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VERTICAL AND LONGITUDINAL PHYTOPLANKTON DISTRIBUTION AND BIODIVERSITY IN A TROPICAL MAN-MADE LAKE, MALAYSIA

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Abstract

Vertical and longitudinal phytoplankton distribution was conducted (February 2019 - January 2020). Transparency, pH & TSS were high at photic water but decreased gradually into aphotic except pH that was opposite. The chemical parameters were low at the surface and increased with deeper water. The physical parameters except pH were slightly lower during the wet season but conductivity and total phosphorous were slightly higher during the dry season. There were six phytoplankton groups which comprised Chlorophyta(37%), Pyrrhophyta(24%), Bacillariophyceae(20%), Cyanopyta(17%), Chrysophyta(1%) & Charophyta(1%). A total of 1,472 species were recorded from 57 genera. The mean values of phytoplankton (mg/L) in Riverine, Transitional and Lacustrine were 18.79, 13.46 & 24.68 and 2.88, 2.55 & 2.00 for photic & aphotic respectively. The ANOVA results showed significant diference between longitudinal (photic & aphotic) with regards to phytoplankton at P=0.05. This means that the higher phytoplankton density reported at photic shows more availability of nutrients and the water's stability and better health status of the Reservoir. Phytoplankton encountered in the water body reflect the average ecological condition, and therefore, can be used as an indicator of water quality.

Keywords: zone, transparency, phosphorous, parameters and management.

1. INTRODUCTION

It is widely accepted that three longitudinal zones can be distinguished in a typical reservoir-riverine zone, transitional zone, and lacustrine zone in the direction of inflow (Wetzel 2001). The lacustrine zone (which resembles the lentic habitat), riverine zone (which corresponds to the river ecosystem), and transition zone (Thornton *et al*. 1990) (Figure 1). All these three zones have unique physical, chemical, and biological characteristics that differentiate the limnology of a dam from one another (Ford, 1990; Wang *et al.* 2011). Various physics and chemistry gradients exist from the riverine to the lacustrine zone, including main gradients of width, depth, flow, nutrients, organic matter, and eutrophic properties (Shao *et al.* 2010). Other gradients can also exist, such as sediment deposition (Baxter 1977), water clarity (Bemot *et al.,* 2004). Correspondingly, biotic gradients, such as of plankton community (Shao *et al.* 2010), also have been observed in these zones. Recognition of longitudinal zonation in a reservoir is of great practical importance for effectively managing and utilizing reservoirs. For example, different zones should have respective assessment methodology and standards for nutrition status because these zones have different eutrophication sensitivity. The Riverine zone, in general, is situated away from the outlet and is also the main source for water inflow from the parent river or watershed into the dam area. This zone is relatively shallow, narrow, and showing well mixing of water; thus, it maintains an aerobic environment. Due to the thin structure of the channel, the water velocity is at a high rate but

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decreasing as it moves towards the dam area. This zone's physical and chemical attributes are similar to the lotic system (Smoot and Findlay 2001). The transition zone is situated in between the riverine and lacustrine zone in the dam area. This area is a deeper and broader basin. The riverine and lacustrine zone borders often change depending on the water level and water inflow from the riverine zone (Kimmel *et al.* 1990). This zone has decreased water flow and decreased abiotic turbidity, resulting in a greater photic layer (Smoot and Findlay 2001). The productivity of this zone depends more on the concentration of allochthonous (Thornton *et al.* 1990; Lind and Barcena 2003). The lacustrine zone resembles a lake's ecosystem where the water body can be divided into several layers characterized by water mixing. The rate of organic production is usually higher than the decomposition rate, thus creating a potential where nutrients will limit this zone. The organic matter in this zone is basically from the death or senescence of aquatic organisms (Kimmel *et al.* 1990).

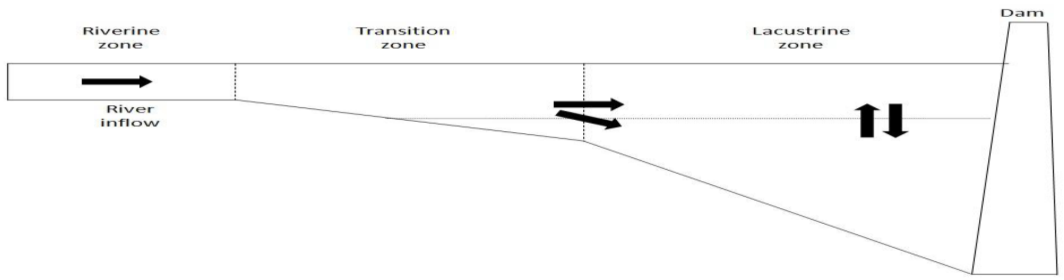

Fig. 1 Longitudinal cross-section view showing three distinct zones defined by the slope of a dam (Thornton et al. 1990).

