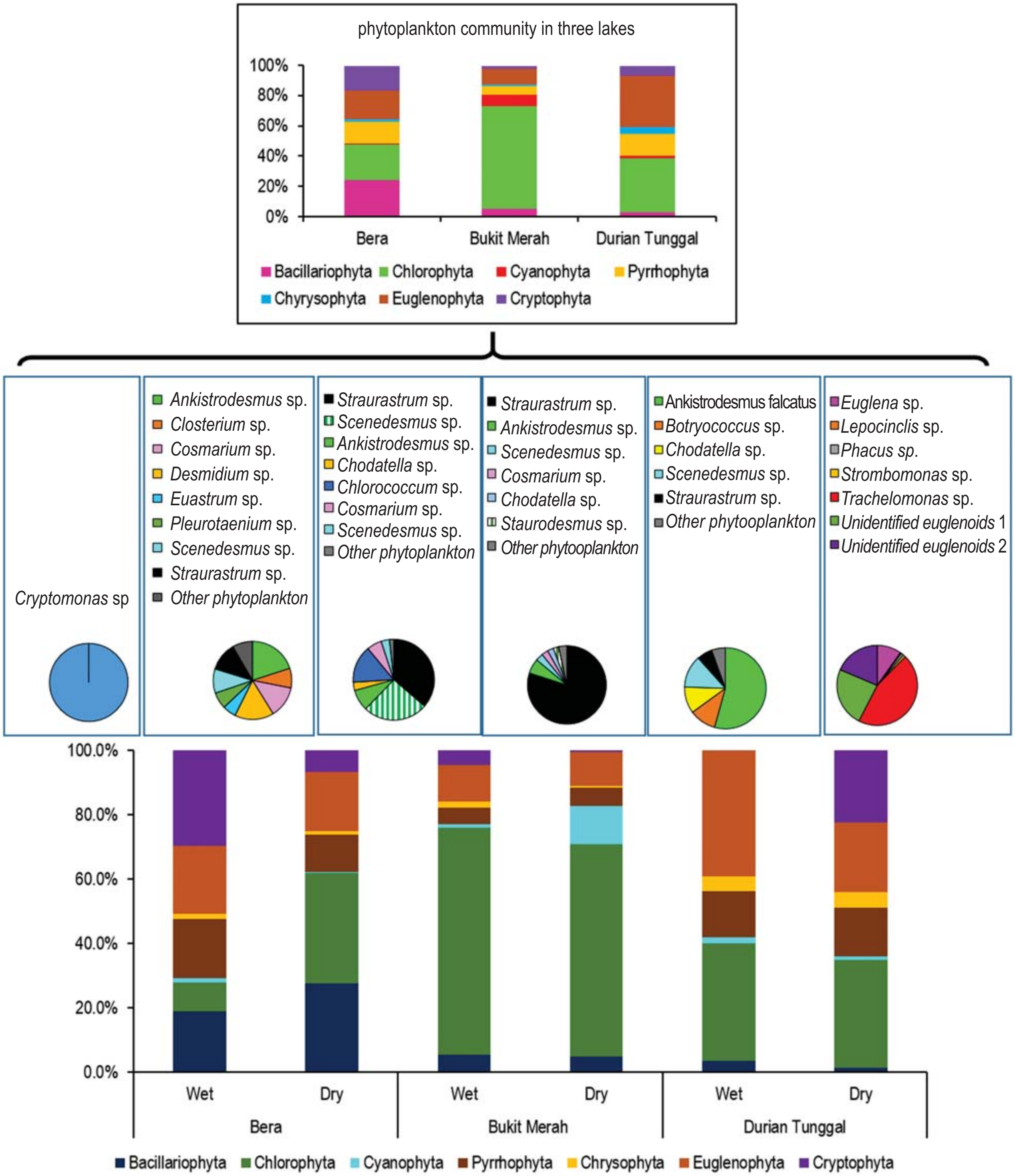


Fig. 3 : Phytoplankton group assemblages in different lakes (bars) and dominant species composition (pie charts)

