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Assessment of the Water Quality of the Western Boundary of Kuching Wetland National Park, Sarawak, Malaysia

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ABSTRACT

Kuching Wetland National Park (KWNP) is one of the RAMSAR wetlands in Malaysia, a wetland of international importance. Understanding the water quality of the riverine system that drains the KWNP is crucial for sustainable management of the wetland. Hence, the water quality of Sibu Laut River, which forms the western boundary of the park, is described in this study. Three samplings were carried out during low tide along the western boundary of the wetland. Sub-surface and near-bottom water samples at six selected sampling sites were taken and analysed for physico-chemical parameters. The variations between sub-surface and near-bottom water column of those parameters were detectable and due mainly to the influence of tidal currents. A peak of sub-surface organic phosphorus was observed at station 2 next to the village of Sibu Laut whereas elevated near-bottom organic phosphorus was observed at station 4 near to the shrimp farm. Organic phosphorus represents a significant fraction of the total phosphorus, comprising from 59.76% to 83.64% and 62.50% to 78.67% for sub-surface and near-bottom water, respectively. In contrast, inorganic phosphorus was extremely low at most of the stations. There is a significant correlation between organic phosphorus and chlorophyll *a*, which indicates association of organic phosphorus and phytoplankton in the study area. The present study showed that Sibu Laut River had minimal pollution impact to the wetland, except the elevated sub-surface organic phosphorus near the Sibu Laut Village and elevated near-bottom organic phosphorus near the shrimp farm. Continuous monitoring program is important for early detection of future threats to the water quality of Sibu Laut River.

Keywords: Kuching Wetland National Park, phosphorus, physico-chemical parameter, Sibu Laut River, water quality

INTRODUCTION

Kuching Wetland National Park, KWNP is the first RAMSAR wetland (Ramsar Site No.: 1568) in Sarawak and the fifth in Malaysia. The park covers an area of 6610 ha of the former Sarawak Mangrove Forest Reserve and is located 15 km from Kuching city. It was classified as a totally protected area and gazetted as a national park in 2002 (Gazette No.: 3512) and listed as a RAMSAR wetland in 2005 (Wetlands International, 2013). Sibu Laut River is one of the rivers that drain the mountainous region at the upper reaches of the wetland and the mangrove swamp within the delta at the estuary. It forms the western boundary of the wetland together with Salak River to the east and Loba Kilong River to the north.

Surroundings of the Sibu Laut River have undergone profound and rapid changes over the past 30 years. Despite of traditional settlement, the river is bounded by new housing development, aquaculture farms, and increasing tourism activities, all of which can have adverse impacts on the river as boundary of RAMSAR site. The population growth and accompanying land-use changes could cause environmental degradation such as pollution and eutrophication, modification and loss of habitat and local communities (Alvarez-Cobelas *et al*., 2001; Braga *et al*., 2000; Chandra *et al*., 2010; Hogland, 1994; Meyer-Reil & Koster, 2000; Ouyang *et al*., 2005).

Water quality deterioration is one of the greatest concerns among the environmental degradation. Regular monitoring is an essential tool to gauge the quality of water and to make management decisions for improving or protecting the intended uses. Hence, the water quality information is presented for Sibu Laut River to provide an overview of the western boundary condition of Kuching Wetland National Park. This is necessitated by the

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potential influence of the inflowing water to the wetland since the quality of the inflowing water will greatly influence the status of a wetland. Phosphorus was focused in the present study as phosphorus was one of the main pollutants discharged from domestic wastewater (Ling *et al*., 2010). Elevated phosphorus concentration was reported near to the villages located along Sibu Laut River (Soo *et al*., 2014).

MATERIALS & METHODS

Study Area and Sampling Stations

Kuching Wetland National Park (KWNP) is located in western Sarawak with the geographical location of N01° 40' 59" - N01° 41' 18" / E110° 12' 16" - E110° 16' 20". The area experiences a humid tropical climate with an annual rainfall of 3,600 - 4,000 mm. The region is not directly exposed to the northeast monsoon. The rainfall is the lowest during June and July, and reaches a peak in December and January. The temperature ranges from 19°C to 36°C, receives an average of 5 hours of sunshine per day (Malaysian Meteorological Department, 2013). The locations of the six sampling stations were shown in Figure 1. The first station was located at the most downstream of Sibu Laut River and station 2 was located at Loba Kilong River near to the Sibu Laut Village. Station 3, 4, 5, and 6 were located along the western boundary of the KWNP which is also the main river of Sibu Laut until the most upper reaches of the river. Station 3 was located near to the Telaga Air town and a public jetty; and station 4 was close to a shrimp farm.