2. MATERIALS AND METHODS

2.1. Study area

The phytoplankton abundance and diversity of the vertical and longitudinal zones was investigated in the Puah Reservoir (5 05 N 102. 45E / 5.083N 102.750E), which is located in a mountainous Hulu Terengganu catchment, at the north of the existing Kenyir Dam in Kuala Berang, Daerah Hulu Terengganu, Negeri Terengganu Darul Iman. It is about 50 km from Bandar Gua Musang – Hulu Terengganu roadway and about 65km west of Kuala Terengganu, Peninsular Malaysia. This reservoir was constructed in 2016 to produce multiple benefits, e.g., flood prevention, hydro-electric power generation, fishing, and recreational use. Puah reservoir in Peninsular Malaysia is a man-made body of water with an area of 6,979 ha and an average depth of twenty meters. It is one of the three reservoirs in the Hulu Terengganu. Along this main channel, many branches are forming a dendritic shape, with the branches extending up submerged valleys up to 2 km from the main axis. The maximum water depth is 48m and is situated 296m above sea level.

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2.2. Sampling

Samples were collected monthly from March 2018 to February 2020, except in April and August due to logistical issues and grouped into different seasons. Wet season included samples from October – January while dry season was from February – September. Samples of photic water (area that receives light penetration) was collected monthly from seven sampling stations coded as P1, P2, to P7 in three replicates per sampling station and concentrated using Henson's standard plankton net having pore size of 25μm and transfer into airtight dark 100ml bottles preserved in Lugol's solution and stored in a cool box containing ice cube at temperature of approximately 4 ºC before transferring to Biological Science Laboratory USM. A total of 140 samples (photic and aphotic) were used for this investigation. From each of the sampling station, 10 samples were collected for photic and aphotic zone amounting to 60 samples from the riverine zone, 40 samples in the transitional zone and 40 samples for lacustrine zone. The higher number of samples from the riverine zone was because samples were taken from the three sources of water into the reservoir while two point of sampling was assigned for transitional and lacustrine zones as shown in Table 1.

Water was also collected with a vertical integrating sampler (3.0-L vertical Van Dorn water sampler) which collects water from the aphotic region. The average Secchi disk depth was 2.82m and aphotic was calculated as 2.7 times the depth of the Secchi disk which is the part of the reservoir that does not receive sunlight (Serrano *et al.* 2004). Hence aphotic zone ranged between 7.73 to 17.66m. Water samples were taken to Chemistry Laboratory of Tenaga National Berhad (TNB) Kuala Lumpur for nutrient analysis {Chemical Oxygen Demand (COD), total phosphorus (TP) and total nitrogen} were measured using a Hach Colorimeter (Hach DRB200). Basic environmental parameters such as water temperature, water pH, conductivity and total suspended solids (TSS) were measured *in situ* during sampling using a multiparameter water quality meter (YSI Professional Plus handheld multi-probe). Dissolved oxygen was measured using a DO meter (YSI Pro DSS Water Quality Digital Meter) as well as Biochemical Oxygen Demand (BOD).

Table1. Shows the description of the sampling stations.

Code	Sampling Station Description	Zone	Coordinates
P1	Terengganu Mati (River Terengganu from the upstream and the main source of water to the reservoir).	riverine	5°12'30.75"N 102°32'17.01"E
P2	Limbing Besar	riverine	5°10'10.50"N 102°34'29.11"E
P3	Pelagong	riverine	5° 9'3.67"N 102°33'1.19"E
P4	Sireh	transition	5° 8'44.54"N 102°33'47.21"E
P5	Tambat Outlet (This is the point where water used for power generation from Tembat Dam is emptied into Puah Reservoir).	transition	5°12'33.09"N 102°34'56.17"E
P6	Centre Dam	lacustrine	5° 9'31.93"N 102°35'12.24"E
P7	**Power Intake (This is where water is taken to run the turbans for electricity generation).**	lacustrine	5° 9'1.97"N 102°35'50.62"E

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2.3. Procedures

Preserved samples were left to settle to the bottom of the measuring cylinder and concentrated to a 100 ml working volume. The upper 90 ml was gently siphoned off after the settling leaving the concentrated phytoplankton in the bottom. The concentrated 10 ml sample was transferred to a vial, where 1ml was obtained for cell counting using Sedgwick-Rafter chamber (using random transect near the top or bottom of the slide for counting) with the aid of inverted microscope (Model: ASAHI Binocular Microscope) and identification was guided by related identification keys {APHA (2005), Edward and David (2010), Miriam and Nicole (2012) and Rosen and Amand (2015)}.

Statistical Analysis

Species diversity for each zone was determined using the Richness and Evenness (***J'***) Index run by PRIMER (Plymouth Routines in Multivariate Ecological Research) version 6. Cluster analysis was performed to examine the similarity in distribution of phytoplankton on longitudinal zone. Pearson's correlation was performed to indicate relationships between physico-chemical and biological parameters. Statistical differences was determining where there was significant correlation using the one-way analysis of variance (ANOVA) (Statistical Package for the Social Sciences, version 20). The t test (independent- samples test) was used to test the difference in phytoplankton and physico-chemical between dry and wet seasons.

