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Water Quality and Aquatic Insects Study at the Lower Kinabatangan River Catchment, Sabah: In Response to Weak La Niña Event

(Kajian Kualiti Air dan Serangga Akuatik di Hilir Sungai Kinabatangan, Sabah: Respons kepada Fenomena La Niña Berskala Lemah)

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ABSTRACT

A study on water quality and aquatic insects has been conducted at the Lower Kinabatangan River Catchment, Sabah, Malaysia. The quality of water surface and aquatic insects' composition were studied in streams near to oil palm plantation (OP), secondary forest (SF) and oxbow lake (OB). The study also aims to identify the seasonal variation in the aquatic insects' composition during the weak La Niña event. A total of 135 water samples and 1678 aquatic insect individuals (four orders and 14 families) were collected during fieldwork campaign that spanned over the inter-monsoonal period, wet and dry seasons between October 2004 and June 2005. OP has the highest abundance of aquatic insects particularly during the dry season. Biological indices showed that all stations were in moderate water category. The water quality index (WQI) was calculated and indicated that the quality of the river categorised into Class II. Discriminant analysis (DA) was employed to classify the independent variables into mutually-exclusive groups. Suspended sediment (SS) and chemical oxygen demand (COD) were high during the wet season. Suspended sediment was high in oxbow lake and could be a strong reason behind low abundance of aquatic insects. Precipitation anomalies were found to affect seasonal variations of water quality and aquatic insects at the Lower Kinabatangan River.

Keywords: Aquatic insects; average score per taxa (ASPT); biological monitoring work party (BMWP); Lower Kinabatangan River catchment; water quality index (WQI)

ABSTRAK

Sebuah kajian kualiti air dan serangga akuatik telah dilakukan di Hilir Sg. Kinabatangan, Sabah, Malaysia. Kajian ini bertujuan untuk mengkaji kualiti air serta serangga akuatik dari tiga jenis guna tanah: ladang kelapa sawit (OP), hutan sekunder (SF) dan tasik ladam (OB); serta untuk mengenal pasti variasi musim sewaktu fenomena La Niña berskala lemah. Sebanyak 135 sampel air telah dianalisis dan 1678 individu serangga akuatik (empat order dan 14 famili) telah berjaya dikumpul sewaktu kerja lapangan dijalankan. Kajian dilaksanakan sewaktu musim perantara-monsun, musim hujan dan kering dari Oktober 2004 sehingga Jun 2005. OP didapati mempunyai taburan serangga akuatik yang tertinggi khususnya sewaktu musim kering. Indeks biologi menunjukkan semua stesen persampelan dikategorikan sebagai sederhana bersih. Pengiraan Indeks Kualiti Air juga turut dilakukan dan kualiti Hilir Sg Kinabatangan berada di dalam kelas II. Analisis diskriminan (DA) telah dilaksanakan bagi mengelaskan pemboleh ubah tak bersandar berdasarkan kumpulan yang sama. Sedimen terampai (SS) dan permintaan oksigen kimia (COD) mempunyai nilai yang tinggi sewaktu musim hujan. Nilai SS yang tinggi di kawasan tasik ladam berkemungkinan menjadi faktor penyumbang jumlah taburan serangga akuatik yang rendah di situ. Anomali hujan didapati mempengaruhi kualiti air dan taburan serangga akuatik mengikut variasi musim di Hilir Sg. Kinabatangan.

Kata kunci: Hilir Sungai Kinabatangan; indeks kualiti air (WQI); purata skor setiap takson (ASPT); serangga akuatik; unit kerja kawalan biologi (BMWP)

INTRODUCTION

Tropical floodplains play a significant role in providing highly productive ecosystem services (Pettit et al., 2011), vital to a range of ecosystem processes (Hamilton 2002). They are mainly characterised by seasonal inundation (Hamilton 2002; Mayora et al. 2013), received high solar radiation (Saigusa et al. 2008) and rich in biodiversity (Bruford et al. 2010). However, deforestation, active land development, land conversion for mechanized agriculture such as oil palm plantations (Mercer et al. 2013), industrial and domestic waste discharge (Azrina et al. 2006) often contribute to river water quality deterioration in the tropical regions. In Malaysia, rainforest conversion to cocoa and oil palm plantations in Bukit Tekam, Pahang circa 1977 and 1986 (Douglas 1999) and Sabah (Jakobsen et al. 2007) was showed to increase surface run-off, suspended sediment loads and nutrients (i.e. nitrogen and phosphorus). Furthermore, Azrina et al. (2006) reported that oil palm plantations and sewage wastes are among the main contributors to pollutants in Langat River, while recently, Mercer et al. (2013) found that stream invertebrate community in oil palm plantations in Sarawak was less abundance and diverse compared to rainforest streams.

There is always growing interest among the aquatic ecologists to understand the relationship between river water quality and the distribution and diversity of aquatic insects with the possibility to use the aquatic insects as bioindicators for streams water quality and ecosystem functioning and integrity (Bonada et al. 2006). These changes in the aquatic habitats are connected to the anthropogenic activities (Al-Shami et al. 2011, 2010; Boyero et al. 2009; Che Salmah et al. 2013; Dudgeon 2006). Therefore, human activities such as logging, agricultural activities and road construction change physical and chemical characteristics of the streambeds such as deposition input and sedimentation (Che Salmah et al. 2013). Ultimately, these changes in the aquatic ecosystems will affect the community structure of aquatic organisms including aquatic insects (Al-Shami et al. 2011; Dudgeon 2006).

Water quality assessment and monitoring by using physico-chemical and biological parameters have been widely used to determine the status and quality of water bodies particularly in wetland areas (Bonada et al. 2006; Spieles & Mitsch 2000). Aquatic insects has been widely used as indicators for monitoring river quality (Yoshimura 2012) due to its continuous response to a variety of perturbations, present in a wide array of aquatic habitats, relatively easy to sample and process and standardised methods of collection and analysis have been greatly progressed (Al-Shami et al. 2011; Whiles et al. 2000). Various ecological studies have highlighted the relationship between water quality and aquatic insects in Malaysia (Mohd. Rasdi et al. 2012; Wahizatul et al. 2011; Yap & Rahim 2011), while some of the recent studies reported: Effects of land use changes to aquatic insects (Al-Shami et al. 2011; Che Salmah et al. 2013; Jinggut et al. 2012; Mercer et al. 2013); seasonal variations of Ephemeroptera, Plecoptera and Trichoptera (EPT) (Suhaila et al. 2012) and influence of canopy cover and substrate embeddedness to EPT distribution (Suhaila & Che Salmah 2014). However, to date, there is still a huge gap in the knowledge of aquatic insects and ecological understanding of the tropical streams (Al-Shami et al. 2011). Nonetheless, using macroinvertebrates as bioindicators is neither popular nor widespread in the SE Asian region although this approach is proven to be simple, cheap, efficient and widely used to assess the streams quality in other parts of the world (Bonada et al. 2006). In Malaysia, few studies had highlighted application of benthic macroinvertebrates as bioindicators to assess the water quality of the contaminated rivers (Al-Shami et al. 2011; Azrina et al. 2006).

It is an acceptable fact that streams in SE Asia including those in Peninsular Malaysia and Borneo are hotspots for global aquatic biodiversity (Al-Shami et al. 2014, 2013a, 2013b; Che Salmah et al. 2014). Despite that, there is lacking in the information about the drivers of stream invertebrates diversity and distribution in relation to physical and chemical parameters of water quality. Thus, the present study highlights the spatio-seasonal variations of river water quality and aquatic insects in the Lower Kinabatangan River (LKR) Catchment, Sabah to achieve the following objectives: investigate the surface water quality and aquatic insects distribution in streams located in an oil palm plantation (OP), a secondary forest (SF) and an oxbow lake (OB); study the abundance and diversity of aquatic insects of the Lower Kinabatangan River Catchment; and identify the seasonal variability of surface water quality and aquatic insects composition.

Materials and Methods

Study Site

The Kinabatangan River is the largest and longest river in Sabah, reaching 560 km inland and has a total catchment area of 16,800 km^2 (Josephine et al. 2004). The river floodplain represents ~23% of Sabah (Boonratana 2013) and one of the most significant wetlands in Malaysia for rich diversity of biological communities (Bruford et al. 2010). The mean annual rainfall varying between 2500 and 3000 mm while mean daily temperatures ranging from 22 to 32°C (Boonratana 2000; Josephine et al. 2004). The area is characterised by seasonal inundation during the northeast monsoon (between October and March) (Harun et al. 2014). It is a complex phenomenon that common in tropical wetlands, and often caused by different water sources through numerous pathways (Tockner & Stanford 2002).