Sampling Techniques

Sub-surface and near-bottom water samples were collected during low tide for three different sampling periods (May, July, and September) in year 2010. Portable Global Positioning System (GPSMAP® 76CSx, GARMIN) was used to determine the actual coordinates of the sampling stations and to re-confirm the location of the stations during subsequent sampling periods. Water depth and river width were measured using a depth sounder (PS-7, Hondex) and a range finder (Elite 1500, Bushnell) while physico-chemical parameters including salinity, pH, temperature, dissolved oxygen (DO), and turbidity were measured using a refractometer (MR100ATC, Milwaukee), a pH meter with temperature probe (HI 8424, Hanna), a DO meter (HI 9142, Hanna), and a turbidity meter (HI 93703, Hanna), respectively. Three replicates of water

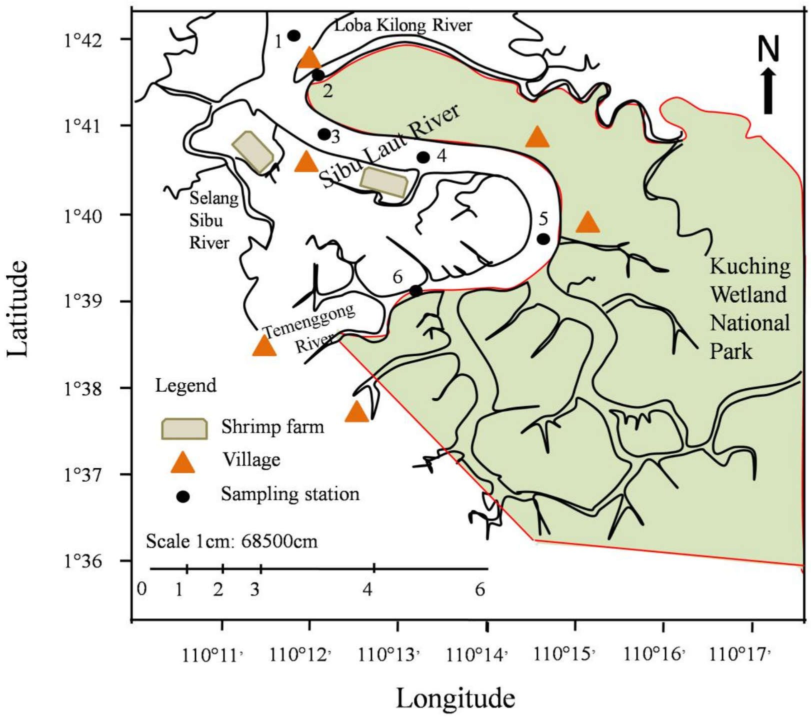

Figure 1. Study area and sampling stations.

samples were taken from the sub-surface (≈ 1 m below surface water) and near-bottom (≈ 1 m above river bed) of the water column by using a two-litre Wildco® Van Dorn water sampler for the determination of chlorophyll *a*, total suspended solids, and phosphorus (total phosphorus, inorganic phosphorus, and organic phosphorus). Water samples were placed in iceboxes and transported to the laboratory for immediate analysis (Jenkins *et al*., 2005; Parsons *et al*., 1984).

Analytical Techniques

Concentrations of chlorophyll *a* were determined from triplicate samples filtered through 0.7 µm Whatman GF/F filters and extracted for 24 hours using 90% (v/v) aqueous acetone. Total suspended solids were assayed by filtration of an adequate sample volume through 0.7 µm Whatman GF/F filter paper and dried at 105°C. The filtered water samples were then used to determine phosphorus concentrations. Inorganic phosphorus was determined by colorimetric ascorbic acid method by using a spectrophotometer (DR2800, Hach) at wavelength 880 nm while total phosphorus was determined as inorganic phosphorus after acid digestion of samples. The concentration of organic phosphorus was calculated by the difference of total phosphorus and inorganic phosphorus. All phosphorus concentration was expressed as mg PO_4^{3-} l^{-1} in the present study (Jenkins *et al*., 2005; Parsons *et al*., 1984).