3. RESULTS

3.1 Physico-chemical Parameters

In the present investigation, it has been found that the light penetration or Sechi disc transparency is moderate. During the study, the maximum mean transparency recorded was 3.31m at lacustrine and the lowest 2.62m recorded at riverine as shown in Table . In this investigation, longitudinal TSS in Puah Reservoir were 7.16 mg/L, 1.44 mg/L and 1.96 mg/L for riverine, transitional and lacustrine respectively. Mean values of conductivity (photic) in the longitudinal zones are 26.6 μS/cm, 27.9 μS/cm and 25.96 μS/cm for riverine, transitional and lacustrine while 20.95 μS/cm, 23.8 μS/cm and 23.34 μS/cm recorded for riverine, transitional and lacustrine respectively in aphotic. Similarly, the mean values of temperature (photic) in the longitudinal zones are 29.9°C, 30.39°C and 29.9°C for riverine, transitional and lacustrine while 27.8°C, 28.18°C and 28.18°C recorded for riverine, transitional and lacustrine respectively in aphotic. The mean values of pH(photic) in the longitudinal zones are 6.48, 6.55 and 6.49 for riverine, transitional and lacustrine while 7.78, 7.82 and 7.46 were recorded for riverine, transitional and lacustrine respectively in aphotic. The pattern for dissolved oxygen recorded in this study resembles the typical pattern shown in a tropical reservoir. This trend shows the level of dissolved oxygen was higher in the photic (6.25, 6.22 and 6.12) mg/L and decreased in the aphotic (4.26, 4.95 and 3.19) mg/L. The mean values of BOD (photic) in the longitudinal zones are 2.86 mg/L, 2.40 mg/L and 2.49 mg/L for riverine, transitional and lacustrine while 3.37 mg/L, 2.55 mg/L and 5.34 mg/L recorded for riverine, transitional and lacustrine respectively in aphotic. The longitudinal mean values of COD at photic (26.92, 28.9 and 24.43) mg/L were higher than that of aphotic (23.86, 23.69 and 23.88) mg/L recorded for riverine, transitional and lacustrine respectively. In

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the present investigation, the mean TP values (photic) in the longitudinal zones are 0.37 mg/L, 0.39 mg/L and 0.49 mg/L for riverine, transitional and lacustrine while aphotic recorded 0.32 mg/L, 0.30 mg/L and 0.30 mg/L recorded for riverine, transitional and lacustrine respectively in aphotic. Mean values of TN (photic) in the longitudinal zones are 2.72 mg/L, 2.08 mg/L and 2.99 mg/L and for riverine, transitional and lacustrine while 1.83 mg/L, 2.99 mg/L and 2.78 mg/L were recorded for riverine, transitional and lacustrine respectively in aphotic.

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Table 2. shows the descriptive statistics of parameters based on longitudinal.

Longitudinal		SD(m)	TSS(mg/L)	Conductivity(µS/cm)		Temp(°C)		pH		DO(mg/L)		BOD(mg/L)		COD(mg/L)		AN(mg/L)		TP(mg/L)		TN(mg/L)		Nitrate(mg/L)		Nitrite(mg/L)	
		photic	photic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic	photic	aphotic
Riverine	mean	2.62	6.91	26.60	20.95	29.90	27.77	6.48	7.75	6.24	4.26	2.86	3.37	26.92	23.86	2.62	0.21	0.37	0.32	2.72	1.83	0.01	0.02	0.00	0.01
	sdv	0.74	28.40	9.37	13.56	1.69	2.03	0.44	2.39	0.80	2.04	2.37	3.09	27.68	28.92	0.75	0.29	0.25	0.40	3.58	5.55	0.01	0.06	0.00	0.02
	min	0.10	0.10	9.30	0.02	22.80	22.90	4.47	4.78	4.51	0.12	0.10	0.10	1.00	1.00	0.10	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	max	4.50	181.00	83.80	48.60	32.60	30.90	7.32	15.37	7.98	7.60	13.80	14.20	136.00	139.00	4.50	1.55	1.33	1.94	18.30	33.00	0.05	0.32	0.02	0.18
Transitional	mean	2.90	1.50	27.86	23.78	30.39	28.18	6.55	7.82	6.23	4.95	2.40	2.55	28.90	23.69	0.38	0.45	0.39	0.30	2.08	2.99	0.02	0.01	0.00	0.00
	sdv	0.72	1.26	4.30	14.90	1.44	1.90	0.34	2.45	0.68	2.05	1.71	2.29	35.04	25.14	2.00	1.87	0.25	0.45	2.48	7.97	0.04	0.01	0.00	0.02
	min	0.18	0.10	21.30	0.02	26.40	24.30	6.00	5.61	4.65	0.05	0.10	0.30	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	max	4.70	5.90	38.90	51.40	32.40	31.10	7.57	15.32	7.39	7.90	7.60	11.70	167.00	98.00	13.00	12.00	1.34	2.13	7.70	45.00	0.25	0.03	0.01	0.11
Lacustrine	mean	3.13	1.95	25.96	23.34	29.96	28.18	6.49	7.46	6.12	3.19	2.49	5.34	24.43	23.88	0.09	1.04	0.49	0.30	2.99	2.78	0.02	0.01	0.01	0.01
	sdv	0.90	3.84	2.79	13.43	2.08	1.76	0.34	2.09	0.91	2.68	1.71	3.91	22.40	33.48	0.09	2.55	0.43	0.29	4.15	6.83	0.02	0.04	0.00	0.02
	min	0.10	0.20	22.00	0.02	22.30	25.30	5.94	5.47	3.16	0.02	0.00	0.90	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	max	5.91	25.70	36.00	48.60	32.20	31.10	7.53	15.45	7.18	8.60	8.40	14.90	81.00	182.00	0.35	13.20	2.37	1.18	13.80	29.00	0.11	0.29	0.02	0.14