In the early 1950s until 1987, the Lower Kinabatangan was subjected to commercial logging activity (Boonratana 2000) and more than 60000 ha of the lowland rainforest in the flood-free zone of this area had been converted to cocoa and oil palm plantations (Boonratana 2000). In 2007, the area cultivated with oil palm in the Kinabatangan District accounted for about 28% (217,949 ha) of the total oil palm areas in Sabah (Norwana et al. 2011).

Surface Water Quality

Water samples were collected from streams in the Lower Kinabatangan River Catchment in Sandakan, Sabah. Sampling stations were located at Sukau area and included sites that were selected based on three types of land use and their accessibility: Sg. Resang (oil palm plantation: OP) (05° 32' 906" N, 118° 20' 230" E), Sg. Lumun (secondary forest: SF) (05° 32' 542" N, 118° 18' 513" E) and Danau Kalinanap (ox-bow lake: OB) (05° 29' 182" N, 118° 15' 785" E) (Figure 1).

Water quality physico-chemical parameters (total dissolved solids (TDS), pH, temperature, dissolved oxygen (DO) and conductivity) were measured *in situ* in the inter-monsoonal period (October 2004), wet season (December 2004 and February 2005) and dry season (June 2005 and August 2005) by using a water quality multiprobe meter (YSI 6000 model). Within each area, a total of 135 samples

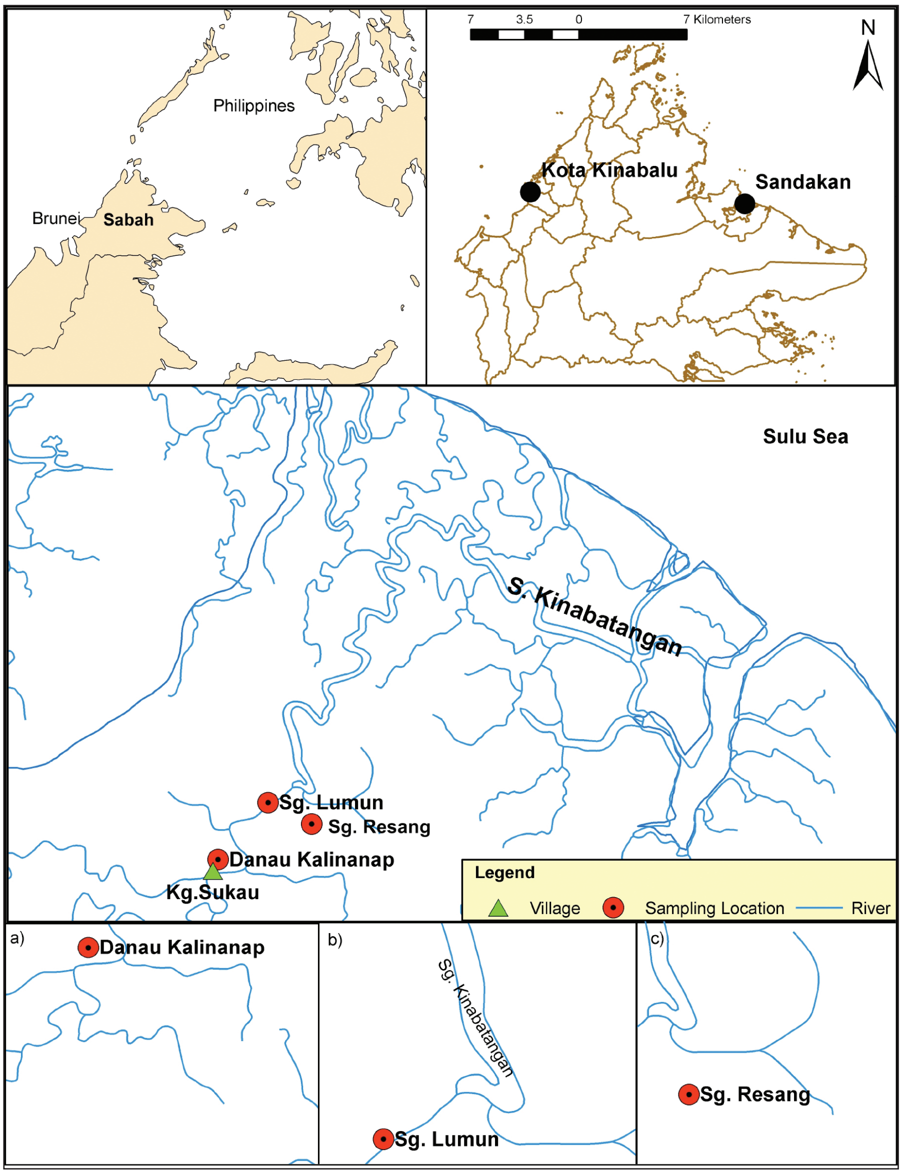

FIGURE 1. The location of sampling stations (circles) at the Lower Kinabatangan River Catchment

were collected in 200 mL high-density-polyethylene (HDPE) bottles pre-washed with 10% hydrochloric (HCl) acid and deionised water. Water samples were filtered immediately after sampling using a pre-combusted glass-fibre filter and kept in dark at 4°C.

At each sampling station, water samples were obtained near the surface. Samples for chemical oxygen demand (COD) analysis were mixed with reagents for COD in a glass cell and digested with Merck Thermoreactor Model TR 320 at 148°C for 2 h. After digestion, the sample was cooled to room temperature. Both Ammonia nitrogen (NH_3-N) and COD were determined by the photometric methods using Merck Spectroquant NOVA 60; the methods being analogous to EPA standards (EPA 1993). Suspended sediment (SS) and biochemical oxygen demand (BOD) were determined in the laboratory by using Gravimetric and Winkler's methods respectively (APHA 1992).

WATER QUALITY INDEX (WQI)

Parameters for Water Quality Index (WQI) consisted of DO, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen, SS and pH were calculated based on a standard formula for each parameters (Department of Environment Malaysia 2012). In this study, WQI was determined only during the wet and dry seasons. Best-fit equations were used to convert the values to the sub-indices (SIs) and then aggregated to calculate the WQI:

$$WQI = 0.22(SIDO) + 0.19(SIBOD) + 0.16(SICOD) + 0.15(SIAN) + 0.16(SISS) + 0.12(SIpH) \quad (1)$$

where, SIDO = Sub-index DO; SIBOD = Sub-index BOD; SICOD = Sub-index COD; SIAN = Sub-index $NH^{3-}N$; SISS = Sub-index SS; and SIpH = Sub-index pH.

The WQI classification according to water usage and consumption is shown in Table 1.

AQUATIC INSECTS

Aquatic insects were collected at the same stations for surface water samples by using a D-frame aquatic net (mesh size 250 µm) against water current and dragged along the riverbank up to a distance of 1 m (Alakananda et al. 2011). Thereafter, samples were placed into a white pan with sufficient water. Leaves, twigs and other large debris were washed off and discarded. Aquatic insects were sorted at the field and placed in universal bottles containing 80% ethyl alcohol (Merritt & Cummins 1984). Samples were labelled with date of sampling, location and a brief description of habitat type. The identification of aquatic insects was done in the laboratory and was up to family level.

In this study, the Biological Monitoring Work Party (BMWP) and the Average Score Per Taxa (ASPT) were used to calculate the biotic indices for the aquatic insect community. It is based on measures of the relative abundance of various taxa present or available at site and the associated tolerance value of these taxa combined in order to produce a numerical score (Canfield et al. 1998). Modified BMWP and ASPT scores from Thailand were initiated in 2002 due to the absence of taxa in the standard BMWP, while several other taxa that present might be a good prospect as useful indicators (Mustow 2002). Therefore, standard BMWP and ASPT have been compared with $BMWP^{THAI}$ and $ASPT^{THAI}$ to see the potential of applying the modified scores in the LKR.

STATISTICAL ANALYSIS

Paired sample t-test and discriminant analysis (DA) were employed to the precipitation and water quality data sets, respectively, by using statistical package SPSS version 21.0. In corresponding to weak La Niña event in 2005/2006, a paired sample t-test was applied to compare the significant differences between precipitation in 2005 and 2000 until 2010. 10 years span of precipitation data were obtained from the Meteorological Department in Kota Kinabalu, Sabah. Discriminant analysis (DA) was employed to discriminate the water quality data according to the type of land use and the seasonal variations into mutually-exclusive clusters in LKR. The canonical correspondence analysis (CCA) of CANOCO program (ter Braak 1989; ter Braak & Prentice 1988) was applied to explore the relationship between water quality variables and aquatic insects data in LKR (log(X+1)). The Monte-Carlo permutation tests (999 permutations) was applied to test the significance of the produced canonical axes at $p<0.05$.