Statistical Analysis

The Wilcoxon sign-rank test was used to compare the physico-chemical parameters of sub-surface and near-bottom water samples. The Spearman rank correlation was used to determine the relationship between phosphorus and chlorophyll *a*. All null hypotheses were rejected at p value ≤ 0.05 unless stated otherwise.

RESULTS

General Physico-chemical Parameters

Table 1 summarises the mean, standard deviation, minimum, and maximum values of 12 physico-chemical parameters along the western boundary of Kuching Wetland National Park during low tide. The water depth of the boundary ranged from 4.8 ± 0.9 m to 22.0 ± 3.8 m during low tide. The deepest area was observed at station 1 (sea boundary) and the shallowest segment was at station 2 (Loba Kilong River). The river width ranged from 177.4 ± 17.3 m to 613.7 ± 43.9 m. The widest segment was at station 4 while the narrowest was at station 2. Salinity, temperature, pH, and DO in the water are rather consistent at all stations collected during the three sampling periods. Mean values of salinity, pH, DO, and temperature are 28.0 ± 0.9 ppt, 7.75 ± 0.16, 4.49 ± 0.13 mg O_2 l^{-1}, and 29.8 ± 0.2°C, respectively.

Table 1. Mean, standard deviation (SD), minimum (min), and maximum (max) values of the physico-chemical parameters along the boundary of Kuching Wetland National Park for three sampling periods (May, July, and September) in 2010. N = 6.

Parameters	Mean	SD	Min	Max
Depth, m	13.5	6.1	4.8	22.0
Width, m	445.8	178.2	177.4	613.7
Salinity, ppt	28.0	0.9	26.6	29.2
Temperature, °C	29.8	0.2	29.6	30.0
pH	7.75	0.16	7.52	7.96
Dissolved Oxygen, mg l^{-1}	4.49	0.13	4.27	4.61
Turbidity, NTU	6.37	3.26	2.94	11.1
Total Suspended Solids, mg l^{-1}	29.8	8.7	20.9	40.6
Total Phosphorus, mg l^{-1}	0.029	0.004	0.022	0.034
Inorganic Phosphorus, mg l^{-1}	0.008	0.001	0.006	0.008
Organic Phosphorus, mg l^{-1}	0.021	0.004	0.014	0.026
Chlorophyll *a*, mg m^{-3}	0.8	0.2	0.6	1.1

Near-bottom salinity steadily increased along the river towards the river mouth. The trend was less apparent for sub-surface salinity (Figure 2). Lower salinity was due to input of freshwater at the upper reaches of the river while the high salinity was due to seawater intrusion from the South China Sea during high tide. Sub-surface salinity was significantly lower than those near-bottom values at all stations (Table 2, p value $\leq$ 0.05) except station 4 (p value > 0.05). However, salinity variation between sub-surface and near-bottom water column was differed among stations. Noticeable variation between sub-surface and near-bottom salinity was observed at downstream as shown in Figure 2. Salinity in the near-bottom water was 30.0 ± 1.0 ppt at station 1 while the sub-surface salinity was 28.3 ± 1.5 ppt. The mean difference of salinity between sub-surface and near-bottom water column at upper reaches of the river was less than 1 ppt (Table 2).

The pH values of the water were found in the range of 7.52 ± 0.28 to 7.90 ± 0.26 and 7.53 ± 0.29 to 8.01 ± 0.24 for sub-surface and near-bottom water columns, respectively. The pH increased towards the river mouth except slightly lower pH at station 2 which is located at the confluence of the Sibu Laut River and Loba Kilong River (Figure 2). Wilcoxon sign-rank test indicated that sub-surface pH was significantly lower than near-bottom values at all station (Table 2, p value $\leq$ 0.05).