Chlorophyta density increased, while Cryptophyta, Pyrrophyta and Euglenophyta decreased significantly from wet to dry season. Dominant species were *Cryptomonas* sp*., Peridinium* sp. and *Trachelomonas* sp. The dominance of Cryptophyta and Bacillariophyceae in Bera Lake is consistent with existing literature findings regarding natural lakes (Naselli-Flores and Barone, 2000). In an earlier study on Bera Lake in the 1970s, Chlorophyta was reported to be more dominant, contributing 50% of the average species composition, followed by Bacillariophyceae (Furtado and Mori, 1982). Seasonal patterns of

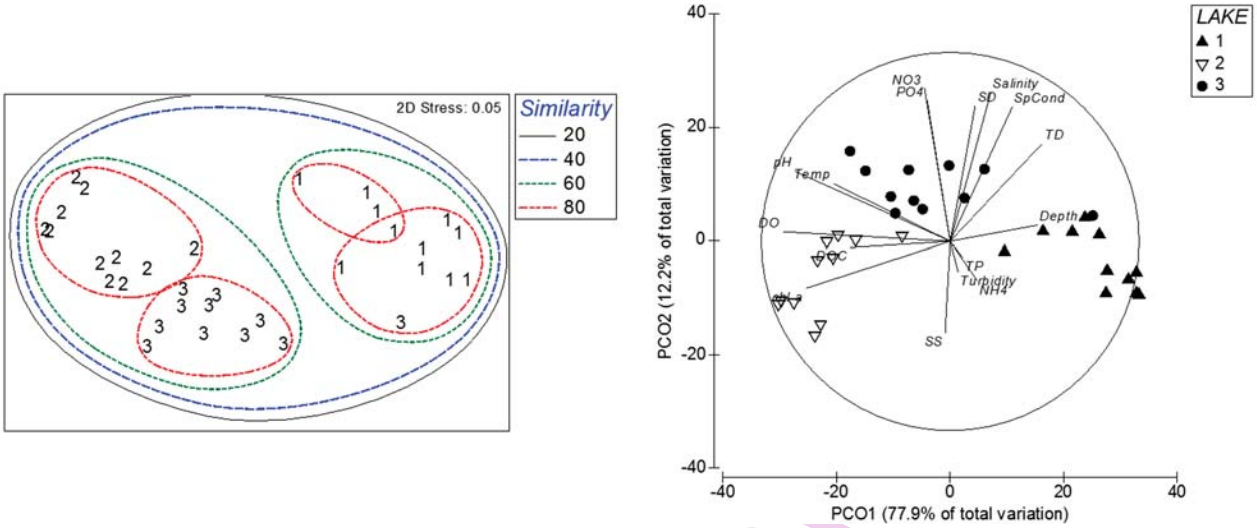


Fig. 4 : NMDS and PCoA biplots of phytoplankton assemblages in lacustrine zones. Number indicates lake; 1 – Bera, 2 – Bukit Merah; 3 – Durian Tunggal

Bacillariophyceae in this lake were consistent with the earlier findings, where higher densities were reported during April to June, whilst a reduction in Cryptophyta could be related to changes in water level. Water level influenced the dominance of Cryptophyta in Peipsi Lake, Estonia (Haldna *et al*., 2008) and increased algal bloom in Peri Lake, Brazil (Fuentes and Petricio, 2015). Phytoplankton density was found higher after monsoon season, between the month of January to April, which corresponded to increase in DO and pH levels in lake after monsoon (Golder and Chattopadhyay, 2016). The presence and abundance of Cryptophyta in Bera Lake require further investigation, however, as it was not reported earlier in this natural lentic system.

In Durian Tunggal, Euglenophyta and Chlorophyta were dominant groups during dry and wet season, respectively, whilst in Bukit Merah Reservoir, Chlorophyta was dominant group during both dry and wet seasons. A marked decrease in the density of euglenophytes and an increase in cryptophytes were observed during dry season. *Trachelomonas* spp., *Ankistrodesmus falcatus* and *Scenedesmus* sp. were the most dominant species in Durian Tunggal Reservoir. Euglenophytes were reported to occur predominantly in organically rich fresh waters (Likens, 2010); the higher density of phytoplankton in Durian Tunggal was probably related to high ammonium concentrations. Ammonia is known to be the dominant source of nitrogen for the growth of euglenoids (Wetzel, 2001).