RESULTS

WEAK LA NIÑA EVENT 2005/2006

Table 2 presents the significant values for the paired sample t-test between precipitation in 2005 and 2000 until 2010 (10 years span). Significant differences in precipitation data were found between 2005 and 2000; 2005 and 2001;

TABLE 1. Classification and status of water quality based on WQI calculation (Department of Environment Malaysia 2004)

WQI (Class)	Category	Classification in terms of water usage
0-25 (V)	Very bad	Extensive treatment is required
26-50 (IV)	Bad	Irrigation
51-70 (III)	Medium	Recreational use with body contact
71-90 (II)	Good	Water supply – conventional treatment required
91-100 (I)	Excellent	Conservation of natural environment. Water supply – practically no treatment necessary except disinfection or boiling

TABLE 2. Paired two-sample t-test to compare the significant differences between precipitation in 2005 and within 10 years span

Year	*p* value
2005 and 2000	0.01*
2005 and 2001	0.04*
2005 and 2002	0.17
2005 and 2003	0.10
2005 and 2004	0.31
2005 and 2006	0.05
2005 and 2007	0.07
2005 and 2008	0.01*
2005 and 2009	0.09
2005 and 2010	0.45

*Significant at $p < 0.05$

as well as 2005 and 2008 which possibly corresponded to the weak La Niña event in 2005/2006.

SURFACE WATER QUALITY

Table 3 summarises of the surface water quality data of the LKR during the inter-monsoonal period (October 2004), wet (December 2004 and February 2005) and dry seasons (June and August 2005). The COD values were consistently high at all sampling stations during the wet season. However, BOD concentrations were high in OB during the dry season and also found higher in two sampling stations (OP and SF) during the wet season. As regards to Malaysia Interim National Water Quality Standards (INWQS), COD was categorised in a range of Class III to IV, while BOD in Class II (Department of Environment 2009). Other physico-chemical parameters such as suspended sediment (SS) and ammonia nitrogen (NH_3^-N) were categorised in Class II. Table 4 presents the water quality classification based on INWQS in Malaysia and the definition for each class.

Figure 5 exhibits seasonal variations of surface water samples during the inter-monsoonal period, wet and dry seasons. It was found that suspended sediment and ammonia nitrogen (NH_3^-N) were significant during the dry season, which characterised by precipitation anomaly. Inversely, both total dissolved solids (TDS) and conductivity were high in the wet season cluster. In terms of spatial differences, surface water of the Lower Kinabatangan River exhibit remarkable variations according to different types of land use, which presented by discriminant functions (Figure 4). It has been found that COD was high in oil palm plantations (OP), while SS was high in oxbow lake (OB).

Table 5 presents the WQI for each sampling station which consisted of water quality data in the wet and dry seasons. WQI mean values for each sampling station were not significantly different: OP (81.8), SF (81.9) and OB (81.7). All sampling stations were categorised in Class II with implication that the water is suitable for human consumption with conventional treatment. It also can be used for recreational purposes with body contact (Zainudin 2010).

COMPOSITION AND DISTRIBUTION OF AQUATIC INSECTS

A total of 1678 individuals comprising four aquatic insect orders and 14 families were identified. Hemiptera was the dominant order as it accounted for six family and made up 43% of the total number of aquatic insects collected. Odonata with two families accounted for 14.3% of the total number aquatic insects in LKR. However,

TABLE 3. Summary of the surface water quality data in the Lower Kinabatangan River Catchment during the inter-monsoonal, wet and dry seasons (standard deviation values in parentheses)

Sampling station	pH	DO (mg/L)	Temperature (°C)	TDS (mg/L)	Conductivity (µS/cm)	Salinity (%)	SS (mg/L)	NH_3–N (mg/L)	BOD (mg/L)	COD (mg/L)
Inter-monsoonal (Oct. 2004)										
Sg. Resang (OP)	5.3 (0.6)	6.1 (0.6)	27.4 (0.2)	134 (53.2)	206.8 (81.4)	0.10 (0.04)	47.0 (22.3)	0.46 (0.01)	**	**
Sg. Lumun (SF)	5.2 (0.1)	5.1 (0.4)	25.6 (0.0)	43 (0.3)	66.2 (0.4)	0.03 (0.0)	50.0 (22.0)	0.10 (0.02)	**	**
Danau Kalinanap (OB)	7.0 (0.1)	1.9 (0.5)	28.8 (0.1)	57 (0.4)	88.0 (0.9)	0.04 (0.0)	60.0 (15.1)	0.13 (0.03)	**	**
Wet season (Dec. 2004 and Feb. 2005)										
Sg. Resang (OP)	5.3 (0.6)	6.2 (0.4)	26.7 (0.5)	69 (6.3)	110.8 (11.8)	0.05 (0.01)	33.0 (13.9)	0.11 (0.06)	2.1 (0.9)	100.0 (8.7)
Sg. Lumun (SF)	5.8 (0.6)	5.6 (0.5)	25.4 (0.5)	34 (14.4)	52.9 (21.6)	0.01 (0.0)	49.0 (12.3)	0.05 (0.02)	3.2 (1.2)	51.4 (14.8)
Danau Kalinanap (OB)	6.7 (0.4)	3.6 (1.5)	27.1 (1.2)	50 (12.0)	76.9 (18.1)	0.03 (0.0)	96.0 (25.0)	0.11 (0.04)	3.1 (1.2)	45.8 (7.3)
Dry season (June and Aug. 2005)										
Sg. Resang (OP)	6.5 (0.1)	4.3 (1.6)	29.2 (0.4)	75 (15.5)	236.5 (124.1)	**	42.0 (16.8)	0.11 (0.04)	1.3 (0.4)	53.8 (21.3)
Sg. Lumun (SF)	6.7 (0.2)	3.5 (0.6)	27.9 (1.1)	60 (2.3)	175.3 (106.5)	**	75.0 (44.8)	0.26 (0.14)	2.9 (1.0)	36.8 (10.8)
Danau Kalinanap (OB)	6.6 (0.1)	4.1 (0.2)	29.0 (0.1)	61 (14.4)	180.9 (111.1)	**	49.0 (33.5)	0.13 (0.05)	3.6 (3.0)	35.1 (16.1)

** - Data not available

TABLE 4. Interim National Water Quality Standard (INWQS) in Malaysia and the definition for each class (after Zainudin 2010)

*Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
pH		6.5-8.5	6.5-9.0	6.5-8.5	5.0-9.0	5.0-9.0	-
DO	mg/L	7	5-7	5-7	3-5	< 3	< 1
Temperature	ºC	-	Normal + 2ºC	-	Normal + 2ºC	-	-
TDS	mg/L	500	1000	-	-	4000	-
Conductivity	µS/cm	1000	1000	-	-	6000	-
Salinity	%	0.5	1	-	-	2	-
SS	mg/L	25	50	50	150	300	300
AN	mg/L	0.1	0.3	0.3	0.9	2.7	> 2.7
BOD	mg/L	1	3	3	6	12	> 12
COD	mg/L	10	25	25	50	100	> 100

*Physico-chemical parameters presented in this study

Definition and beneficial use for each class:

Class I — Conservation of natural environment
Water supply I - Practically no treatment necessary (except by disinfection or boiling only)
Fishery I - Very sensitive aquatic species

Class IIA — Water supply II - Conventional treatment required
Fishery II - Sensitive aquatic species

Class IIB — Recreational use with body contact

Class III — Water supply III - Extensive treatment required
Fishery III - Common of economic value, and tolerant species; livestock drinking.

Class IV — Irrigation

Class V — None of the above

TABLE 5. Water Quality Index (WQI) for each sampling site

WQI Subindex	Sg. Resang (OP)	Sg. Lumun (SF)	Danau Kalinanap (OB)
SIDO	100	100	100
SIBOD	91.8	87.0	84.9
SICOD	36.3	50.8	55.9
SISS	77.9	68.2	60.0
SIAN	85.6	85.3	88.0
SIpH	93.2	96.3	98.7
WQI	81.8	81.9	81.7

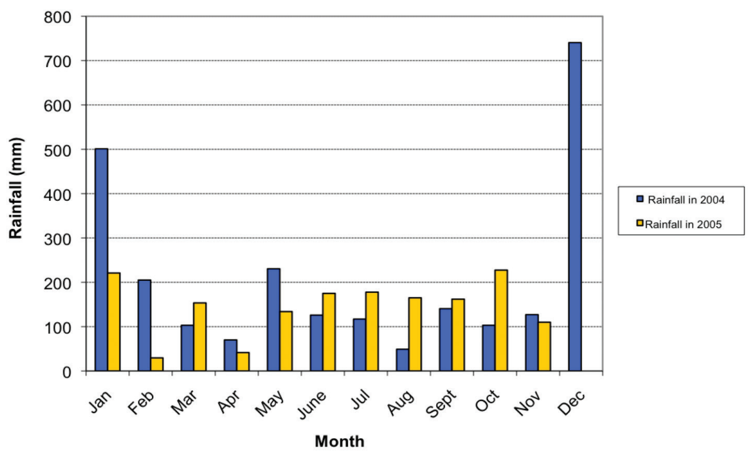

FIGURE 2. Rainfall data at the Kota Kinabatangan during the sampling campaign. (Source: Meteorological Department, Kota Kinabalu, Sabah)

coleopterans were less presented with only one family and comprised 0.1% of the aquatic insects community in LKR (Table 6).

