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The ecology of littoral zone Chironomidae in four artificial, urban, tropical Malaysian lakes

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Abstract

Urbanization is increasingly compromising lakes in the rapidly developing countries of tropical Southeast Asia. Greater understanding of the ecology of tropical lakes is essential in order to determine the best ways to protect and manage them. A comparison was made of the species richness, abundance and diets of Chironomidae in two forest lakes (both created by damming rivers - one in an urban forest reserve, one adjacent to an urban area) and two urban park lakes (ex- tin mine lakes) in Kuala Lumpur, Malaysia. 19 species of chironomids were recorded (10 collector-gatherers, one collector-filterer, one shredder, 3 predators and 4 predators/grazers). The most abundant species were *Polypedilum leei*, *Tanytarsus formosanus*, *Zavreliella marmorata* and *Procladius* sp.. Conductivity was highest in the urban park lakes due to pollution. Temperature was also highest in the urban park lakes due to lower riparian canopy cover and lower macrophyte abundance. Larval abundance (mostly collector-gathering Chironominae) was significantly higher in the forest lakes compared to the urban park lakes, which could be related to cleaner water and higher vegetation cover which provided more food resources (leaf litter and periphyton) and more microhabitats. Predatory tanypods were most abundant in forest lakes which also had the highest numbers of their prey (Chironominae). Four predatory species of Tanypodinae supplemented their diet with blue-green algae in two of the urban lakes. Only one collector-filterer (*Corynoneura* sp.) was recorded (only in the forest lakes).

Keywords Community structure · Species richness · Functional feeding groups

Introduction

Globally only 0.01% of the world's water is freshwater covering 0.8% of the land surface yet freshwater ecosystems are particularly vulnerable to human impacts (Dudgeon et al. 2006). Lakes and ponds comprise about 3% of the world's freshwater bodies with a huge number being small and undervalued (Downing et al. 2006). The contribution of these small lakes is increasingly becoming recognized to be important and different from larger lakes in several aspects such as nutrient and carbon cycling (Hanson et al. 2007; Downing 2010; Read and Rose 2013) as well as responses to climate change (Winslow et al. 2015). Most of the research has been in temperate regions and little is known of small tropical lakes, yet these differ from temperate lakes in many aspects (Lewis 1996, 2000; Danger et al. 2009), including threats and management (Jeppesen et al. 2005).

As with other natural ecosystems such as rivers and streams, lakes are also negatively impacted by urbanization. The effects of urbanization on streams – the "urban stream syndrome" – is well known and results in distinctive changes to the physico-chemistry and ecology of urban streams (Walsh et al. 2005). The urban stream syndrome has frequently been observed in temperate regions and is also applicable in tropical streams (Yule et al. 2015). Although less is known regarding the impacts of urbanization on lakes and even less is known about tropical lakes, urbanization has been shown to cause similar problems in lakes as in streams due to increases in sedimentation, nutrients, and heavy metals and loss of biodiversity (Naselli-Flores 2008; Sharip and Zakaria 2008).

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Tropical Malaysia has very few natural lakes (e.g. Tasik Bera and Tasik Cini – both floodplain lakes) but they have received more extensive research due to their environmental and socio-economic importance compared to artificial lakes (Sharip and Zakaria 2008). Thousands of small artificial lakes have arisen in the past century due to previous tin mining activities (Yule 2004). Many of these ex-mining pools have simply been abandoned, while some are now used for recreation, the focus of housing estates, dumping industrial and domestic waste, and flood control. Several public parks have been built around rehabilitated ex-mining pools in urban areas such as Kuala Lumpur. Such urban lakes have been shown to offer many benefits such as recreation, aesthetic values and provision of an aquatic ecosystem for flora and fauna (Elmqvist et al. 2004; Shojaei et al. 2013). In particular they are potential refuges for fish and wildlife in an urban environment. Given the paucity of natural lakes in Malaysia, these artificial lakes are highly valuable thus it is important that management of these lakes includes consideration of societal and ecological needs (Baron et al. 2002; Chester and Robson 2013).

Despite the ease of accessibility and high public contact with urban lakes, there have been very few studies of Malaysia's urban lakes. Although a basic water quality assessment of two urban lakes has been undertaken (Said et al. 2012a, b), there have been no published biological studies. This information is valuable as the littoral zones of urban lakes are teeming with organisms and are also the forefront of exposure to urbanization, which could lead to changes in the lake communities. This study investigates factors affecting the biodiversity and distribution of a common group of littoral residents – Chironomidae (Insecta, Diptera) in four artificial lakes in Kuala Lumpur – two ex-tin mining lakes in urban parks, and two forested lakes (one in an urban forest park dominated by secondary forest, one in a primary forest reserve to the east of the city) which were created by the damming of small rivers.