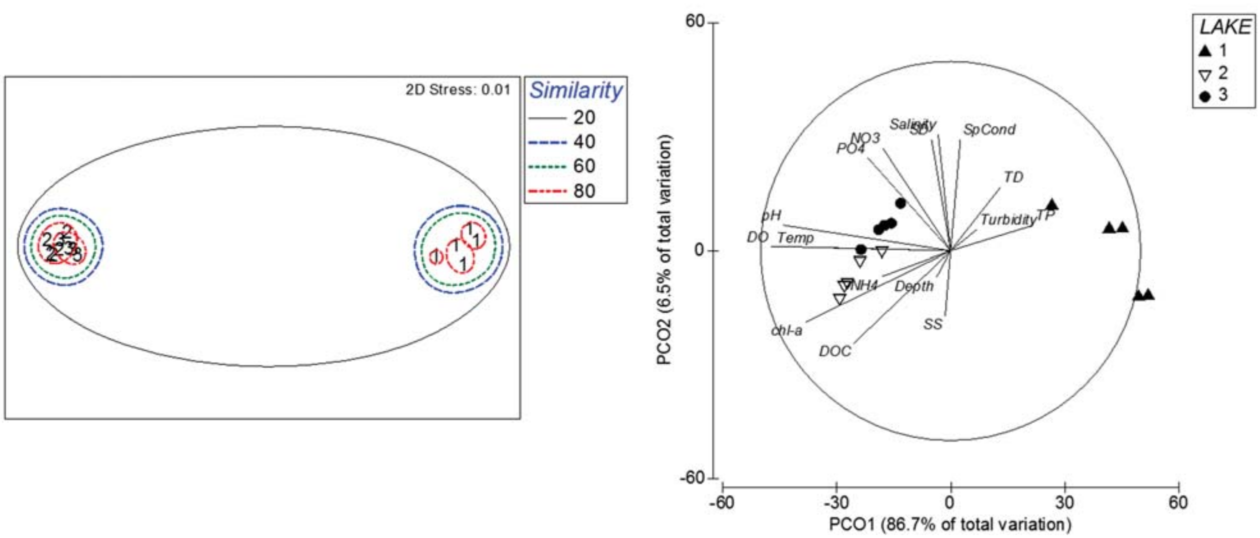


Fig. 5 : NMDS and PCoA biplots of zooplankton assemblages in lacustrine zones. Number indicates lake; 1 – Bera, 2 – Bukit Merah; 3 – Durian Tunggal

Table 2 : Results of PERMANOVA tests

Source	df	SS	MS	Pseudo-F	P-values	Unique permutations
Phytoplankton						
Lake	2	13303	6651.4	23.039	0.003*	935
Depth (Lake)	6	1755.4	292.56	2.256	0.019	
Residual	24	3111.4	129.64			
Total	32	19502				
Zooplankton						
Lake	2	14669	334.7	42.621	0.001**	995
Residual	12	2065.1	172.09			
Total	14	16735				

Note : * $P<0.05$; ** $P\leq0.001$

Straurastrum sp., *Staurodesmus* sp. and *Ankistrodesmus* sp. were the most dominant species in Bukit Merah reservoir. A higher abundance of cyanobacteria in Bukit Merah was consistent with the findings in eutrophic systems that documented high dominance of filamentous and large–colony forming cyanophytes such as *Anabaenopsis* spp., *Planktothrix* spp. and *Anabaena* spp. in the eutrophic Lake Aranchio due to nutrient availability and modulation in light environment (Naselli-Flores and Barone, 2000). This study found higher phytoplankton densities in the man-made Bukit Merah reservoir compared to the natural Bera lake, probably due to the higher nutrient concentrations in the former. Mean phytoplankton density in Bera Lake and in the Durian Tunggal and Bukit Merah reservoirs were 295.6 cells ml^{-1}, 1381.7 cells ml^{-1} and 13, 388.2 cells ml^{-1}, respectively