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3.2 Phytoplankton

A total of 1,461 number of individuals were recorded from 57 genera for all stations throughout the sampling period at photic. There were six phytoplankton groups at photic zone in Puah Reservoir which comprised Bacillariophyceae (diatoms), Chlorophyta (green algae), Cyanobacteria (blue-green algae), Pyrrhophyta (dinoflagellates), Chrysophyta (golden-brown algae) and *Charophyta* (filamentous). Chlorophyta dominated the community with a marked 526(36.00%) of the total phytoplankton density, followed by Pyrrhophyta 361(24.70%), Bacillariophyta 302(20.70%) and Cyanophyta 250(17.10%). Chrysophyta and Charophyta contributed a small portion to the phytoplankton abundance 12(0.80%) and 10(0.70%) respectively as showed in Table 3. A total of 197 number of individual were recorded from 28 genera in aphotic dominated by Cyanophyta 89(46.18%) of the total phytoplankton density, followed by Chlorophyta 72(36.55%), Pyrrhophyta 23(11.68%) and Bacillariophyceae 13(6.60%) as presented in Table 4. The most dominant genus from the study was *Peridinium, Staurastrum, Ansterionella, and Oscillatoria.* The number of phytoplankton in riverine, transitional and lacustrine were 620, 302 & 539 and 98, 59 & 40 for photic and aphotic respectively (Table 5). The highest mean of phytoplankton recorded in Puah Reservoir (1,198 orgs/ml) was during the dry season at photic and the lowest during the wet season (50 orgs/ml) in aphotic as shown in Figure 2.

The frequency of occurrence per station (%) of phytoplankton at photic shows that P1, P2 and P3 had 225(15.40), 195(13.40) and 200(13.70) respectively. P4, P5, P6 and P7 had 115(8.08), 184(12.60), 237(16.20) and 302(20.70) respectively (Table 3). While that of aphotic shows that P1, P2 and P3 had 41(20.18), 27(13.71) and 30(15.23) respectively. P4, P5, P6 and P7 had 34(17.26), 25(12.69), 16(8.12) and 24(12.18) respectively (Table 4). The highest frequency of phytoplankton was recorded at P7 (20.70%) and lowest at P4 (8.08%) for photic while 8.12% and 20.41% as minimum and maximum at P6 and P1 for aphotic respectively.

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Table 3. Checklist for the Occurrence, Distribution and Abundance of Phytoplankton Density Obtained From Puah Reservoir at photic zone from Feb. 2019- Jan. 2020.

Phyla/Family	**Species**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total Organism (org/mL)**	**Frequency**
Bacillariophyta	*Asterionella spp*	9	8	7	7	23	28	59	141	**20.70%**
	Aulacoseira granulata	0	0	0	1	0	0	0	1	
	Chaetoceros spp	0	13	13	5	2	7	0	40	
	Botryococcus braunii	27	5	11	6	3	6	6	64	
	Cyclotella spp	0	0	0	3	0	0	14	17	
	Cymbella sp	0	0	0	0	1	0	0	1	
	Diatoma spp	4	2	5	0	0	0	0	11	
	Dinobryon cylindricum	0	0	4	0	0	2	2	8	
	Leptoclindrus danicus	0	0	0	0	0	0	0	0	
	Melosira spp	0	0	0	0	0	3	0	3	
	Nitzschia sp	0	0	0	0	1	0	0	1	
	Pinnularia spp	0	0	0	0	2	0	0	2	
	Skeleunema spp	2	0	3	1	0	0	0	6	
	Sorastrum americanum	0	0	0	0	0	2	0	2	
	Tabellaria spp	0	0	4	0	0	0	0	4	
	Triceratium favus Ehr.	0	0	0	0	0	0	1	1	
	***Total* Bacillariophyta**	**42**	**28**	**47**	**23**	**32**	**48**	**82**	**302**	
Charophyta	*Actinastrum gracillimum*	0	2	3	0	2	2	0	9	**0.70%**
	Desmidium sp	0	0	1	0	0	0	0	1	
	Total Charophyta	**0**	**2**	**4**	**0**	**2**	**2**	**0**	**10**	
Chlorophyta	*Ankistrodesmus spp*	0	9	0	2	15	11	1	38	**36.00%**
	Chlorella spp	5	5	0	0	0	0	0	10	
	Chodatella quadriseta	16	26	2	5	2	26	11	88	
	Codium fragile	0	0	0	0	0	1	0	1	
	Dactylococcopsis spp	2	0	0	2	0	0	0	4	
	Entransia dichloroplastes	0	0	0	0	0	0	0	0	
	Eudorina spp	0	0	0	0	0	4	0	4	
	Microcystis viridis	0	0	0	0	0	2	0	2	
	Microspora amoena	0	0	0	0	2	0	0	2	
	Mougeotia spp	0	0	18	0	23	17	30	88	
	Oocystis spp	0	0	0	0	0	0	3	3	