Dissolved oxygen profiles throughout the Sibu Laut River were generally well aerated, ranging from 4.26 to 4.79 mg O_2 l^{-1}. Sub-surface DO was significantly higher at station 2, whereas near-bottom DO was significantly higher at station 4 (Table 2, p value $\leq$ 0.05). The study area had minimal temperature difference between sub-surface and near-bottom water columns (Figure 2). Temperature of the sub-surface water was 30.0 ± 0.2ºC while 29.7 ± 0.2ºC at near-bottom water. There was only 0.3ºC difference between the sub-surface and near-bottom water. Wilcoxon sign-rank test indicated that sub-surface temperature was significantly higher than near-bottom temperature at stations 3, 4, 5, and 6 (Table 2, p value $\leq$ 0.05).

Similar to salinity and pH, water turbidity increased towards river mouth from 2.99 ± 1.40 NTU to 8.48 ± 0.26 NTU and 2.90 ± 1.53 NTU to 13.76 ± 7.40 NTU for sub-surface and near-bottom water columns, respectively. Near-bottom water was more turbid at downstream. Wilcoxon sign-rank test also indicated that near-bottom turbidity was significantly higher than sub-surface values at stations 1, 2, and 3 (Table 2, p value $\leq$ 0.05). Total suspended solids in the study area ranged from 21.5 ± 7.65 mg l^{-1} to 29.7 ± 8.63 mg l^{-1} and 20.3 ± 5.08 mg l^{-1} to 53.3 ± 29.16 mg l^{-1} for sub-surface and near-bottom water, respectively. Figure 2 shows that near-bottom total suspended solids were steadily increasing towards downstream direction while total suspended solids in the sub-surface water were rather consistent at all stations. Total

Table 2. Summary of Wilcoxon sign-rank test and mean differences of 10 physico-chemical parameters between sub-surface and near-bottom water of six stations along the boundary of Kuching Wetland National Park for May, July, and September in 2010.

Parameter	Station					
	1	2	3	4	5	6
Salinity, ppt	(-1.67)**	(-1.33)**	(-1.00)**	NS	(-0.67)*	(-0.44)**
Temperature, °C	NS	NS	(+0.27)**	(+0.64)**	(+0.59)**	(+0.30)**
pH	(-0.11)**	(-0.13)**	(-0.09)**	(-0.03)**	(-0.03)**	(-0.01)*
Dissolved Oxygen, mg l^{-1}	NS	(+0.17)**	NS	(-0.23)**	NS	NS
Turbidity, NTU	(-6.01)*	(-5.28)*	(-3.40)*	NS	NS	(+2.08)*
Total Suspended Solids, mg l^{-1}	(-26.3)**	(-21.7)**	(-10.0)**	(-3.7)**	NS	NS
Total Phosphorus, mg l^{-1}	NS	(+0.020)**	NS	(-0.018)**	NS	NS
Inorganic Phosphorus, mg l^{-1}	NS	NS	NS	NS	(-0.003)**	(-0.001)*
Organic Phosphorus, mg l^{-1}	NS	(+0.020)**	NS	(-0.017)**	NS	NS
Chlorophyll *a*, mg m^{-3}	NS	NS	NS	(+0.2)**	(+0.3)**	NS

NS = No significant difference.
Mean difference between surface and near-bottom values are shown in parentheses. + indicates surface value averaged higher; - indicates bottom value averaged higher. N = 3.
Wilcoxon significance values: * p value $\leq$ 0.10, ** p value $\leq$ 0.05

suspended solids in the sub-surface water at downstream varied greatly at station 1, 2, and 3. The most distinct variations were observed at station 1 and station 2. Near-bottom total suspended solids were significantly higher than sub-surface total suspended solids from station 1 to station 4 (Table 2, p value ≤ 0.05).