Two-dimensional NMDS plots indicated phytoplankton assemblages (Fig 4) and zooplankton assemblages (Fig.5) in the natural Bera lake were distinctly separated from the phytoplankton and zooplankton assemblages in the man-made lakes. PERMANOVA results concerning lakes indicated significant variability in phytoplankton and zooplankton abundance between lakes (Table 2, P<0.05). However, variability in phytoplankton abundance was also significant at depth scale. PCoA results indicated that phytoplankton communities in Bera lake was positively correlated to DOC and negatively correlated to DO. Phytoplankton communities in Durian Tunggal tended to characterize lakes having clear water with low turbidity and TSS, and they were positively correlated to conductivity. Phytoplankton assemblages in Bukit Merah were positively correlated to Chla, DO and DOC. Zooplankton assemblages in the natural lake were positively correlated to turbidity and negatively correlated to DO, while zooplankton assemblages in two man-made lakes were associated to nutrients.

In Bera Lake, a lower phytoplankton density, consistent with low Chla values, was probably due to lower pH levels and higher turbidity that reduced light penetration. Depth, which influences the underwater light regime, is also an important factor for shaping phytoplankton abundance. Additionally, Bera lake has massive stands of macrophytes that could inhibit phytoplankton growth through competition of nutrients (Kosten *et al*., 2012) or allelopathic mechanism (Mulderij *et al*., 2005). Asma' *et al*. (2014) reported that phytoplankton in the littoral zone of a tropical man-made lake was significantly lower compared to limnetic zone.

In Bukit Merah Reservoir, chlorophytes were the most dominant phytoplankton group. A marked increase in cyanobacteria density was likely due to the lower N : P ratio, probably resulting from a lower water level and subsequent reduction in external nutrient inputs (Noges *et al*., 2003; Haldna *et al*., 2008). Qualitative observation indicated the presence of patches of greenish-coloured waters in certain part of lake. Phytoplankton density was greater at surface layer and decreased alongside depth, consistent with the findings in Shingu Reservoir, Korea where phytoplankton community varied strongly with depth; highest abundance was observed in the surface layer (Kwon *et al*. 2009). The growth of many phytoplankton species was reported to be controlled by light intensity (Naselli-Flores and Barone, 2000) when other growth factors such as nutrients were not limiting. A marked increase in turbidity was likely due to the sediment re-suspension, which has previously been suggested as commonly occurring in this large reservoir (Sharip and Zaki, 2014) and which could affect light availability. In other shallow lakes such as Liman Lake in India, intense mixing promoted the dominance of low light tolerant phytoplankton species (Soylu and Gonulol, 2010).

T-test analysis indicated that differences in phytoplankton between natural Bera Lake and man-made Bukit Merah Lake were significant in terms of Bacillariophyceae and Chlorophyta, Euglenophyta and Cryptophyta (P<0.05). SIMPER analysis indicated that the average dissimilarity of phytoplankton assemblages between Bera and Bukit Merah Lake was 50.1%. Average dissimilarities in phytoplankton assemblages between surface-mid depth, surface-bottom and mid-bottom depth were 16.6%, 19.4% and 12.6%, respectively. T-test analysis indicated that differences in phytoplankton between shallower Bukit Merah Lake and deeper Durian Tunggal Reservoir were significant in terms of Chlorophyta, Euglenophyta, Chrysophyta and andBacillariophyceae (P<0.05). SIMPER analysis indicated that the average dissimilarity in phytoplankton assemblages between Bukit Merah and Durian Tunggal was 28.1%. Average dissimilarities in phytoplankton assemblages between surface-mid-depth, surface-bottom and mid-bottom depth were 12.8%, 21.2% and 16.7% respectively.