In general, the hemipteran gerrid was dominant and were found at all sampling stations and throughout the sampling campaign. They formed the highest density up to

593 individuals in secondary forest (SF). Overall, they also represented the highest abundance in all stations surveyed with 1355 individuals comprising 81% of the total insects collected. This followed by Corixidae (253 individuals) and Coenagrionidae (36 individuals) from orders of Hemiptera and Odonata, respectively.

INFLUENCE OF WATER QUALITY PARAMETERS ON ABUNDANCE OF AQUATIC INSECTS

Canonical correspondence analysis (CCA) indicated that the total extent variation or total inertia (TI) in aquatic insects abundance had an eigenvalue of 2.541; eigenvalues of the eight water quality physico-chemical parameters explained 13.7% of the total variance (TVE) (Table 7). The CCA biplot is shown in Figure 3. The first CCA axis consisted of DO, BOD and COD. However, the second CCA axis consisted pH, temperature, TSDS and SS. The CCA output indicated that the families of Naucoridae, Macrovellidae and Nymphomyidae preffered high concentrations of TDS and acidic environments (less pH). The families of Gerridae and Ceratopogonidae showed relative tolerance to COD, SS and elevation in the stream water temperature.

TABLE 6. Abundance and diversity of aquatic insects according to inter-monsoonal, wet and dry seasons for each sampling station: OP = Sg. Resang; SF = Sg. Lumun; and OB = Danau Kalinanap

Taxa/Order/Family	Sampling station/season								
	Inter-Monsoonal (Oct. 2004)			Wet season (Dec. 2004 & Feb. 2005)			Dry season (June & Aug. 2005)		
	OP	SF	OB	OP	SF	OB	OP	SF	OB
1. Hemiptera									
Gerridae	10	77	6	42	91	-	390	425	314
Corixidae	145	3	-	103	-	-	-	-	2
Macrovellidae	1	1	-	1	-	-	-	-	-
Naucoridae	1	-	-	-	-	-	-	-	-
Helotrephidae	-	-	-	1	-	-	-	-	-
Pleidae	-	-	-	1	-	-	-	-	-
2. Odonata									
Coenagrionidae	-	-	-	25	-	11	-	-	-
Libellulidae	-	-	-	4	-	12	-	-	-
3. Diptera									
Sciomyzidae	-	-	-	1	-	-	-	-	-
Nymphomyiidae	1	-	-	-	-	-	-	-	-
Dolichopodidae	-	-	-	1	-	-	-	-	-
Culicidae	-	-	-	-	1	-	-	-	-
Ceratopogonidae	-	2	-	-	-	-	-	-	1
4. Coleoptera									
Dytiscidae	-	-	-	4	-	1	-	-	-
TOTAL	158	83	6	183	92	24	390	425	317

TABLE 7. Correlation, eigenvalues, and variance explained for the first two axes of canonical correspondence analysis (CCA) for aquatic insect abundance (log10(X+1)) and water quality parameters in the Lower Kinabatangan River Catchment, Sabah, Malaysia. Total inertia (TI)=2.451. Sum of all canonical eigenvalues=0.349. Total variance explained (TVE= 13.73%)

Parameter	Axis 1	Axis 2
pH	-0.041	-0.239
DO (mg/L)	-0.545	0.133
Temperature (°C)	-0.013	-0.137
TDS (mg/L)	-0.060	0.468
Conductivity (µS/cm)	-0.076	0.078
SS (mg/L)	-0.064	-0.142
BOD (mg/L)	-0.107	0.096
COD (mg/L)	-0.227	-0.127
Eigenvalues	0.15	0.087
Species-environment correlations	0.606	0.633
Cumulative % variance:		
of species data	5.9	9.3
of species-environment relation	43	67.8

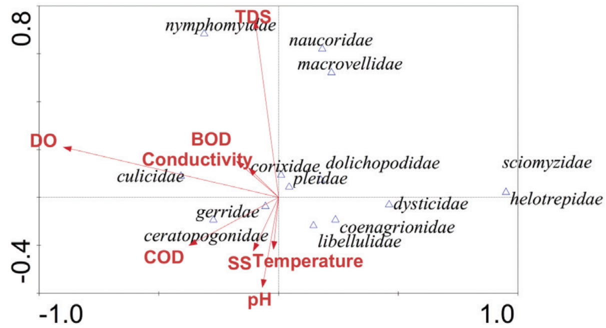

FIGURE 3. Ordination diagram (CCA) for the first two canonical axes of the water quality variables and aquatic insects abundance at the Lower Kinabatangan River Catchment

Interestingly, Culicidae showed remarkable dependence on DO. However, other families such as Dysticidae, Coenagrionidae, Corixidae and Libellulidae can tolerate deterioration in DO concentrations. The families of Corixidae, Dolichopodidae and Pleidae showed moderate tolerance to TDS but high tolerance to BOD.

BIOLOGICAL WATER QUALITY ASSESSMENT

The BMWP and ASPT values for all stations were in the moderate water quality category with slight pollution (some organic pollution probable), while both $\text{BMWP}^{\text{THAI}}$ and $\text{ASPT}^{\text{THAI}}$ relatively also indicated similar results (Table 8). It was considered that the water quality for all sampling stations was moderate. However, ASPT value for OB during the wet season indicated that the water quality of the lake was fairly clean.

DISCUSSION

PHYSICO-CHEMICAL PARAMETERS

The subindex values for suspended sediment (SS) indicated that all sampling stations were slightly polluted, which possibly due to active land development in this area. Logging activity is known to contribute sediment into the river systems (Che Salmah et al. 2013). Deforestation and poor cultivation of the catchments, particularly in the upper reaches were identified as main factors leading to the increment of sediment loads within rivers in Malaysia and throughout Southeast Asia (Pringle & Benstead 2001). The subindex values for ammonia nitrogen (AN) for all stations reflect the water as slightly polluted. With reference to the Interim National Water Quality Standards for Malaysia (INWQS), the concentration of AN in this study was low and fall into Class II. The values were still below the permissible limit where ammonia nitrogen level for rivers in Malaysia is 0.90 mg/L (Rosli et al. 2010). Sewage, fertilizers, agricultural wastes have been identified as major sources of high ammonia nitrogen concentration in rivers and streams (Ballance 1996). Subindex value for BOD was the highest at OP could be associated with oil palm mill effluent (POME). It has been estimated that BOD value for untreated POME is 25000 mg/L, which may cause severe effect to aquatic system if discharged directly into the river (Ma 1999). There are about 20 palm oil mills located at Kinabatangan area where the effluents may be directly discharged into the river through man-made channels and to the ground (Department of Environment Malaysia 2009; Hai et al. 2001).

DISTRIBUTION AND DIVERSITY OF AQUATIC INSECTS COMMUNITY

High abundance of hemipteran families especially Gerridae and Corixidae were most related to the environmental conditions, as indicated by the CCA results. The water striders, water skaters or pond skaters (Gerromorpha) normally can be found at lentic areas including limnetic and lotic surfaces. They are supported by surface tension of the water and the unwettable hydrofuge pile of their tarsi and tibiae (Orr et al. 2004). Most species from this order are aware to waves propagated in the surface film, which may be used for perceiving prey, predators or potential mates (Yang et al. 2004). The second higher abundance of aquatic insects were from order Odonata. Odonata are potentially considerable as indicators of environmental disturbance, especially by logging activities or pollution. This includes phases of the life span, some groups being more readily sampled as larvae, others as adults (Orr et al. 2004).

Both standard and modified BMWP and ASPT scores categorised that all sampling stations were in moderate quality during the inter-monsoonal, wet and dry seasons. Previous studies with almost similar setting that had been carried out in Malaysia, the BMWP and ASPT scores indicated that Juru River, Penang in moderate quality (Al-Shami et al. 2011) Langat River, Selangor as polluted (Azrina et al. 2006) and upper part of Semenyih River, Selangor was categorised as clean, while downstream was polluted (Yap et al. 2003). These studies were also complemented by the water quality index, thus, placed great emphasis on aquatic insects as potential bioindicators of river ecosystems, particularly in the tropical regions.