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	Pandorina spp	0	0	0	0	0	5	7	12	
	Pediastrum simplex	2	0	3	2	0	0	8	15	
	Pithophora sp	0	0	0	0	0	1	0	1	
	Scenedesmus spp	22	8	6	0	8	0	13	57	
	Sorastrum americanum	0	0	4	0	0	0	0	4	
	Spirogyra sp	0	0	0	0	0	0	1	1	
	Spondylosium planum	0	0	0	0	0	0	1	1	
	Staurastrum spp	17	39	21	9	5	17	74	182	
	Straurastrum cuspidatum	0	0	0	5	0	0	0	5	
	Tetrapedia reinschiana	1	0	0	0	0	0	0	1	
	Uluthrix spp	0	0	7	0	0	0	0	7	
	Total Chlorophyta	**65**	**87**	**61**	**25**	**55**	**84**	**149**	**526**	
Chrysophyta	*Dinobryon cylindricum*	0	0	0	0	2	0	0	2	**0.80%**
	Synura	0	0	0	10	0	0	0	10	
	Total Chrysophyta	**0**	**0**	**0**	**10**	**2**	**0**	**0**	**12**	
Cyanophyta	*Anabaena sp.*	0	0	0	0	0	1	0	1	**17.10%**
	Aphanizomenon gracile	3	0	0	0	0	0	0	3	
	Calothrix spp	5	13	0	0	0	6	0	24	
	Gloeotrichia sp	0	0	0	0	0	1	3	4	
	Golenkinia radiata	2	0	0	0	0	2	0	4	
	Gomphosphaeria lacusiri	0	0	0	1	0	5	0	6	
	Microcystis spp	0	0	1	0	0	1	3	5	
	Nodularia spumigena	6	0	0	9	0	0	0	15	
	Oscillatoria spp	24	16	23	18	35	25	26	167	
	Sacconema spp	0	0	0	0	0	2	0	2	
	Schizothrix sp	3	1	3	5	2	1	1	16	
	Synedra ulna	0	3	0	0	0	0	0	3	
	Trichodesmium sp	0	0	0	0	0	0	0	0	
	***Total* Cyanophyta**	**43**	**33**	**27**	**33**	**37**	**44**	**33**	**250**	
Pyrrophyta	*Pelvetia fastigiata*	3	0	0	0	0	0	0	3	**24.70%**
	Peridinium spp	72	45	61	27	56	59	38	358	
	Total Pyrrophyta	**75**	**45**	**61**	**27**	**56**	**59**	**38**	**361**	
Total	**G. Total organisms (org/ml)**	**225**	**195**	**200**	**118**	**184**	**237**	**302**	**1461**	
	Frequency (%)	15.4	13.4	13.7	8.08	12.6	16.2	20.7		**100**
Taxa	**Species**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total Organism (org/ml)**	**Frequency**

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Table 4. Checklist for the Occurrence, Distribution and Abundance of Phytoplankton Density Obtained From Puah Reservoir at aphotic zone from Feb. 2019- Jan. 2020.

Phyla/Family	Species	P1	P2	P3	P4	P5	P6	P7	**Total Organism (org/mL)**	Frequency
Bacillariophyta	*Asterionella gracillama*		1	1	0	0	0	0	2	**6.60%**
	Thalassionema nitzchioides	0	0	0	1	0	0	0	1	
	Bacteriastrum varians	0	0	0	1	0	0	0	1	
	Chaetoceros spp	0	0	0	0	1	2	0	3	
	Pinnularia braunii	0	0	0	0	0	3	0	3	
	Schizothrix calcicola	0	0	0	0	0	2	0	2	
	Sorastrum americanum	0	0	0	1	0	0	0	1	
	Total	**0**	**1**	**1**	**3**	**1**	**7**	**0**	**13**	
Chlorophyta										**36.55%**
	Ankistrodesmus spp	0	0	1	0	0	0	0	1	
	Codium fragile	1	0	0	0	0	0	0	1	
	Chlorella spp		0	0	0	1	0	0	1	
	Chodatella quadriseta	23	4	4	3	6	0	0	40	
	Oedogonium spp	1	1	0	0		0	0	2	
	Closterium moniliferum	0	0	0	0	2	0	0	2	
	Thalassiothrix frauenfeldii	0	0	0	1	0	1	0	2	
	Pediastrum spp	0	1	1	0	0	0	0	2	
	Scenedesmus dimorphurs	0	0	0	0	1	0	0	1	
	Staurastrum spp	10	1	1	4	0	0	2	18	
	Tetraedron incus	0		1	0	0	0	0	1	
	Uluthrix spp	0	1	0	0	0	0	0	1	
	Total	**35**	**8**	**8**	**8**	**10**	**1**	**2**	**72**	
Cyanophyta	*Calothrix spp*	0	0	6	0	0	0	2	8	**45.18%**
	Ceratium hirundinella	0	1	0	0	0	0		1	
	Golenkinia radiata	0	0	4	0	0	0	1	5	
	Lyngbya spp	0	0	2	0	0	0		2	
	Oscillatoria spp	5	11	6	15	8	6	15	66	
	Schizothrix calcicola	1	1	0	0	0	0	3	5	
	Phormidium spp	0	0	0	0	1	0	0	1	
	Synedra spp	0	0	0	0	0	0	1	1	
	Total	**6**	**13**	**18**	**15**	**9**	**6**	**22**	**89**	
Pyrrophyta	*Peridinium spp*	0	5	3	8	5	2	0	23	**11.68%**
	Total	**0**	**5**	**3**	**8**	**5**	**2**	**0**	**23**	
	G. Total organisms (org/ml)	**41**	**27**	**30**	**34**	**25**	**16**	**24**	**197**	100
	Frequency (%)	**20.81**	**13.71**	**15.23**	**17.26**	**12.69**	**8.12**	**12.18**	**100**	
Taxa	**Species**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**Total Organism (org/ml)**	