Phosphorus

Total phosphorus in the study area ranged from 0.020 ± 0.009 mg l^{-1} to 0.043 ± 0.033 mg l^{-1} and 0.023 ± 0.007 mg l^{-1} to 0.037 ± 0.016 mg l^{-1} for sub-surface and near-bottom water, respectively. Elevated sub-surface total and organic phosphorus were observed at station 2 whereas higher near-bottom total and organic phosphorus were found at stations 3, 4, 5, and 6. Phosphorus in the water column was mainly organic phosphorus, which constituted more than 70% of the total phosphorus. Organic phosphorus in the water column contributed 59.76% to 83.64% and 62.50% to 78.67% of total phosphorus for sub-surface and near-bottom water, respectively. Wilcoxon sign-rank test indicated that sub-surface total phosphorus and organic phosphorus were significantly higher than near-bottom values at station 2 (Table 2, p value ≤ 0.05). The concentration of near-bottom total phosphorus and organic phosphorus at the remaining stations were relatively higher as compared to the sub-surface water (Figure 3). The near-bottom total phosphorus and organic phosphorus were significantly higher than sub-surface water column at station 4 (Table 2, p value ≤ 0.05). Inorganic phosphorus was extremely low at most of the stations, ranging from 0.004 ± 0.002 mg l^{-1} to 0.008 ± 0.005 mg l^{-1} and 0.008 ± 0.005 mg l^{-1} to 0.009 ± 0.004 mg l^{-1} for sub-surface and near-bottom water, respectively.

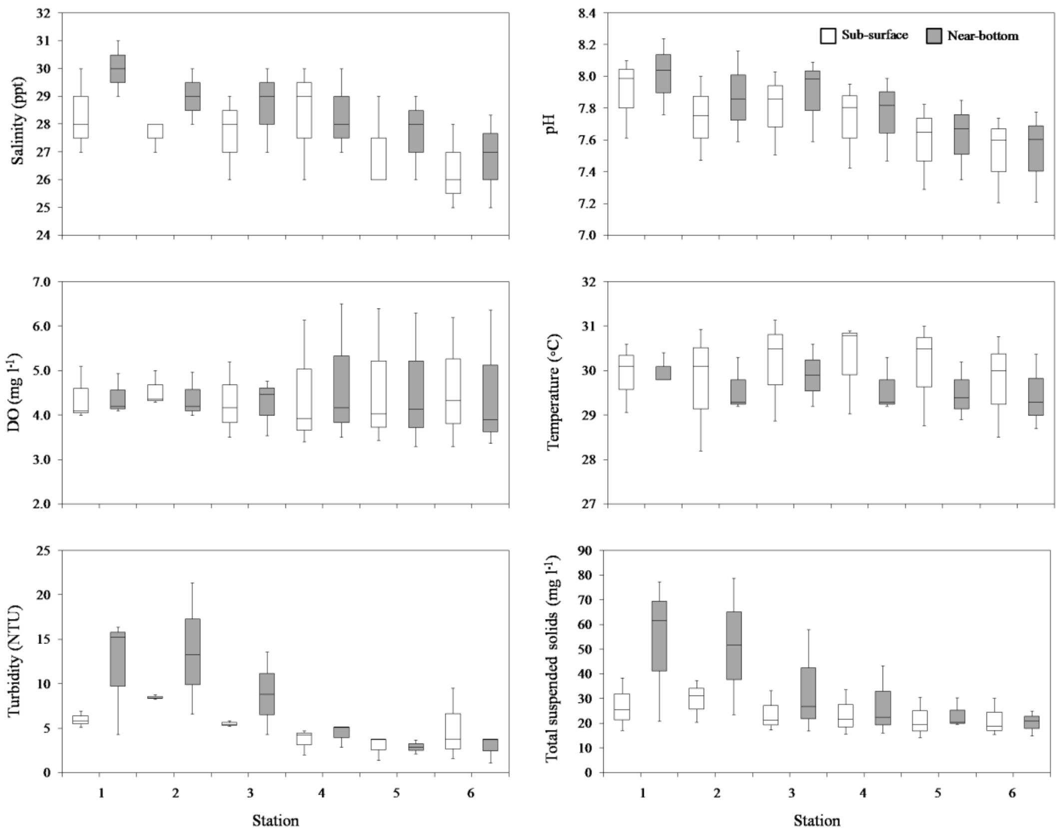

Figure 2. Box-and-whisker plots of physico-chemical parameters that discriminate among the sub-surface and near-bottom water columns of the study area (N = 9).