We chose to study chironomids because they have a worldwide distribution and they are valuable indicators of aquatic-ecosystem responses to environmental and anthropogenic changes (Armitage et al. 1995; Langdon et al. 2006). We hypothesized that the species composition, species richness and abundance of chironomids in the forested lakes would be different from the urban park lakes due to variations in environmental factors and food availability. We predicted that the chironomids in the forested lakes with high allochthonous input and less impact from urbanization (particularly with respect to pollutants) would be (1) higher in abundance and (2) more diverse than in the urban park lakes. We also predicted that (3) due to the availability of different food resources in forested and park lakes, chironomids of the same species might have different diets. We tested this prediction by examining the gut contents of the chironomids.

Methods

We studied two forested and two park lakes in Kuala Lumpur (Fig. 1, Table 1), all located in a lowland environment (<200 m). Four different sites around the littoral zones of each lake were chosen to represent diverse habitats. Kuala Lumpur has a warm, humid tropical climate with an annual temperature range of 23-33 °C. It typically experiences lower rainfall in the middle of the year (May to August) and higher rainfall at the end of the year (October to January).

Forested Lakes

We studied two lakes in forest reserves: a lake in primary forest in the Ampang Forest Reserve (on the edge of the suburb of Ampang) and another in secondary forest in the Kota Damansara Community Forest Park. The lake in Ampang Forest Reserve (Fig. 1a) was originally a reservoir supplying water to Kuala Lumpur which was constructed in 1892 by damming a tributary of the Ampang River. Its entire catchment lies within primary lowland dipterocarp forest. It receives water inflow from three pristine streams and it flows out into the Ampang River. In contrast, the lake in the Kota Damansara Community Forest Park (Fig. 1b) is an artificial urban lake created by damming a small stream in the early 2000s. Apart from the dam wall, the lake is surrounded by secondary dipterocarp forest. It flows out into a drainage channel and it receives runoff from a road which runs beside the dam wall.

Urban Park lakes

Two urban park lakes were also studied: Subang Jaya Lake (Fig. 1c) and Shah Alam Lake (Fig. 1d). Both are former tin mining lakes which have been turned into public parks with sparse trees and drainage channels into and out of the lakes – so they receive road runoff and other pollutants. These two lakes are managed and maintained by the local municipal councils who occasionally remove vegetation from around the banks such as tall grasses and macrophytes. Subang Jaya Lake was officially opened to the public in 1990. Shah Alam Lake lies in Shah Alam Lake Gardens which was developed around seven ex-tin mine lakes. It has a raised wooden platform to observe wildlife such as tortoises, fish and storks. All four lakes are sites for recreation and fishing.

Environmental factors

Environmental factors at each of the four sampling sites of the lakes were measured as follows: air temperature (Kestral 3500), water temperature, pH, dissolved oxygen, and conductivity (EUTECH CyberScan PD650), and light intensity (Lutron LX-103). Spot measurements were taken at each site.