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Table 5. The abundance of phytoplankton (orgs/ml) by longitudinal in Puah Reservoir (Feb 2019 – Jan. 2020).

	Station	No of samples	photic phytoplankton (orgs/ml)	aphotic phytoplankton (orgs/ml)
riverine	P1	11	225	41
	P2	11	195	27
	P3	11	200	30
		33	**620**	**98**
transitional	P4	11	115	34
	P5	11	184	25
		22	**302**	**59**
lacustrine	P6	11	237	16
	P7	11	302	24
		22	**539**	**40**
G. Total		**77**	**1,461**	**197**

PCO of the Hierarchical cluster shows the similarity in the distribution of phytoplankton for photic and aphotic. Riverine & transitional were similar in first order as showed in Figure 3.

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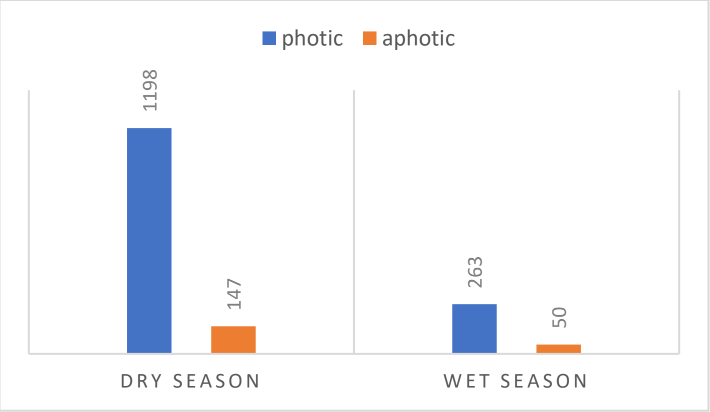

Figure 2. The seasonal abundance of phytoplankton (orgs/ml) in Puah Reservoir (Feb 2019 – Jan. 2020).

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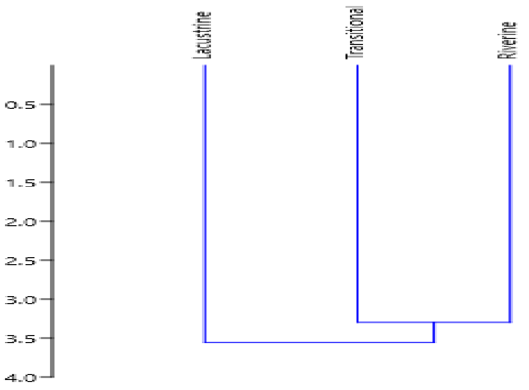

Figure 3. Hierarchical cluster of similarity in phytoplankton distribution for photic and aphotic of riverine, transitional and lacustrine in Puah Reservoir (Feb 2019 – Jan. 2020).3.3 Phytoplankton Diversity

The diversity of species in a particular area depends not only the number of species found, but also in their numbers. Ecologists call the number of species in an area its richness, and the relative abundance of species its evenness. They are both measures of diversity. Analysis of community structure revealed that evenness Index was highest at the photic as 0.74 (riverine) with the lowest as 0.58 (lacustrine) while 0.82 (transitional) and 0.71 (lacustrine) as highest and lowest respectively in the aphotic as presented in Table 6.

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Table 6. Phytoplankton species evenness and richness at photic and aphotic stations (Feb 2019-Jan 2020).