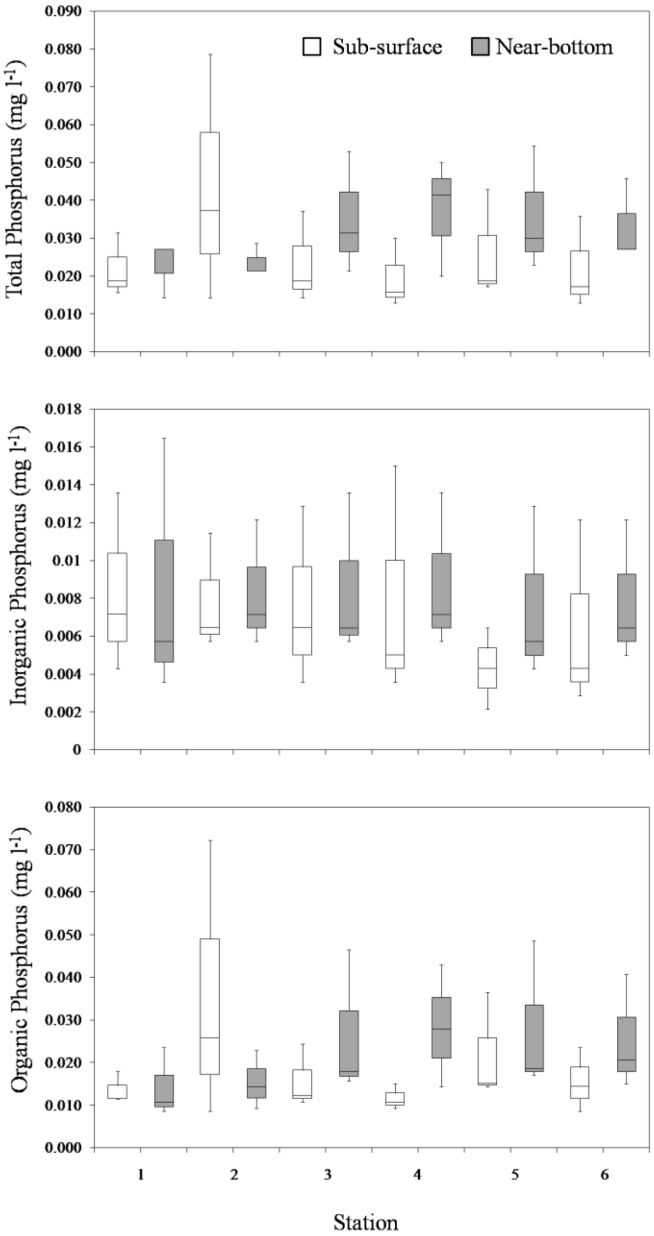

Figure 3. Box-and-whisker plots of phosphorus that discriminates among the sub-surface and near-bottom water columns of the study area (N = 9).

Chlorophyll *a*

Mean values of chlorophyll *a* in the study area ranged from 0.7 ± 0.3 mg m^{-3} to 1.1 ± 0.4 mg m^{-3} and 0.5 ± 0.3 mg m^{-3} to 1.0 ± 0.7 mg m^{-3} for sub-surface and near-bottom water, respectively (Figure 4). The highest mean value of chlorophyll *a* was recorded at station 2 for both sub-surface (1.0 ± 0.4 mg m^{-3}) and near-bottom (1.0 ± 0.7 mg m^{-3}) water columns, respectively. Table 2 shows that sub-surface chlorophyll *a* at station 4 and station 5 were significantly higher than near-bottom chlorophyll *a* (p value $\leq$ 0.05). Analysis of Spearman rank correlation indicated that there was no significant correlation between sub-surface phosphorus and sub-surface chlorophyll *a* (Table 3, p value > 0.05). Table 4 shows that there are strong negative correlations of near-bottom chlorophyll *a* with total phosphorus (r = -0.886, p value = 0.019) and organic phosphorus (r = -0.928, p value = 0.008).

