

Preliminary analysis of physico-chemicals and plankton communities in different oxbow lakes in Malaysia

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(Received 22 February, 2019; accepted 21 April, 2019)

ABSTRACT

The first record of physico-chemical and biological communities from selected Oxbow lakes in Malaysia is reported based on measurement carried out in three water bodies during their lentic condition. Water quality characterisations indicate that the oxbow lakes highly varied with each other. All lakes were mesotrophic based on low chlorophyll-a values. The main parameters differed were conductivity, turbidity, phosphate, alkalinity, nitrate, total phosphorus. The phytoplankton and zooplankton density were significantly differed between oxbow lakes ($p < 0.05$). Phytoplankton densities in these oxbow lakes were much higher than phytoplankton density recorded in other inland waterbodies with similar trophic states. However, species diversity and richness were not varied between the oxbow lakes. Both phytoplankton and zooplankton density in ascending order was OX3 < OX2 < OX1. Plankton density was negatively correlated with temperature, turbidity and total phosphorus.

Key words: Ecological diversity, Plankton, Oxbow lakes, Water quality, Malaysia

Introduction

Being unique waterbodies located in floodplains and influenced by seasonal flooding, oxbow lakes or interchangeably known as floodplain lakes, contain myriad aquatic communities. These shallow waterbodies are normally formed as a result of the riverine process whereby the meandering pattern of river flow changes naturally, forming a separate water pool from the river's main channel. Human activities such as creation of dams, inter-basin diversion and water abstraction are common disturbances to the natural riverine process in many countries leading to the modification of floodplains. Extensive alteration of rivers through channelization and straightening which have been widely carried

out as part of flood mitigation measures further modifies the riverine processes. These floodplain lakes are known to be the most endangered landscapes globally (Wozniak *et al.*, 2014). Despite acting as a refuge to other organisms during low flow and dry weather, oxbow lakes are affected by pollutants transported from the main river including sediments, and inorganic and organic nutrients during high flow and wet seasons.

Continuous and incessant development of landscape within river basins alters not only the hydrological and flood patterns but also water quality of these oxbow lakes. The physico-chemical and biological properties of oxbow lakes are among least researched possibly due to small size and permanent existence of lakes. Extensive work on diversity

of biological communities in oxbow lakes is limited. A few notable publications of oxbow lakes that have been published in scientific literature are found in the Amazon and Orinoco in South America, Sepikramu in Papua New Guinea, Biebrza and Rhine in Europe (Cardoso *et al.*, 2012; Carvalho *et al.*, 2001; Grabowska *et al.*, 2014; Vandenbrink *et al.*, 1993; Vasquez and Rey, 1992; Vyverman, 1996). One example, the effect of water quality on phytoplankton structure in oxbow lakes under pressure anthropogenic and non-anthropogenic impacts (Wozniak *et al.*, 2014). A few studies showed that hydrological connectivity and fluctuating water levels associated with floods alter phytoplankton (Cardoso *et al.*, 2012; Grabowska *et al.*, 2014), macrozoobenthos (Obolowski, 2011) and fish (Goetz *et al.*, 2015) community composition in oxbow lakes. This study aims to characterize the physico-chemical profiles and plankton community abundance and diversity in different oxbow lakes in Malaysia. Unlike other waterbodies such as the natural lakes and reservoirs, studies on oxbow lakes are rarely undertaken. The only oxbow lakes that have been studied are the ones located in Kinabatangan River, Sabah which focus on plankton and fish diversity (Azmi, 2007; Harun *et al.*, 2015; Heng *et al.*, 2006).

Material and Methods

A total of three ox-box lakes were included in this study (Figure 1). The size of the oxbow lakes in de-

scending order are OX3 (54.8 km²) > OX1 (12.5 km²) > OX2 (4.75 km²). In terms of land use, the catchment area of OX2 was still forested while the catchments of OX1 and OX3 were composed of palm oil plantation and forest (Table 1). All samples were collected during the dry seasons where the water pools were lentic and disconnected from the main river. Samples were collected at two locations to represent each oxbow lake. In situ measurement of temperature, dissolved oxygen (DO), pH, conductivity, salinity and turbidity were carried out using multiparameter probe while water samples were collected using Van Dorn sampler. Water samples were stored at 4 °C prior to analysis in the external laboratory for chlorophyll-a, total phosphorus (TP), ammoniacal nitrogen, nitrate and total nitrogen analyses. Phytoplankton samples were collected by taking water samples using van dorn sampler at surface whilst zooplankton samples were collected using 60 µm plankton net. Phytoplankton and zooplankton samples were preserved in the field with Lugol's solution and 5% buffered formalin respectively prior to enumeration using inverted and compound microscopes in the laboratory.