Stations	Photic		Aphotic	
	Richness	Evenness (***J'***)	Richness	Evenness (***J'***)
Riverine	207	0.74	33	0.78
Transitional	150	0.67	30	0.82
Lacustrine	270	0.58	20	0.71

4. DISCUSSION

Based on the overall mean recorded for light penetration or Sechi disc transparency (2.62m to 3.31m), Puah Reservoir was classified as a mesotrophic lake (Bigham *et al.,* 2015). This study correlated with that of Abu Bakar (2014) in Temengor Reservoir (2.6 m to 4.2 m) but had higher transparency compared to selected reservoirs in Johor (0.24 to 0.48m) (Sharip *et al.* 2017). There was a positive correlation between transparency temperature (0.347) and pH (0.315), P-value of 0.05 at the photic zone while negatively correlated with temperature (- 0.327), pH (- 0.660) & DO (- 0.496) with p-value of 0.01 at the aphotic at p-value of 0.01. The ANOVA results showed that there was a sig dif. between the Riverine, Transitional and Lacustrine with regards to transparency at P=0.05. Tukey's test showed that the mean Secchi depth measured in the wet season was significantly higher ($p<0.005$) than Dry season.

TSS values have a high negative correlation with transparency and temperature in Puah Reservoir. Seasonal changes of total suspended solid were also recorded in this study. Results obtained showed that suspended solids were low during the dry season (2.6 mg/L) and increased drastically during the wet season (8.4 mg/L). Consequently, reducing light transmission through the water and so lowering the rate of photosynthesis in the reservoir (Abolude *et al.,* 2012).

The relative decrease of conductivity at hypolimnion in this study was probably due to the decomposition of the organic component such as dead organisms subsided out from epilimnion which released ions into the water (Dent *et al.* 2014). Seasonal fluctuations of conductivity were recorded during the study period. The highest mean of conductivity recorded in Puah Reservoir (34.96 µS/cm) was during the transition from dry to wet season. The increase of conductivity was assumed to be caused by insufficient flows of freshwater due to low rainfall (Mohammad *et al.* 2015). Also, variations in the ionic composition of precipitation and rain dilution effect caused the conductivity readings to vary seasonally in this study.

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The water temperature showed a gradual decrease from the surface to the deeper layer at all sampling stations. An equivalent surface and bottom layer water temperatures were observed throughout the study period, hence there was no sig dif. between the photic and the aphotic based on temperature recorded. The mean temperature for this study (28.22 to 30.62°C) photic and (26.5 to 29°C) aphotic was lower than Tasik Kenyir (30 to 32ºC) as reported by Siti-Zahrah *et al.* (2005) but same with Sembrong Dam (28.62-30.92°C) (Mohd-Asharuddin, 2016). A higher mean of temperature recorded at surface water is expected in a tropical reservoir due to the strong impact of solar radiation and air temperature (van Vliet *et al.* 2013). Slightly higher temperatures were recorded during the dry season (29.3 to 30.4°C) especially in May to August due to an increase in transparency compared with the wet season (26.9 to 28.2°C) in this study.

The pH values were recorded to be higher in the deeper depths (7.46 to 7.82) mean range in the aphotic zone. This could be attributed to the low photosynthesis process which increases dissolved carbon dioxide. The pH level of the reservoir water was not influenced by the seasonal regime. The water of the Puah Reservoir was thus acidic throughout the study period (6.39 and 6.50) for wet and dry seasons. hence the reservoir exhibits an appropriate buffer capacity. The mean pH range values for the current study are within the WHO (2005) acceptable limits of 6.5–8.5 for natural water bodies indicating a slightly acidic condition for the Puah Reservoir. The pH negatively correlated with conductivity (- 0.660) with p-value of 0.01 but positively correlated with temperature (0.404, p=0.01) & DO (0.443, 0.01), p-value of 0.05 at the aphotic zone. The ANOVA results showed that there was a sig dif. between longitudinal of photic with regards to pH at P=0.05. Tukey's test also showed that transitional was significantly different from riverine & lacustrine in mean pH measured longitudinally.

In the present investigation, the DO ranged between 3.19 to 6.25 mg/L which indicates an unpolluted & healthy water body. Dissolved oxygen recorded in Puah Reservoir at photic was similar with Chenderoh Reservoir (5.08 to 6.36 mg/L) (Meor *et al.* 2002) but lower than Lake Tanganyika (7.17-7.71 mg/L) (Lambert *et al.* (2020)). The high concentration of dissolved oxygen at the surface layer recorded in this study was probably due to the photosynthesis process by algae which released oxygen in the water column. Besides that, water mixings that dissolved the oxygen in surface water and the atmosphere were also assumed to cause high dissolved oxygen levels at the upper layer of the water column according to Akindele and Olutona (2015). A lower DO value recorded in aphotic explained the use of dissolved oxygen for both biological and chemical processes which was high in this layer (Kuznetsov 2014). The dissolved oxygen level recorded during the wet season (4.10 mg/L) was slightly lower than the dry season (6.30 mg/L) in this study. This was probably due to less solar radiation during heavy rain which caused a decrease in photosynthetic activity. DO negatively correlated with conductivity (- 0.496) but positively correlated with pH (0.443) at p-value of 0.01 at the aphotic. ANOVA results showed longitudinal sig dif. in aphotic at P=0.05. Similarly, Tukey's test showed that the mean seasonal DO has sig. dif. at photic (wet season higher to dry season) at p<0.005.