TABLE 8. The standard BMWP and ASPT with comparison to $BMWP^{THAI}$ and $ASPT^{THAI}$ for each sampling station

Station	Sg. Resang (OP)	Sg. Lumun (SF)	Danau Kalinanap (OB)
Inter-Monsoonal (IM)			
BMWP	15	10	5
$BMWP^{THAI}$	15	10	5
ASPT	5	5	5
$ASPT^{THAI}$	5	5	5
Wet Season (WS)			
BMWP	34	5	19
$BMWP^{THAI}$	32	5	17
ASPT	5.7	5	6.3
$ASPT^{THAI}$	5.3	5	5.7
Dry Season (DS)			
BMWP	5	5	10
$BMWP^{THAI}$	5	5	10
ASPT	5	5	5
$ASPT^{THAI}$	5	5	5

SPATIO-SEASONAL VARIATIONS

Tables 3 and 6 present the summary of the surface water quality data and aquatic insects, respectively, which obtained at three sampling stations during the inter-monsoonal, wet and dry seasons. High rainfall has been observed in June and August 2005 during the dry season, while low amount of precipitation occurred in February 2005 (wet season) (Figure 2).

Spatial variations in surface water quality of LKR were presented by two discriminant functions. Figure 4 plots the first and second discriminant function for each parameter. Discriminant function 1 explains 91% of the variance in the data and confirmed a negative correlation between SS and DO particularly in oxbow lake (OB). This is reflected by high concentrations of SS in OB in December 2004 and February 2005 (wet season). It could also be affected by semi-lotic system of this oxbow lake, which allowed sediment transportation into the lake system (Glinska-Lewczuk 2009). This analysis also suggests that COD was dominant in oil palm plantation (OP), followed by secondary forest (SF) and OB. COD is a parameter to represent total organic matter in water bodies (Hur & Cho 2012) and has been showed positively correlated with agricultural and industrial discharges (Song et al. 2009).
Variation in the distribution of aquatic insects across sampling stations showed that the highest abundance and diversity was in oil palm plantation (OP), followed by secondary forest (SF) and oxbow-lake (OB). Oil palm plantations have been reported may increase nutrient and sediment export into streams (Comte et al. 2012) while secondary forests have been showed to return high amounts of nutrients in litter fall and act as nutrient sinks (Brown & Lugo 1990; Silva et al. 2011), therefore significant in the aquatic food web structure and ecosystem processes (Douglas 2005). This suggests that abundant organic matter in oil palm plantation and secondary forest could have influenced the high distribution of aquatic insects in LKR. For example, Fitzherbert et al. (2008) reported higher invertebrate variations in oil palm plantations, compared to primary forests. A recent water quality study in Kinabatangan, Sabah, indicated high concentrations of dissolved organic carbon (DOC) in streams drained from oil palm plantations and secondary forests, ranged from 7.26 to 15.30 mg/L and 7.42 to 11.17 mg/L, respectively (Harun 2013). In addition, low abundance of aquatic insects could be resulted from high concentrations of suspended sediment, which is a significant factor in determining the complexity of food web and consequently reflected the effect of pollution (Yule et al. 2010). In selected rivers in Kuching, Sarawak, lower abundance and diversity of aquatic insects was found in oil palm plantations, compared to primary forest, which could be resulted from high concentration of suspended sediment and pesticide contamination (Mercer et al. 2013).

In terms of seasonal variation, discriminant analysis showed that suspended sediment (SS) was dominant in the dry season (Figure 5), which could be resulted from the export of particulate matter into the water bodies from sediment transport and erosion (Mustapha et al. 2012; Viers et al. 2009). Consistent high COD concentrations at all sampling stations during the wet season (Table 3) could be associated with active land development in this area, therefore, high amount of dissolved organic matter (DOM) could be transported (Josephine et al. 2004). Other studies based on monsoon cycle in other tropical areas also showed variations in both COD and BOD concentrations. For example, high COD concentration during the wet season was exhibited in Danjiangkou Reservoir, China (Li et al. 2009) and in the Lake of the Francesa, Brazil (mean: 36.6 mg/L) (Kimura et al. 2011). Inversely, high COD values during the dry season also have been observed in Semarang, Indonesia (Mangimbulude et al. 2009); upper Ogun River in Nigeria (Adeogun et al. 2011) and Pearl River Delta, China (Fan et al. 2012). BOD concentrations

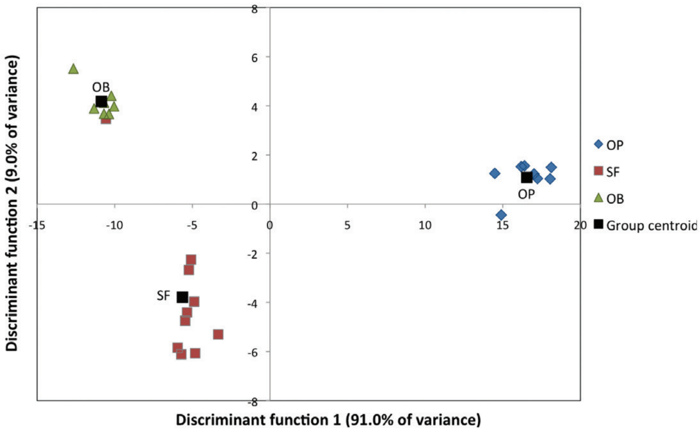

FIGURE 4. Discriminant analysis function for surface water quality at different type of land use at the Lower Kinabatangan River Catchment

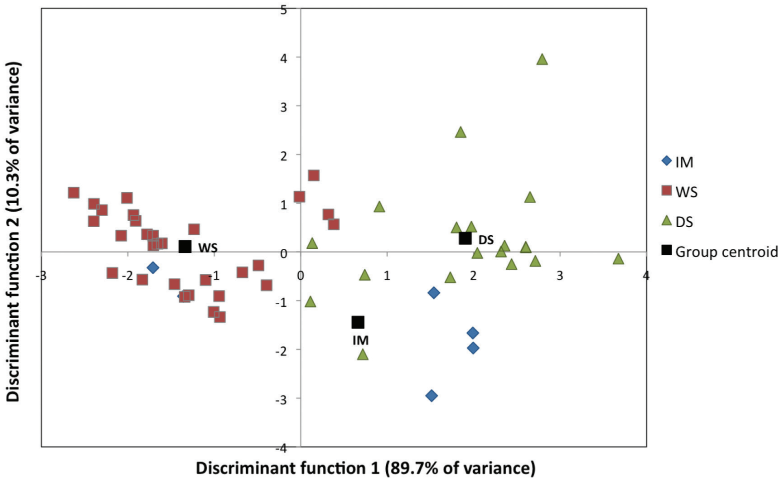

FIGURE 5. Discriminant analysis function for each inter-monsoonal period, wet and dry seasons at the Lower Kinabatangan River Catchment

were varied during both wet and dry seasons could be associated with organic loads in this area. It has been found that BOD has positive relationship with organic pollution such as domestic sewage (Islam et al. 2012), therefore could indicate microbial activities in the water bodies (Nakamura et al. 2007; Pant & Adholeya 2007). High level of BOD during the dry season also has been observed in Chini Lake, Malaysia (Islam et al. 2012) and Pearl River Delta, China (Fan et al. 2012) and Kathmandu Valley, Nepal (Rutkowski et al. 2007). In comparison with other rivers in Malaysia, the WQI values for Juru River ranged from class III to class IV (Al-Shami et al. 2011), Langat River (Azrina et al. 2006), 53.6-81.9 (II-III) in the Linggi River (Ahmad et al. 2002), 26.43-86.9 (II-V) in the Penang River (Maznah & Mansor 2002) and 47.59-54.35 (III-IV) in the Petani River (Hazzeman et al. 2006).

Distribution of aquatic insects in LKR was characterised with relatively high abundance of aquatic insects as a total of 1678 individuals were collected representing four orders and 14 families. Interestingly, high abundance of hemipteran gerrid at all sampling stations was found during the dry season (June and August 2005 with higher total rainfall). This could be related to high concentration organic matter as indicated by SS and BOD values were higher during this period. In New Brunswick, Canada streams, strong correlation has been showed by hemipteran gerrid and terrestrial carbon (Jardine et al. 2008). Annual runoff has been reported positively correlated with watershed export of dissolved organic carbon (DOC) (Mulholland 2003). Hemipteran (mainly Gerridae) and coleopteran in degraded streams of northwest Mississippi were found abundant at sites with high conductivity, ammonia (NH_4), total phosphorus and total solids concentrations (Maul et al. 2004). The results reported in the study also supported the possibility of application of Hemiptera as indicators of elevated (present or past) nutrient levels in the stream systems. The correlation is possibly caused by preys (food) that are more abundant at locations with increased nutrient concentrations (Maul et al. 2004). This is supported by previous studies which demonstrated that Corixidae feed on stream bottom organic matter containing algae, diatoms (Alahmed et al. 2009; Cummins 1973; Sweeney & Schnack 1977) and Gerridae feed on detritivores and small arthropods at or near water surface that could be more abundant related to increasing nutrient concentrations (Cummins 1973; Jardine et al. 2008; Sih & Watters 2005). Fernandez and Lopez Ruf (2005) reported that Gerridae was found in streams that subjected to agricultural and cattle-rearing activities in La Plata estuary, Argentina. Consequently, a water quality and macroinvertebrates study conducted in Juru River, Malaysia showed that *Limnogonus* sp. (Gerridae) is highly sensitive to low oxygen levels, high BOD and COD, agricultural and municipal pollutants (ammonia-N, nitrate-N) and industrial contaminants (chloride, sulphate, Al, Zn, Ni and Cu) (Al-Shami et al. 2011).