Biodiversity indices were calculated for each oxbow lake: the Shannon-Wiener diversity index (H₂), Simpson dominance index, Margalef's species richness index (d) and Pielou evenness index (J₂). Biodiversity index were calculated based on the formula described in Maguran (2013). Higher Shannon-wiener and Margalef's index means higher spe-

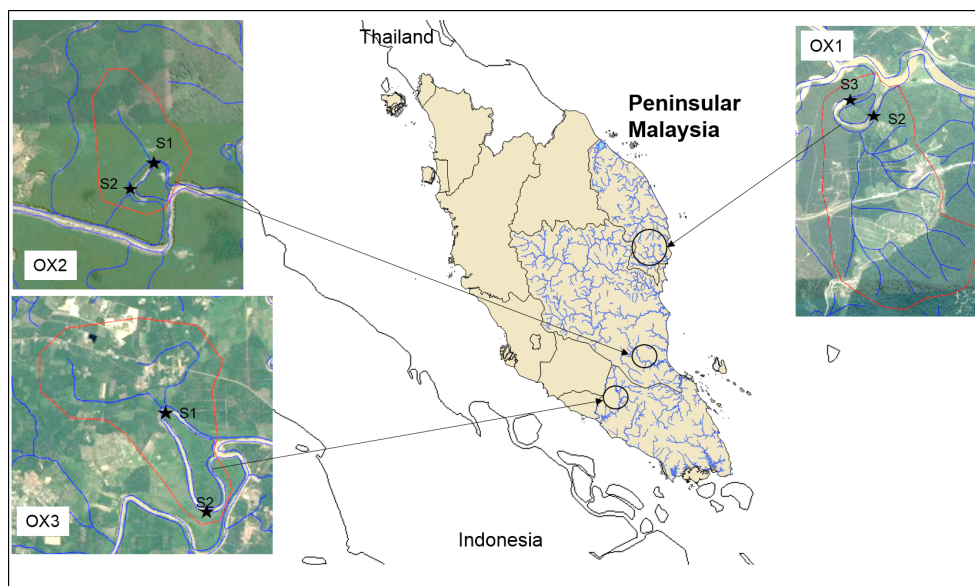


Fig.1. Study site and location of sampling area.

Table 1. Characteristics of studied oxbow lakes.

River	Oxbow Lake	Geographic coordinates	Surface area, (acres)	Shoreline length (km)	Land use
Chukai River, Terengganu	OX1	103° 18.536'E, 4° 12.571'N	12.5	3.1	Forest, palm oil plantation
Rompin River, Pahang	OX2	103° 10.059'E, 2° 52.927'N	4.75	1.96	Forest
Muar River, Johor	OX3	102° 48.844'E, 2° 20.736'N	54.8	7.57	Forest, palm oil plantation

cies richness and diversity. Pielou's evenness represents equitability in distribution of species while Simpson dominance represents the reverse of evenness or dominance of species. Species abundance data were square roots transformed while TP values were log-transformed to improve normality. ANOVA and non-parametric Spearman's rank order correlation analyses were performed on the environmental parameters and plankton diversity and density to determine if any significant relationships existed among the parameters. All analyses were performed using Microsoft Excel and SPSS.

Results and Discussion

Physico-chemical quality

The mean water quality condition of the three lakes (Table 2) appeared to be highly varied. The oxbow lake in Rompin (OX2) is characterised as low in DO and highly enriched with TP and thus more eutrophic. The DO level, pH and conductivity were similar in both oxbow lakes located in Muar (OX3)

and Chukai (OX1). OX3 is characterised as highly turbid, alkaline and enriched with nitrate but low in chlorophyll while OX1 is characterised as depleted of TP and nitrate. Parameters that were significantly difference between lakes were conductivity, turbidity and phosphate ($p < 0.01$), alkalinity, nitrate and TP ($p < 0.05$).