In Bera Lake, rotifer was the dominant zooplankton group during both dry and wet seasons (Fig. 6). Dominant rotifer species were *Philodina* sp., *Lecane* sp. and *Arcella* sp. A marked increase in copepods was observed during dry spell compared to wet period. In Durian Tunggal, rotifers and copepods were the dominant groups during dry and wet seasons, respectively, whilst in Bukit Merah Reservoir rotifers were the dominant group during both dry and wet seasons. *Polyarthra* sp., *Keratella* sp., and *Hexarthra* sp. were the most dominant species in Durian Tunggal reservoir. *Difflugia* sp. and *Polyarthra* sp. were the most dominant species in Bukit Merah reservoir. A significant increase in cladocerans and a decrease in rotifers were observed during dry spell compared to wet period. Mean zooplankton density was lowest in Bera Lake (18.3 ind.ml^{-1}), followed by Durian Tunggal (800.2 ind.ml^{-1}) and Bukit Merah (950.0 ind. ml^{-1}). Seasonal changes of water level and abiotic factors regulated zooplankton dynamics in floodplain lake, Laguna Grande in Argentina, with shift from rotifers to cladocerans in cold seasons (Chaparro *et al*., 2016).

This study found higher zooplankton densities in both man-made lakes compared to the natural lake, probably due to higher phytoplankton densities in the former. Higher zooplankton density in the man-made Bukit Merah compared to the natural Bera Lake indicated that the establishment of zooplankton communities in this reservoir might be associated with environmental factors rather than lake age. Similar observation on the effects of human activities and lake age on zooplankton species richness was reported by Dodson *et al*., (2007) in their study on 3 to 9500-years-old lakes. The results of the present study indicate that water chemistry has greater effects on the biological community in the older lake (Bukit Merah) than the new ones (Durian Tunggal).

Marked changes in zooplankton assemblages were observed in Durian Tunggal Reservoir between the sampling periods. A significant decrease in rotifersmight be associated with an increase in salinity and conductivity, which decreased rotifer diversity. Salinity increase has been found to affect the change in terms of species richness and diversity of rotifer (Sarma *et al*., 2006; Bielanska-Grajner and Cudak, 2014). High turbidity and predation pressure at low waters can also decrease the zooplankton abundance. High turbidity reduces phytoplankton populations and subsequently results in a shift in food resources for zooplankton. These patterns may explain the variation found in three different tropical lakes included in this study. SIMPER analysis indicated that the average dissimilarity between Bera and Bukit Merah Lake was 66.4%. Rotifer and copepod contributed 41.8% and 32.6%, respectively, of the overall dissimilarity in zooplankton group. SIMPER analysis indicated that the average dissimilarity between Bukit Merah Lake and Durian Tunggal was 10.5%. Cladocerans and copepods contributed 77.8% of the overall dissimilarity in zooplankton group.

The results of the present study indicates variations among phytoplankton and zooplankton assemblages in all three lake ecosystems. The management of tropical lakes needs to consider the unique characteristics of plankton assemblages and variations in water quality, which subsequently alters phytoplankton and zooplankton abundance. Development of algal dominance might differ amongst lakes, subsequently requiring different control and management measures. Further, the study reveals that cyanobacterial bloom might be a concern in Bukit Merah Reservoir during prolonged draughts. Since water intake station is tapping water of this reservoir downstream, additional measures may need to be undertaken in the station for utilizing the water during dry periods.

Acknowledgments

This research was supported by the Ministry of Science and Technology of Malaysia, e-Science Fund grant (No. 04-03-09-SF0003). The authors are thankful to DID Kerian District, Perhilitan RAMSAR Tasek Bera and Syarikat Air Melaka Berhad for allowing us to conduct the research at field. Special thanks to Juhaimi Jusoh, Rahimah Abdullah, Aminuddin Jamin, Saim Suratman and Ahmad Jamalluddin Shaaban for their support in this project. We are grateful to Ahmad Taqiyuddin Ahmad Zaki, Mohd. Azril Hilmi Shapai, Mohd. Shukri Abu Bakar, Kamasuahadi Yasin, Nizam and Shukor for their aid in sampling assistance and Perumal Kuppan for his help in enumerating the plankton samples.

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