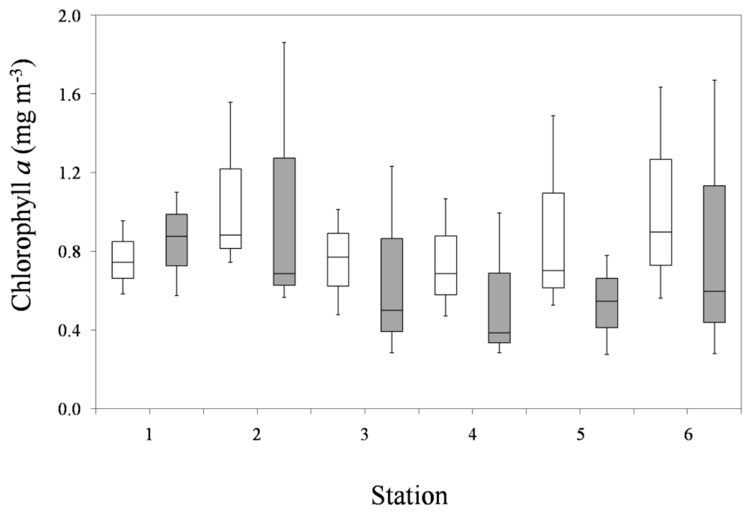

Figure 4. Box-and-whisker plots of chlorophyll *a* that discriminates among the sub-surface and near-bottom water columns of the study area (N = 9).

Table 3. Spearman rank correlation matrix among the chlorophyll *a* and phosphorus species in sub-surface water column of Sibu Laut River and tributaries for May, July, and September in 2010 (N = 6).

	Chlorophyll *a*	Total phosphorus	Inorganic Phosphorus	Organic Phosphorus
Chlorophyll *a*	1.000			
Total phosphorus	0.667	1.000		
Inorganic Phosphorus	-0.372	-0.189	1.000	
Organic Phosphorus	0.714	**0.986**	-0.270	1.000

*Significant values (p value ≤ 0.05) are indicated in bold.

Table 4. Spearman rank correlation matrix among the chlorophyll *a* and phosphorus species in near-bottom water column of Sibu Laut River and tributaries for May, July, and September in 2010 (N = 6).

	Chlorophyll *a*	Total phosphorus	Inorganic Phosphorus	Organic Phosphorus
Chlorophyll *a*	1.000			
Total phosphorus	**-0.886**	1.000		
Inorganic Phosphorus	-0.098	0.098	1.000	
Organic Phosphorus	**-0.928**	**0.986**	0.000	1.000

*Significant values (p value ≤ 0.05) are indicated in bold.

DISCUSSION

Degradation of wetlands has been noticeable for decades. Deterioration in water quality is one of the greatest concerns associated with population growth and accompanying land-use changes. Kuching Wetland National Park which is surrounded by various villages and shrimp farms makes it vulnerable to human activities and susceptible to water quality degradation. This study described the sub-surface and near-bottom water quality of Sibu Laut River which forms the western boundary of Kuching Wetland National Park. Salinity, pH, turbidity, and total suspended solids were significantly higher at the near-bottom water than sub-surface water at most of the stations. In contrast, temperature of sub-surface water was significantly higher than near-bottom water. It is important to note that the differences, while consistent, were small to minimal relative to the values observed. For example, temperature exhibited a mean difference of 0.64°C or less between sub-surface and near-bottom water columns (Table 2). This is probably attributable to slight diurnal stratification due to solar heating of sub-surface water. The strong tidal currents cause the significantly higher turbidity and total suspended solids values in the near-bottom water column at the downstream. Interestingly, there was no significant difference between sub-surface and near-bottom temperature at the deepest station (station 1).