PRECIPITATION ANOMALIES-ENSO EVENT

Seasonal variations for water quality physico-chemical parameters such as COD, BOD and SS in this study were possibly affected by incongruent rainfall distribution, which influenced by with the monsoonal cycle (wet and dry seasons). The seasonal pattern of flooding is one of the key drivers of productivity in wetlands and rates of primary production generally show a prominent degree of both spatial and temporal variations (Davies et al. 2008). For example, the effects of inundation and water level fluctuations are significant in the diversity and dispersal of floodplain vegetation in Amazon (Ferreira et al. 2010; Parolin et al. 2010). However, precipitation anomalies due to the irregular synoptic forcing (El Niño Southern Oscillation (ENSO) have been found to affect monsoon seasonality (Dambul 2005; Dambul & Jones 2008)). Monsoon and ENSO are two of the most influential forces modulating surface climate in the SE Asia (Dambul 2010). Previous studies in Indonesia and Malaysia, have established a significant relationship between rainfall variability and ENSO events (Aldrian & Susanto 2003; Chang et al. 2004; Gomyo & Koichiro 2009; Tangang & Juneng 2004). To be more specific, positive correlation has been observed between SE Asia rainfall anomalies (SEAR) and ENSO evolution, where precipitation patterns are found to be highly affected by the irregular ENSO-related sea surface temperature (SST) anomalies (Juneng & Tangang 2005). The same climatic signals were captured further by Cobb et al. (2007) with lighter isotope of $\delta^{18}O$ (1 to 2 ‰) from cave dripwater sample in Gunung Mulu, Sarawak during the weak La Niña in 2005/2006. The event was found associated with precipitation anomalies in Mulu Cave, Sarawak (Cobb et al. 2007). Therefore, by these climatic evidences, there is a high possibility that seasonal water quality and aquatic insect's variations in LKR has been affected by the similar irregular events.

CONCLUSION

Based on the surface water quality physico-chemical and aquatic insect's assessments, it was concluded that the quality of the Lower Kinabatangan River Catchment is in a moderate level. The physico-chemical parameter is possibly influenced by agricultural activities and the sampling period, either in wet or dry season. Aquatic insects belong to genera within the order of Hemiptera were found abundant during the dry season with higher total rainfall and associated strongly with water quality parameters COD, SS and high temperature. Weak La Niña event in 2005/2006 could play a significant factor in affecting the results, as ENSO forcing is able to override the monsoon normal features.

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REFERENCES

Adeogun, A.O., Chukwuka, A.V. & Ibor, O.R. 2011. Impact of abattoir and saw-mill effluents on water quality of Upper Ogun River (Abeokuta). *American Journal of Environmental Sciences* 7: 525-530.

Ahmad, A., Maimon, A., Othman, M.S. & Pauzi, A.M. 2002. The potential of local benthic macroinvertebrates as a biological monitoring tool for river quality assessment. In *The Regional Symposium on Environment and Natural Resources*. pp. 464-471.

Al-Shami, S.A., Md. Rawi, C.S., Ahmad, A.H. & Mohd. Nor, S.A. 2010. Distribution of Chironomidae (Insecta: Diptera) in polluted rivers of the Juru River Basin, Penang, Malaysia. *Journal of Environmental Sciences* 22(11): 1718-1727.

Al-Shami, S.A., Md. Rawi, C.S., Ahmad, A.H., Abdul Hamid, S. & Mohd Nor, S.A. 2011. Influence of agricultural, industrial, and anthropogenic stresses on the distribution and diversity of macroinvertebrates in Juru River Basin, Penang, Malaysia. *Ecotoxicology and Environmental Safety* 74: 1195-1202.

Al-Shami, S.A., Heino, J., Che Salmah, M., Abu Hassan, A., Suhaila, A. & Madrus M.R. 2013a. Drivers of beta diversity of macroinvertebrate communities in tropical forest streams. *Freshwater Biology* 58(6): 1126-1137.

Al-Shami, S.A., Md. Rawi, C.S., Ahmad, A.H. & Madrus, M.R. 2013b. Biodiversity of stream insects in the Malaysian Peninsula: Spatial patterns and environmental constraints. *Ecological Entomology* 38(3): 238-249.

Al-Shami, S.A., Md. Rawi, C.S., Ahmad, A.H., Madrus, M.R. & Al Mutairi, K. 2014. Importance of regional diversity and environmental conditions on local species richness of aquatic macro-invertebrates in tropical forested streams. *Journal of Tropical Ecology* 30: 335-346.

Alahmed, A.M., Alamr, S.A. & Kheir, S.M. 2009. Seasonal activity and predatory efficacy of the water bug Sigara hoggarica posson (Hemiptera: Corixidae) against the mosquito larvae Culex quinquefasciatus (Diptera: Culicidae) in Riyadh City, Saudi Arabia. *Psyche: A Journal of Entomology* 6: 90-95.

Alakananda, B., Mahesh, M.K., Supriya, G., Boominathan, M., Balachandran, C. & Ramachandra, T.V. 2011. Monitoring tropical urban wetlands through biotic indices. *J. Biodiversity* 2: 91-106.

Aldrian, E. & Dwi Susanto, R. 2003. Identification of three dominant rainfall regions within Indonesia and their relationship to sea surface temperature. *International Journal of Climatology* 23(12): 1435-1452.

APHA. 1992. *Standard Methods for the Examination of Water and Wastewater*. 18th ed. Washington: American Public Health Association, AWWA, MPCE.

Azrina, M.Z., Yap, C.K., Rahim Ismail, A., Ismail, A. & Tan, S.G. 2006. Anthropogenic impacts on the distribution and biodiversity of benthic macroinvertebrates and water quality of the Langat River, Peninsular Malaysia. *Ecotoxicology and Environmental Safety* 64: 337-347.

Ballance, R. 1996. Physical and chemical analysis. In *Water Quality Monitoring: A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes*, edited by Ballance, R. & Bartram, J. Great Britain: E & FN Spon.

Bonada, N., Prat, N., Resh, V.H. & Statzner, B. 2006. Developments in aquatic insects biomonitoring: A comparative analysis of recent approaches. *Annual Review of Entomology* 51: 495-523.

Boonratana, R. 2013. Fragmentation and its significance on the conservation of Proboscis Monkey (Nasalis larvatus) in the Lower Kinabatangan, Sabah (North Borneo). In *Primates in Fragments*. New York: Springer. pp. 459-474.

Boonratana, R. 2000. Ranging behavior of Proboscis Monkeys (Nasalis larvatus) in the Lower Kinabatangan, Northern Borneo. *International Journal of Primatology* 21: 497-517.

Boyero, L., Ramirez, A., Dudgeon, D. & Pearson, R.G. 2009. Are tropical streams really different? *Journal of the North American Benthological Society* 28(2): 397-403.

Brown, S. & Lugo, A.E. 1990. Tropical secondary forests. *Journal of Tropical Ecology* 6: 1-32.

Bruford, M.W., Ancrenaz, M., Chikhi, L., Lackman-Ancrenaz, I., Andau, M., Ambu, L. & Goossens, B. 2010. Projecting genetic diversity and population viability for the fragmented orang-utan population in the Kinabatangan floodplain, Sabah, Malaysia. *Endangered Species Research* 12(3): 249-261.

Canfield, T.J., Brunson, E.L., Dwyer, F.J., Ingersoll, C.G. & Kemble, N.E. 1998. Assessing sediments from upper Mississippi River Navigational Pools using a benthic invertebrate community evaluation and the sediment quality triad approach. *Archives of Environmental Contamination Toxicology* 35: 202-212.

Chang, C.P., Wang, Z., Ju, J. & Li, T. 2004. On the relationship between western maritime continent monsoon rainfall and ENSO during northern winter. *Journal of Climate* 17: 665-672.