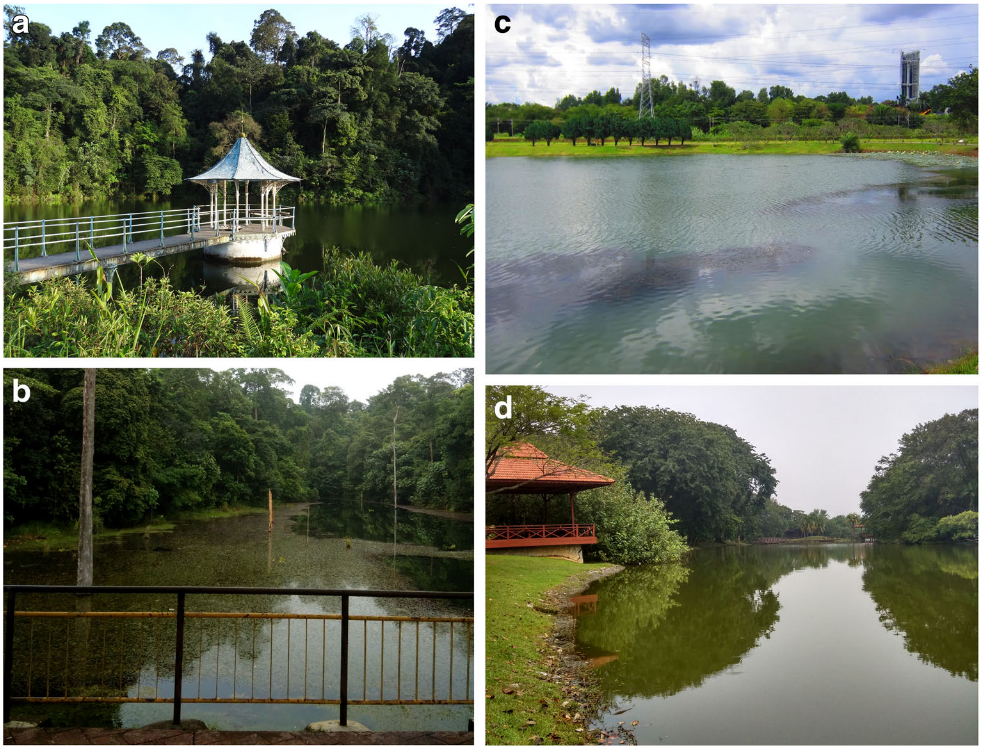

Fig. 1 The study sites: (**a**) Ampang lake, (**b**) Kota Damansara lake, (**c**) Subang Jaya lake and (**d**) Shah Alam lake

The percentage of canopy cover, leaf litter cover, vegetation cover at bank (e.g. grasses and shrubs), macrophytes and wood in the water were estimated qualitatively by observation with the aid of a grid depicting % cover. The substrate composition of the lakes was classified into mud/silt (<0.5 mm), sand (0.5–2 mm), gravel (2–64 mm), cobbles (65–256 mm) and boulders (>256 mm) and these data were computed into a substrate index (Suren 1996):

$$\begin{aligned}\text{Substrate index (SI)} &= 0.07 \times \%\text{boulder} + 0.06 \times \%\text{cobble}\\ &\quad + 0.05 \times \%\text{gravel} + 0.04 \times \%\text{sand}\\ &\quad + 0.03 \times \%\text{mud/silt}\end{aligned}$$

Sample collection and processing

Macroinvertebrates were haphazardly collected by kick sampling using a 250 μm mesh dip net at four sites around each lake for 2 min per site. Each sample covered about 5 m along the banks with care taken to dislodge fauna from within the substrate and among the macrophytes in the littoral zone. Dip-net sampling has been shown to be suitable for macroinvertebrate sampling in the littoral zone of lakes (e.g. Kashian and Burton 2000; García-Criado and Trigal 2005; Heatherly et al. 2005). The samples were placed in a tray of water and the net was rinsed to remove debris and fauna. The samples were then sorted to remove large macroinvertebrate predators (e.g. water scorpions and dragonfly larvae) and debris such as twigs and leaf litter. The samples were then preserved in 70% alcohol for sorting in the laboratory using a stereo microscope (Zeiss Stemi DV4). Chironomids were removed and placed in vials with 70% alcohol for taxonomic identification, determination of abundance and gut analysis. Sampling was performed once for each lake between January to March 2014.

Chironomidae communities and diets

Preserved Chironomidae larvae were mounted on slides in polyvinyl alcohol lactophenol mountant and examined under a Zeiss AXIO Lab. AI compound microscope. The identity of each larva was determined to the lowest taxonomic level possible (keys by Cranston 2004, 2007, 2010). The species richness and abundance of each chironomid species at each site was determined. The gut contents of the mounted chironomids with at least partially filled guts were assessed using a compound microscope to determine their diets. Gut contents were categorized as: 1) fine particulate organic matter (FPOM, particles <500 μm), 2) coarse particulate organic matter (CPOM, particles 500 μm–1 mm), 3) fungal hyphae, 4) leaf-litter fragments, 5) algae, and 6) animal tissue. The larvae were then assigned to functional feeding groups, i.e. shredders, collector-filterers, collector-gatherers, grazers, or predators following Merritt and Cummins (1996). Collector-gatherers were distinguished from collector-filterers based on field and laboratory observations of their mode of feeding.