Phosphorus is an important element that contributes significantly to agricultural and industrial development, mainly in the use as agricultural fertilisers, animal feed additions, detergents and metal treatment (Ashley *et al*., 2011; Smit *et al*., 2009). However, discharges of agricultural and industrial effluents with excessive phosphorus will deteriorate water quality and cause eutrophication (Braga *et al*., 2000; Hart *et al*., 2004; Huang *et al*., 2003; Jarvie *et al*., 2006). In the present study, measurements of phosphorus concentration revealed sub-surface total phosphorus and organic phosphorus enrichment at station 2. Since station 2 is near to Sibu Laut Village, the elevated phosphorus concentration maybe due to the wastewater discharged from the village. Phosphorus is an important component of domestic detergents as Ling *et al*. (2010) reported high loading of reactive phosphorus from the household wastewater into rivers in Kuching, Sarawak. Troussellier *et al*. (2004) demonstrated that orthophosphate increased in the vicinity of wastewater disposal area in front of the hospital near Senegal River Estuary while Huang *et al.* (2003) suggested that the land based pollutants near Shenzhen Bay greatly contributed to the increased phosphate concentration in that area. Organic phosphorus concentration in the sub-surface water at station 2 was significantly higher (p value ≤ 0.05) compared to the near-bottom concentration. This further supported the fact that sub-surface water was influenced by the domestic wastewater discharged from the village of Sibu Laut.

Station 3 and station 4 were located near to Telaga Air town, jetty and shrimp farm. No elevated sub-surface organic and inorganic phosphorus concentrations were found at station 3 and station 4 compared to other stations. Station 3 and station 4 were located at the main river of Sibu Laut which is wider and deeper compared to station 2 which is located at the tributary of Sibu Laut River. Hence, the wastewater discharged from the jetty and shrimp farm did not deteriorate the sub-surface water quality of Sibu Laut River. Nevertheless, higher near-bottom total phosphorus and organic phosphorus were observed at stations 3, 4, 5, and 6. The near-bottom total phosphorus and organic phosphorus were significantly higher than sub-surface water column at station 4 suggesting that phosphorus from the shrimp farm effluents maybe accumulated in the sediment and re-suspended to the near-bottom water column (Pomeroy *et al*., 1965).

Phosphorus is one of the nutrients most likely to limit the rate of phytoplankton production (Xu *et al*., 2008). The present study showed that organic phosphorus may play an important role in controlling primary productivity in Sibu Laut River. Spearman rank correlation calculated for the whole Sibu Laut River showed a close relationship between chlorophyll *a* and organic phosphorus concentration for near-bottom water column. The negative correlation between organic phosphorus and chlorophyll *a* at the near-bottom water column suggested that it was rapidly utilised by the phytoplankton community.

Overall, the phosphorus concentration of Sibu Laut River monitored in this study meets the Malaysia Marine Water Quality Criteria and Standard for mangroves estuarine and river-mouth waters (class E), which is 75 µg l^{-1} for phosphate (Department of Environment, 2014). Besides, the chlorophyll *a* concentration is considered as Class I or 'very good', and equated to oligotrophic and/or mesotrophic status as values of all the chlorophyll *a* were lower than 2 mg m^{-3} (Molvaer *et al*., 1997; Smith *et al*., 1999). Sibu Laut River as the western boundary of Kuching Wetland National Park had minimal pollution impact to the wetland except the elevated sub-surface organic phosphorus concentration near the Sibu Laut Village and elevated near-bottom organic phosphorus near the shrimp farm. Regular monitoring is necessary to guarantee a sustainable use of water resources in the Sibu Laut River and to minimise the eutrophication risk to the Kuching Wetland National Park.

CONCLUSION

This study provides baseline information on the water quality of Sibu Laut River for the management of the ecosystem as well as the ecosystem for the Kuching Wetland National Park, Sarawak, Malaysia. Variations of the physico-chemical parameters between sub-surface and near-bottom water columns were detectable in Sibu Laut River and due mainly to the influence of tidal currents. The phosphorus in Sibu Laut River consists mainly of organic phosphorus whereas inorganic phosphorus concentration was extremely low and nearly undetectable. Elevated sub-surface organic phosphorus concentration near Sibu Laut Village was observed in this study. No noticeable enrichment of sub-surface phosphorus was found at stations near to jetty and shrimp farm, but higher near-bottom organic phosphorus was found at those stations. Chlorophyll *a* was found to be negative correlated with total and organic phosphorus in near-bottom water of Sibu Laut River. Overall, results revealed an acceptable water quality along the Sibu Laut River according to the Malaysia Marine Water Quality Criteria and Standard. It is concluded that Sibu Laut River had minimal pollution impact to Kuching Wetland National Park.

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