Che Salmah, M.R., Al-Shami, S.A., Madrus, M.R. & Ahmad, A.H. 2014. Biological and ecological diversity of aquatic macroinvertebrates in response to hydrological and physicochemical parameters in tropical forest streams of Gunung Tebu, Malaysia: Implications for ecohydrological assessment. *Ecohydrology* 7(2): 496-507.

Che Salmah, M.R., Al-Shami, S.A., Madrus, M.R. & Ahmad, A.H. 2013. Local effects of forest fragmentation on diversity of aquatic insects in tropical forest streams: Implications for biological conservation. *Aquatic Ecology* 47(1): 75-85.

Cobb, K.M., Adkins, J.F., Partin, J.W. & Clark, B. 2007. Regional-scale climate influences on temporal variations of rainwater and cave dripwater oxygen isotopes in northern Borneo. *Earth and Planetary Science Letters* 263(3-4): 207-220.

Comte, I., Colin, F., Whalen, J.K., Grünberger, O. & Caliman, J.P. 2012. Agricultural practices in oil palm plantations and their impact on hydrological changes, nutrient fluxes and water quality in Indonesia: A review. *Advances in Agronomy* 116: 71-124.

Cummins, K.W. 1973. Trophic relations of aquatic insects. *Annual Review of Entomology* 18(1): 183-206.

Dambul, R. 2010. Monsoon indicators for Borneo. *Geografia Online Malaysian Journal of Society and Space* 6(3): 1-12.

Dambul, R. 2005. Relationships between Large-scale Circulation and Surface Climate: A Case Study for Borneo. PhD Thesis. University of East Anglia.

Dambul, R. & Jones, P. 2008. Regional and temporal climatic classification for Borneo. *Geografia Online Malaysian Journal of Society and Space* 5: 1-25.

Davies, P.M., Bunn, S.E. & Hamilton, S.K. 2008. Primary production in tropical streams and rivers. In *Tropical Stream Ecology*, edited by Dudgeon, D. London: Academic Press.

Department of Environment Malaysia, 2012. *Environmental Quality Report 2012*. Malaysia: Kementerian Sains, Teknologi dan Alam Sekitar.

Department of Environment Malaysia, 2009. *Environmental Quality Report 2009*. Malaysia: Ministry of Science, Technology and Environment.

Douglas, I. 1999. Hydrological investigations of forest disturbance and land cover impacts in South-East Asia: A review. *Philosophical Transactions of the Royal Society B: Biological Sciences* 354: 1725-1738.

Douglas, M. 2005. River and wetland food webs in Australia's wet-dry tropics: General principles and implications for management. *Marine and Freshwater Research* 56: 329-342.

Dudgeon, D. 2006. The impacts of human disturbance on stream benthic invertebrates and their drift in North Sulawesi, Indonesia. *Freshwater Biology* 51(9): 1710-1729.

Environmental Protection Agency (EPA) Methods. 1993. Method 410.4. *The Determination of Chemical Oxygen Demand by Semi-automated Colorimetry,* edited by O'Dell, J.W. Revision 2.0. Ohio: US Environmental Protection Agency.

Fan, X., Cui, B., Zhang, K., Zhang, Z. & Shao, H. 2012. Water quality management based on division of dry and wet seasons in Pearl River Delta, China. *CLEAN - Soil, Air, Water* 40: 381-393.

Fernandez, L.A. & Lopez Ruf, M.L. 2006. Aquatic Coleoptera and Heteroptera inhabiting waterbodies from Berisso, Buenos Aires province, Argentina. *Revista de Biología Tropical* 54(1): 139-148.

Ferreira, C.S., Piedade, M.T.F., de Oliveira, A. & Franco, A.C. 2010. Plant reproduction in the Central Amazonian floodplains: Challenges and adaptations. *AoB Plants* plq009.

Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Brühl, C.A., Donald, P.F. & Phalan, B. 2008. How will oil palm expansion affect biodiversity? *Trends in Ecology & Evolution* 23(10): 538-545.

Glinska-Lewczuk, K. 2009. Water quality dynamics of oxbow lakes in young glacial landscape of NE Poland in relation to their hydrological connectivity. *Ecological Engineering* 35: 25-37.

Gomyo, M. & Koichiro, K. 2009. Spatial and temporal variations in rainfall and the ENSO-rainfall relationship over Sarawak, Malaysian Borneo. *SOLA* 5: 41-44.

Hai, T.C., Ng, A., Prudente, C., Pang, C. & Yee, J.T.C. 2001. Balancing the need for sustainable oil palm development and conservation: The lower Kinabatangan floodplains experience. *ISP National Seminar 2001: Strategic Directions for the Sustainability of the Oil Palm Industry*. pp. 1-53.

Hamilton, S.K. 2002. Comparison of inundation patterns among major South American floodplains. *Journal of Geophysical Research* 107: 8038.

Harun, S. 2013. Water quality dynamics in a lowland tropical catchment: The Kinabatangan river, Sabah, Malaysia. Unpublished PhD Thesis. University of Birmingham, UK.

Harun, S., Baker, A., Bradley, C., Pinay, G., Boomer, I. & Hamilton, R.L. 2014. Characterisation of dissolved organic matter in the Lower Kinabatangan River, Sabah, Malaysia. *Hydrology Research* In Press.

Hazzeman, H., Maznah, W.O.W. & Mansor, M. 2006. River classification based on the physico-chemical properties in the Pentai River Basin. In *International Conference on Environment*. Penang, Malaysia.

Hur, J. & Cho, J. 2012. Prediction of BOD, COD, and total nitrogen concentrations in a typical urban river using a fluorescence excitation-emission matrix with PARAFAC and UV absorption indices. *Sensors* 12(1): 972-986.

Islam, M.S., Ismail, B.S., Barzani, G.M., Sahibin, A.R. & Ekhwan, T.M. 2012. Hydrological assessment and water quality characteristics of Chini Lake, Pahang, Malaysia. *American-Eurasian J. Agric. & Environ. Sci*. 12: 737-749.

Jakobsen, F., Hartstein, N., Frachisse, J. & Golingi, T. 2007. Sabah shoreline management plan (Borneo, Malaysia): Ecosystems and pollution. *Ocean & Coastal Management* 50: 84-102.

Jardine, T.D., Kidd, K.A., Polhemus, J.T. & Cunjak, R.A. 2008. An elemental and stable isotope assessment of water strider feeding ecology and lipid dynamics: Synthesis of laboratory and field studies. *Freshwater Biology* 53: 2192-2205.

Jinggut, T., Yule, C.M. & Boyero, L. 2012. Stream ecosystem integrity is impaired by logging and shifting agriculture in a global megadiversity center (Sarawak, Borneo). *Science of the Total Environment* 437: 83-90.

Josephine, R., Alfred, R.J. & Rajah, I. 2004. Integrated river basin management planning for the Kinabatangan Catchment, Sabah: Approach and strategy. *Proceedings for World Water Day 2004*. pp. 1-10.

Juneng, L. & Tangang, F.T. 2005. Evolution of ENSO-related rainfall anomalies in Southeast Asia region and its relationship with atmosphere-ocean variations in Indo-Pacific sector. *Climate Dynamics* 25(4): 337-350.

Kimura, S.P.R., de Almeida Neto, A.F., da Silva, M.G.C. & Pierucci, S. 2011. Anthropogenic effects on the water quality at a pond in the Amazon Region. *Chemical Engineering* 24: 1255-1260.

Li, S., Cheng, X., Xu, Z., Han, H. & Zhang, Q. 2009. Spatial and temporal patterns of the water quality in the Danjiangkou Reservoir, China. *Hydrological Sciences Journal* 54(1): 124-134.

Ma, A.N. 1999. Treatment of palm oil mill effluent. In *Oil Palm and the Environment: A Malaysian Perspective*, edited by Singh, G., Lim, K.H., Teo, L. & David, L.K. Kuala Lumpur: Malaysian Oil Palm Growers Council.

Mangimbulude, J.C., Breukelen, B.M.V., Krave, A.S., Straalen, N.M.V. & Röling, W.F.M. 2009. Seasonal dynamics in leachate hydrochemistry and natural attenuation in surface run-off water from a tropical landfill. *Waste Management* 29: 829-838.

Maul, J.D., Farris, J.L., Milam, C.D., Cooper, C.M., Testa III, S. & Feldman, D.L. 2004. The influence of stream habitat and water quality on macroinvertebrate communities in degraded streams of northwest Mississippi. *Hydrobiologia* 518: 79-94.

Mayora, G., Devercelli, M. & Giri, F. 2013. Spatial variability of chlorophyll-a and abiotic variables in a river-floodplain system during different hydrological phases. *Hydrobiologia* 717(1): 51-63.