Chlorophyll-a showed strong negative correlation with DO ($r = -0.74$), conductivity ($r = -0.71$) and turbidity ($r = -0.73$). High turbidity levels reduced transparency and light penetration subsequently limiting primary production (Sharip and Zaki, 2014; Sharip and Yusoff, 2017). Significant relationships of chlorophyll-a with conductivity and TDS were reported at Nasti and Bukbhara lakes, India (Hasan *et al.*, 2000). This study illustrated that the three oxbow lakes have low chlorophyll- a values, which mean they were in mesotrophic conditions and have average biological productivity. Chlorophyll-a concentration in other oxbow lakes such as Pantanal oxbow lake during low water level reached $34.8 \mu\text{g L}^{-1}$, considered as hyper-eutrophic.

Table 2. ANOVA results of water quality parameter in the studied oxbow lakes.

Parameter	Unit	Mean			F	p-value
		OX1	OX2	OX3		
Temperature	°C	28.5	28.7	29.4	1.7	0.315
Dissolved oxygen	mg/L	6.6	4.3	6.2	1.0	0.465
pH		6.96	6.82	6.86	0.13	0.886
Conductivity		112.5	62.5	112	380.8	0.000**
Turbidity	NTU	19.7	14.8	72.4	214.2	0.001**
Alkalinity		6.5	13	23	16.9	0.023*
Salinity	ppt	0.05	0.03	0.05	.	.
Ammoniacal nitrogen [#]	mg/L	0.09	0.105	0.035	1.6	0.338
Phosphate [#]	mg/L	<0.01	0.05	0.30	305.6	0.000**
Nitrate [#]	mg/L	<0.01	0.55	1.88	10.2	0.046*
Chlorophyll-a [#]	$\mu\text{g/L}$	4.25	8.1	1.35	5.3	0.104
Total phosphorus [#]	mg/L	<0.01	0.08	0.12	24.7	0.014*
Transparency	m	0.5	0.55	0.5	1.0	0.465

Note: # Log-transformed; * $p < 0.05$, ** $p < 0.01$

Plankton diversity and density

A total of seven divisions of phytoplankton were observed in this study in all three oxbow lakes. Phytoplankton density was lowest in OX3 ($p < 0.05$) (Fig. 2). No significant differences were observed for number of species and Shannon-Wiener diversity index (Table 3). Margalef species richness index was lowest in OX1 while Pielou's Evenness Index (J') was lowest in OX2. Euglenophyta was the dominant phytoplankton group in OX3 and OX2 while Chrysophyta was the dominant group in OX2. *Peridinium* sp. was the most dominant species in OX2 while *Trachelomonas* sp. was most dominant species in OX1 and OX3 (Table 4). Phytoplankton diversity (H') was positively correlated with DO, conductivity and turbidity and were negatively correlated with transparency and chlorophyll-a.

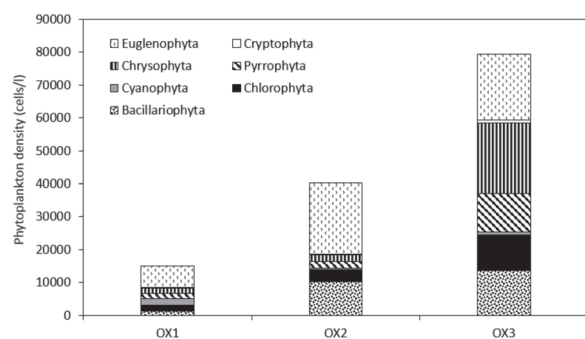


Fig. 2. Phytoplankton density in different oxbow lakes.

Phytoplankton species per sample in all lakes were much higher than the one found in Pantanal Lake. In this work, both oxbow lakes in Terengganu and Muar were impacted by anthropogenic pres-

ures namely oil palm plantation. These oxbow lakes have a high average concentration of different ions and should be characterized by a high average density of phytoplankton. However, only oxbow lake in Terengganu exhibit a positive relationship between phytoplankton density and conductivity consistent with other findings (Wozniak *et al.*, 2014). Low phytoplankton density in Muar oxbow lake could be due to light limitation caused by turbid waters. Phytoplankton density was negatively correlated with temperature, turbidity and TP. Phytoplankton composition in Pahang oxbow lake was more diverse, consistent with finding for the forested oxbow lake (Wozniak *et al.*, 2014). Phytoplankton density in these oxbow lakes were much higher than phytoplankton recorded in other inland waterbodies with similar trophic states (oligotrophic-mesotrophic) such as Putrajaya Lake (433.94 cells/ml) (Jamal *et al.*, 2014) and Bera Lake (295.6 cells/ml) (Sharip and Yusoff, 2017). The number of phytoplankton species in these oxbow lakes were lower than the number of phytoplankton species recorded in Kinabatangan oxbow lakes in Sabah (159 species) (Azmi, 2007).