The seasonal difference was observed between the BOD values at photic and aphotic in both seasons. The mean values of BOD at photic and aphotic were all within the MOEF, (1994) standard of 3 mg/l for bathing and DOE Water Quality Index Classification of Malaysia for class II (Water Supply II – Conventional treatment, Fishery II – Sensitive aquatic

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species.) except in lacustrine of aphotic were values of above 4mg/l were recorded. The results of this study showed that BOD values were generally low throughout the study period and increases from the photic to aphotic region. This may be because of the mixing of the water and hence, an increase in dissolved oxygen, which also raises the activities of organisms in the water and consequently reducing the BOD values.

Generally, the mean COD values show the highest mean in Jan (55.89 mg/L) in wet season & lowest in Oct (5.17 mg/L) in photic during the transition from dry to wet season while aphotic registered highest mean in Sept (41.07 mg/L) (dry season) & lowest in Oct (7.00 mg/L) also during the transition from dry to the wet season. This investigation was similar to the report of Lambert *et al.,* (2020) (20.77-34.35 mg/L) in Lake Tanganyika.

TP was slightly lower from photic to aphotic. Seasonal fluctuation shows a higher record in the wet season. TP values shows highest mean in Dec & Jan (0.60 & 0.60 mg/L) during wet season & lowest in Feb (0.24 mg/L) (transition from wet to dry season) in photic region while aphotic registered highest mean in Dec (0.54 mg/L) (wet season) & lowest in July & Aug (< 0.00) during dry season. Mohammed and Saminu (2012) highlighted that in most water bodies, phosphate appears to be the ultimate limiting factor for biological productivity because it is a n important nutrient for the growth of algae in water according to Trivedy (1986). Although the result of TP was lower than that of Mohd-Asharuddin (2016) (1.05 mg/L) in Sembrong Dam, Lake Tanganyika (0.69-1.71 mg/L) (Lambert *et al.* 2020).

Similarly, TN value was highest in Feb (3.36 mg/L) (transition from wet to dry season) & lowest in Aug (0.76 mg/L) (dry season) in photic while aphotic registered the highest mean in Feb (6.94 mg/L) & lowest in Aug (< 0.001 mg/L). There was a positive correlation between TN with AN (r = 0.661) at the photic The ANOVA results showed that there was no sig dif. between Riverine, Transitional and Lacustrine with regards to TN at P=0.05.

4.1 Phytoplankton

The genera *Staurastrum* from the Desmidiaceae family and *Oscillatoria* from *Oscillatoria*ceae accounted as the most diverse genera with 5 and 6 species recovered which corroborated with the report of Asma *et al.* (2014). The phytoplankton community was dominated by the chlorophytes, which was similar to most phytoplankton community structures in tropical lakes (Laskar and Gupta 2006; Sharma and Tiwari 2018). Phytoplankton monthly distribution showed the highest density at the Lacustrine zone in the dry months of March to September 2019 and gradually declined until the end of the sampling period in January 2020. Phytoplankton positively correlated with pH (r = 0.304), p-value of 0.01. The ANOVA results showed that there was a sig dif. between longitudinal (photic & aphotic) with regards to phytoplankton at P=0.05. PCO of the Hierarchical cluster shows the similarity in the distribution of phytoplankton for both photic and aphotic. Riverine & Transitional were similar in distribution. Seasonal fluctuations of phytoplankton were recorded during the study period. The highest number of phytoplankton recorded in Puah Reservoir (1,198 org/ml) was during the dry season at photic and the lowest during the wet season (50 org/ml) in aphotic. This was due to the high temperature recorded during the dry season, increase in transparency and Higher DO during the dry season which was the most vital environmental factors that regulate the photosynthetic activity of phytoplankton.

5. CONCLUSION

Puah Reservoir is a young Reservoir completed in 2017 and was created for hydroelectric power generation and flood mitigation in Hulu Terengganu. Based on water quality findings from this study, the condition of this reservoir was reasonably good. A total of 1,461 number of individuals were recorded from 57 genera for all stations throughout the sampling period comprising of six phytoplankton groups at photic zone in Puah Reservoir which include Bacillariophyceae (diatoms) (20.70%), Chlorophyta (green algae)(36%), Cyanobacteria (blue-green algae) (17.10%), Pyrrhophyta (dinoflagellates) (24.70%), Chrysophyta (golden-brown algae)(0.80%), and *Charophyta* (filamentous) (0.70%). While a total of 197 number of individual were recorded from 28 genera in aphotic dominated by Cyanophyta (46.18%) of the total phytoplankton density, followed by Chlorophyta (36.55%), Pyrrhophyta (11.68%) and Bacillariophyceae (6.60%). The occurrence per zone of phytoplankton (mg/L) shows that Riverine had 620(photic) & 98 (aphotic), Transitional had 302 org/mL (photic) & 59 org/mL (aphotic) and Lacustrine had 539 org/mL (photic) & 40 org/mL (aphotic). Similarly, phytoplankton had 1.198 org/mL as highest mean during dry season at photic and lowest as 50 org/mL during wet season at aphotic.

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