Maznah, W.O.W. & Mansor, M. 2002. Aquatic pollution assessment based on attached diatom communities in the Pinang River Basin, Malaysia. *Hydrobiologia* 487: 229-241.

Mercer, E.V., Mercer, T.G. & Sayok, A.K. 2013. Effects of forest conversions to oil palm plantations on freshwater macroinvertebrates: A case study from Sarawak, Malaysia. *Journal of Land Use Science* 9(3): 260-277.

Merritt, R. & Cummins, K.W. 1984. Ecology and distribution of aquatic insects. In *An Introduction to the Aquatic Insects of North America*, edited by Merritt, R. & Cummins, K. W. USA: Kendall/Hunt Publishing Company.

Mohd Rasdi, Z., Fauziah, I., Ismail, R., Mohd Hafezan, S., Fairuz, K., Hazmi, A.D. & Che Salmah, M.R. 2012. Diversity of Aquatic Insects in Keniam River, National Park, Pahang, Malaysia. *Asian Journal of Agriculture and Rural Development* 2(3): 312-328.

Mulholland, P.J. 2003. Large-scale patterns in dissolved organic carbon concentration, flux and sources. In *Aquatic Ecosystems: Interactivity of Dissolved Organic Matter*, edited by Findlay, S.E.G. & Sinsabaugh, R.L. London: Academic Press. pp. 139-159.

Mustapha, A., Aris, A.Z., Ramli, M.F. & Juahir, H. 2012. Spatial-temporal variation of surface water quality in the downstream region of the Jakara River, north-western Nigeria: A statistical approach. *Journal of Environmental Science and Health, Part A* 47: 1551-1560.

Mustow, S.E. 2002. Biological monitoring of rivers in Thailand: Use and adaptation of the BMWP score. *Hydrobiologia* 479: 191-229.

Nakamura, H., Suzuki, K., Ishikuro, H., Kinoshita, S., Koizumi, R., Okuma, S., Gotoh, M. & Karube, I. 2007. A new BOD estimation method employing a double-mediator system by ferricyanide and menadione using the eukaryote *Saccharomyces cerevisiae*. *Talanta* 72: 210-216.

Norwana, A., Kunjappan, R., Chin, M., Schoneveld, G., Potter, L. & Andriani, R. 2011. The local impacts of oil palm expansion in Malaysia: An assessment based on a case study in Sabah State. CIFOR Working Papers. pp. 1-26.

Orr, A.G., Butler, S.G., Hamalainen, M. & Kemp, R.G. 2004. Insecta: Odonata. In *Freshwater Invertebrates of the Malaysian Region*, edited by Yule, C.M. & Yong Hoi Sen. Malaysia: Academy of Sciences Malaysia. pp. 409-442.

Pant, D. & Adholeya, A. 2007. Biological approaches for treatment of distillery wastewater: A review. *Bioresource Technology* 98: 2321-2334.

Parolin, P., Lucas, C., Piedade, M.T.F. & Wittmann, F. 2010. Drought responses of flood-tolerant trees in Amazonian floodplains. *Annals of Botany* 105(1): 129-139.

Pettit, N.E., Bayliss, P., Davies, P.M., Hamilton, S.K., Warfe, D.M., Bunn, S.E. & Douglas, M.M. 2011. Seasonal contrasts in carbon resources and ecological processes on a tropical floodplain. *Freshwater Biology* 56(6): 1047-1064.

Pringle, C.M. & Benstead, J.P. 2001. The effects of logging on tropical river ecosystems. In *The Cutting Edge: Conserving Wildlife in Logged Tropical Forests*, edited by Fimbel, R.A., Grajal, A. & Robinson, J.G. New York: Columbia University Press.

Rosli, N., Gandaseca, S., Ismail, J. & Jailan, M.I. 2010. Comparative study of water quality at different peat swamp forest of Batang Igan, Sibu Sarawak. *American Journal of Environmental Sciences* 6: 416-421.

Rutkowski, T., Raschid-Sally, L. & Buechler, S. 2007. Wastewater irrigation in the developing world-Two case studies from the Kathmandu Valley in Nepal. *Agricultural Water Management* 88: 83-91.

Saigusa, N., Yamamoto, S., Hirata, R., Ohtani, Y., Ide, R., Asanuma, J., Gamo, M., Hirano, T., Kondo, H. & Kosugi, Y. 2008. Temporal and spatial variations in the seasonal patterns of CO2 flux in boreal, temperate, and tropical forests in East Asia. *Agricultural and Forest Meteorology* 148: 700-713.

Sih, A. & Watters, J.V. 2005. The mix matters: Behavioural types and group dynamics in water striders. *Behaviour* 142: 1417-1431.

Silva, C.E.M., Gonçalves, J.F.C. & Alves, E.G. 2011. Photosynthetic traits and water use of tree species growing on abandoned pasture in different periods of precipitation in Amazonia. *Photosynthetica* 49: 246-252.

Song, M.Y., Leprieur, F., Thomas, A., Lek-Ang, S., Chon, T.S. & Lek, S. 2009. Impact of agricultural land use on aquatic insect assemblages in the Garonne river catchment (SW France). *Aquatic Ecology* 43(4): 999-1009.

Spieles, D.J. & Mitsch, W.J. 2000. Macroinvertebrate community structure in high- and low-nutrient constructed wetlands. *Wetlands* 20: 716-729.

Suhaila, Ab Hamid & Che Salmah, M.R. 2014. Ecology of Ephemeroptera, Plecoptera and Trichoptera (Insecta) in rivers of the Gunung Jerai Forest Reserve: Diversity and distribution of functional feeding groups. *Tropical Life Sciences Research* 25(1): 61.

Suhaila, A.H., Salmah, M.R.C. & Al-Shami, S.A. 2012. Temporal distribution of Ephemeroptera, Plecoptera and Trichoptera (EPT) adults at a tropical forest stream: Response to seasonal variations. *The Environmentalist* 32(1): 28-34.

Sweeney, B.W. & Schnack, J.A. 1977. Egg development, growth, and metabolisms of Sigara Alternata (Say) (Hemiptera: Corixidae) in fluctuating thermal environments. *Ecology* 58: 265-277.

Tangang, F.T. & Juneng, L. 2004. Mechanisms of Malaysia rainfall anomalies. *Journal of Climate* 17: 3616-3622.

ter Braak, C.J. 1989. CANOCO-an extension of DECORANA to analyze species-environment relationships. *Hydrobiologia* 184(3): 169-170.

ter Braak, C.J. & Prentice, I.C. 1988. A theory of gradient analysis. *Advances in Ecological Research* 18: 271-317.

Tockner, K. & Stanford, J.A. 2002. Riverine flood plains: Present state and future trends. *Environmental Conservation* 29(3): 308-330.

Viers, J., Dupré, B. & Gaillardet, J. 2009. Chemical composition of suspended sediments in World Rivers: New insights from a new database. *Science of the Total Environment* 407: 853-868.

Wahizatul, A.A., Long, S.H. & Ahmad, A. 2011. Composition and distribution of aquatic insect communities in relation to water quality in two freshwater streams of Hulu Terengganu, Terengganu. *J. Sustainability Sci. Manage.* 6(1): 148-155.

Whiles, M.R., Brock, B.L., Franzen, A.C. & Dinsmore, S.C. II. 2000. Stream invertebrate communities, water quality, and land-use patterns in an Agricultural Drainage Basin of Northeastern Nebraska, USA. *Environmental Management* 26: 563-576.

Yang, C.M., Kovac, D. & Cheng, L. 2004. Insecta: Hemiptera, Heteroptera. In *Freshwater Invertebrates of the Malaysian Region,* edited by Yule, C.M. & Yong Hoi Sen. Malaysia: Academy of Sciences Malaysia. pp. 457-490.

Yap, C.K., Rahim Ismail, A., Ismail, A. & Tan, S.G. 2003. Species diversity of macrobenthic invertebrates in the Semenyih River, Peninsular Malaysia. *Pertanika Journal of Tropical Agricultural Science* 26(2): 139-146.

Yap, C.K. & Rahim, I. 2011. Relationships of distribution of macrobenthic invertebrates and the physico-chemical parameters from Semenyih River by using correlation and multiple linear stepwise regression analyses. *Pertanika Journal of Tropical Agricultural Science* 34(2): 229-245.

Yoshimura, M. 2012. Effects of forest disturbances on aquatic insect assemblages. *Entomological Science* 15: 145-154.

Yule, C.M., Boyero, L. & Marchant, R. 2010. Effects of sediment pollution on food webs in a tropical river (Borneo, Indonesia). *Marine and Freshwater Research* 61: 1-10.

Zainudin, Z. 2010. Benchmarking river water quality in Malaysia. *Jurutera* February. pp. 12-15.

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