A total of three division of zooplankton were observed in this study namely Rotifera, Cladocera and Copepoda. Zooplankton density was lowest in OX3 and highest in OX1 ($p < 0.05$). Rotifera was the dominant zooplankton group in all three lakes (Fig. 3). Number of species and Shannon-Wiener diversity index of zooplankton was highest in OX1 and lowest in OX2 ($p < 0.05$). The most dominant zooplankton species were *Anuraeopsis* sp. in OX2, *Hexatra* sp. in OX3 and *Nauplii* and *Keratella cochlearis* in OX1

Table 3. Diversity indices of phytoplankton and zooplankton the studied oxbow lakes.

River	Unit	OX1 (Chukai)	OX2 (Rompin)	OX3 (Muar)
Phytoplankton				
Number of species		21	24	22
Total density	Cells/ml	72870	39058	14258
Shannon-Wiener Diversity, H'		2.382	2.096	2.625
Simpson Dominance		0.873	0.797	0.972
Pielou's Evenness, J'		0.782	0.660	0.849
Margalef's Species Richness, d		4.66	6.28	7.95
Zooplankton				
Number of species		15	8	11
Total density	Ind/L	65.5	43.2	26.6
Shannon-Wiener Diversity, H'		1.729	1.013	1.165
Simpson Dominance		0.741	0.570	0.528
Pielou's Evenness, J'		3.35	1.86	3.05
Margalef's Species Richness, d		0.638	0.488	0.486

(Table 5). Rotifers were generally more abundant than copepods and cladocerans in all lakes with mean percentage in decreasing orders: OX1, OX2 and OX3 (86 %, 67% and 55% of total zooplankton respectively). This is followed with copepods with

Table 4. The total abundance (%) of phytoplankton species in the oxbow lakes

Phytoplankton density (cell mL ⁻¹)	OX1 (Chukai)	OX2 (Rompin)	OX3 (Muar)
Bacillariophyta			
<i>Cyclotella</i> sp.	+	++	+
<i>Cymbella</i> sp.	-	-	+
<i>Fragilaria</i> sp.	-	+	-
<i>Navicula</i> sp.	++	+	+
<i>Nitzschia</i> sp.	+	+	+
<i>Pinnularia</i> sp.	-	+	-
<i>Synedra</i> sp. a	-	-	+
<i>Synedra</i> sp. b	+	+	-
<i>Tabellaria</i> sp.	+	+	+
Chlorophyta			
<i>Ankistrodesmus</i> sp.	-	+	+
<i>Chodatella</i> sp.	-	-	+
<i>Closterium</i> sp.	+	-	-
<i>Cosmarium</i> sp.	+	+	-
<i>Crucigenia</i> sp.	-	+	-
<i>Kirchneriella</i> sp.	-	-	+
<i>Scenedesmus quadricauda</i>	+	+	+
<i>Schroederia</i> sp.	+	-	+
<i>Selenastrum</i> sp.	+	-	-
<i>Tetraedron</i> sp.	-	+	-
Cyanophyta			
<i>Aphanocapsa</i> sp.	-	+	-
<i>Merismopedia</i> sp.	-	-	+
<i>Oscillatoria</i> sp.	+	+	+
<i>Pseudanabaena</i> sp.	+	-	+
Pyrrophyta			
<i>Peridinium</i> sp. a	++	+	+
<i>Peridinium</i> sp. b	+	+	+
Chrysophyta			
<i>Dinobryon sertularia</i>	+	+	+
<i>Mallomonas</i> sp.	+	+	+
Cryptophyta			
<i>Cryptomonas</i> sp.	+	+	+
Euglenophyta			
<i>Euglena acus</i>	+	+	-
<i>Euglena</i> sp.	++	+	++
<i>Lepocinclis</i> sp.	+	-	-
<i>Phacus</i> sp.	+	+	+
<i>Strombomonas</i> sp.	-	+	+
<i>Trachelomonas</i> sp. a	+	+++	++
<i>Trachelomonas</i> sp. b	-	+	-

Notes: - = absent; + = < 10%; ++ = rare (10 – 39.9%); +++ = common (40 – 69.9%); ++++ = abundant (70 – 100%)

Table 5. The total abundance (%) of zooplankton species in the oxbow lakes.

Zooplankton density (cell mL ⁻¹)	OX1 (Chukai)	OX2 (Rompin)	OX3 (Muar)
Rotifera			
<i>Anuraeopsis</i> sp.	+	+++	+
<i>Asplanchna</i> sp.	+	-	-
<i>Brachionus angularis</i>	-	-	+
<i>Brachionus calyciflorus</i>	-	+	-
<i>Collotheca</i> sp.	+	-	-
<i>Euchlanis</i> sp.	+	-	-
<i>Hexathra</i> sp.	+	-	+++
<i>Keratella cochlearis</i>	++	-	+
<i>Lecane</i> sp.	+	-	+
<i>Lecane bulla</i>	+	-	-
<i>Lecane pumila</i>	+	-	+
<i>Lecane unguolata</i>	+	-	-
<i>Philodina</i> sp.	+	+	-
<i>Polyarthra</i> sp.	+	+	++
<i>Trichocerca</i> sp.	+	-	+
Copepods			
Nauplii	+++	++	++
Cyclopoida	+	+	-
Cladocera			
<i>Bosmina</i> sp.	-	-	+
<i>Bosminopsis dietersi</i>	-	+	-
<i>Moina</i> sp.	-	+	-

Notes: - = absent; + = < 10%; ++ = rare (10 – 39.9%); +++ = common (40 – 69.9%); ++++ = abundant (70 – 100%);

percentage abundance of 11% in OX1, 32% in OX2 and 45% in OX3. Cladocerans were not found in OX1 and infrequent observed in OX2 and OX3. OX1 has a significant higher Margalef's species richness index while OX2 has a significantly differing species Pielou's evenness index (J') compared to the other oxbow lakes. The number of zooplankton species in these oxbow lakes were comparable with the number of zooplankton species recorded in other inland waterbodies with similar trophic state (oligotrophic-mesotrophic) such as Pedu (22 species) (Sah *et al.*, 2012) and Dayang Bunting lakes (12 species) (Sah and Hamid, 2017) as well as Kinabatangan water bodies (17 species) (Azmi, 2007).

Zooplankton density were negatively correlated with temperature, turbidity and TP. Similarly, zooplankton diversity (H') was positively correlated with conductivity and chlorophyll-a and wand negatively correlated to TP. Zooplankton density showed positive relationship with phytoplankton density ($r = 0.68$) indicating their potential as measure or indicator of productivity during low water

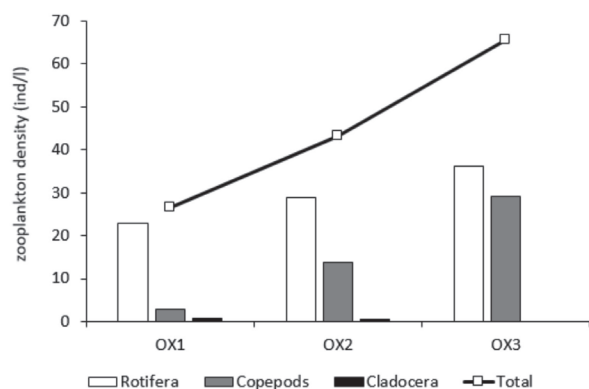


Fig. 3. Zooplankton density in different oxbow lakes.

phase (Zhao *et al.*, 2018). Some study showed that mean densities of zooplankton in oxbow lake were highest during low water phase (Vasquez and Rey, 1992). Similarly, Grawbroska *et al.*, (2014) found that during the low-water phase, phytoplankton biodiversity was the lowest in lentic system and concluded that the isolation of any floodplain lake from the river channel deteriorates its trophic conditions. During low water phase, each oxbow lake that are disconnected from the river exhibit individual characteristics based on their morphology, location and depth (Napiorkowski and Napiorkowska, 2014). High plankton communities in these oxbow lakes provide diverse food for fish communities.

Conclusion

In conclusion, the results of this research provide baseline information of three oxbow lakes which represent a unique aquatic ecosystem within their river system. Environmental factors and the associated biological characteristics (phytoplankton and zooplankton) were uniquely differs between the oxbow lakes. Phytoplankton density were high in all oxbow lakes; dominated by euglenoids in in OX3 and OX2 and Crysophytes in OX1. Rotifer was the dominant zooplankton group in all three lakes. The interaction of these oxbow lakes with hydrological connectivity and watershed interaction needs further investigation in order to develop appropriate strategies for their conservation.

Acknowledgements

This study is supported by the Malaysian Ministry of Natural Resources and Environment, vote number P23170009000421.

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