Table 1 Comparison of the environmental factors of the four lakes

Environmental factors	Locations							
	Forested Lakes				Urban Park Lakes			
	Ampang N 03°09.897 E 101°46.588		Kota Damansara N 03°10.011 E 101°34.860		Subang Jaya N 03°04.914 E 101°35.712		Shah Alam N 03°04.374 E 101°30.828	
	Range	Mean (±SE)	Range	Mean (±SE)	Range	Mean (±SE)	Range	**Mean (±SE)**
Elevation (m)$^{\#}$	165–170	167.25 (1.21)^{a}	53–72	62.5 (4.01)^{b}	22–32	26.5 (2.22)^{c}	3–11	7.25 (1.65)^{d}
Water temperature (°C)*	25.9–28.4	27.4 (0.536) ^{a}	28.0–32.6	30.8 (1.014) ^{b}	29.4–30.5	29.8 (0.236) ^{b}	29.0–38.1	34.0 (2.238) ^{b}
Air temperature (°C) *	26.9–28.5	28.0 (0.359)	27.2–34.3	30.4 (1.869)	26.4–30.6	29.1 (0.941)	31.3–32.9	29.4 (0.336)
pH$^{\#}$	6.0–7.49	6.78 (0.37)	6.4–6.98	6.67 (0.14)	6.57–8.74	7.29 (0.49)	6.9–8.54	7.88 (0.38)
Dissolved oxygen (mg/L)$^{\#}$	5.2–6.1	5.75 (0.22)	4.6–5.69	5.12 (0.27)	4.16–6.82	5.07 (0.60)	4.7–7.1	5.49 (0.54)
Conductivity (µS) *	15.4–21.6	19.62 (1.42) ^{a}	29.4–107.6	50.15 (18.96) ^{b}	164.8–184.1	178.93 (4.71) ^{c}	164.4–182.0	172.4 (3.62) ^{c}
Canopy cover (%)$^{\#}$	0–70	32.5 (16.52)	0–80	42.5 (16.52)	0–80	47.5 (18.87)	0–85	45.0 (18.14)
Light intensity (Lux)$^{\#}$	48,100–220,000	127,275 (35733)	13,040–1,128,000	427,760 (242407)	10,390–457,000	221,598 (92221)	88,300–763,000	403,825 (73810)
Leaf litter cover (%)*	10–100	62.5 (20.56)	10–80	40.0 (14.72)	0–100	40.0 (23.09)	0–60	20.0 (14.14)
Macrophytes (%)*	10–80	42.5 (16.52) ^{a}	10–100	52.5 (18.43) ^{a}	10–50	32.5 (8.54) ^{a}	0	0.0 (0.00) ^{b}
Vegetation cover at bank (%)*	80	80.0 (0.00)	10–90	50.0 (18.26)	15–60	41.3 (9.66)	0–60	30.0 (14.72)
Wood (%)*	0–50	15.0 (11.90)	0–15	6.3 (3.15)	0–30	12.5 (7.50)	0	0.0 (0.00)
Substrate Index (%)*	3.6–4.2	3.9 (0.14) ^{a}	3.7–5.6	4.3 (0.44) ^{ab}	4.4–5.2	4.8 (0.23) ^{ab}	4.0–7.0	6.0 (0.65) ^{b}

ANOVA was performed; * Kruskal-Wallis test was performed. Any groups in a category sharing a common lower-case letter are not significantly different at $P < 0.05$ (Tukey HSD test)

Statistical analyses

The environmental factors were compared between the lakes using one-way ANOVA to determine the significance of individual differences at $p < 0.05$ level after checking for normality using the Shapiro-Wilk test. Environmental factors that did not fulfil the requirement were analysed using the Kruskal-Wallis test instead. All significant means were then compared using Tukey's post-hoc test to show where the differences lie. This was also repeated to compare the species richness and abundance of chironomids among the lakes. Spearman's correlation was used to determine the effects of environmental factors on the species richness and abundance of chironomids among the lakes, as the variables were not normally distributed.

To assess the chironomid communities among the lakes, the data were square root transformed and evaluated using nonmetric multidimensional scaling (NMDS) (McCune and Grace 2002). From the data, Bray-Curtis dissimilarity measures were computed and subsequently subjected to NMDS to produce ordination plots of the chironomid composition of the lakes. The suitability of the ordination plots in explaining the ecological data is dependent on the 2D stress (defined in terms of total scatter of data) which can be assessed as follows (Clarke 1993): stress <0.05 = excellent representation; stress <0.1 = good ordination without giving false inferences; stress <0.2 = practical with possibility of mislead interpretation; stress >0.2 = not suitable for interpretation. Sites that were clustered together in the NMDS plot signified sites that were similar in chironomid composition. All statistical analyses were done using IBM SPSS version 21 statistical software package (SPSS Inc., Chicago, Illinois) with the exception of NMDS (GINGKO version 1.5.8, Bouxin 2005).

Results

Comparison of environmental variables of forested and park lakes

The forested lakes had significantly more macrophytes and other littoral vegetation cover compared to the park lakes (Table 1: Spearman's correlation: Macrophytes, $r = 0.664$, $p = 0.005$, $n = 16$; Vegetation cover at bank, $r = 0.697$, $p = 0.003$, n = 16; Kruskal-Wallis Macrophytes Chi-square = 9.177, $p = 0.027$). Tukey's post-hoc test indicated that the differences lay in the absence of macrophytes in Shah Alam lake. However, this was not the case for vegetation cover at the bank (Kruskal Wallis, Chi-square = 7.101, $p = 0.069$).

In the forested lakes, high canopy cover significantly reduced the penetration of light to the littoral zone, and reduced temperatures (strong negative relationship between canopy cover and light intensity: Spearman's correlation, $r = -0.736$, $p = 0.001$, $n = 16$; water temperature - Kruskal Wallis, Chi-square = 9.035, $p = 0.029$; Table 1). Tukey's post-hoc test indicated that the water temperature of Ampang lake was significantly lower than the others – and this was correlated with high canopy cover (Spearman's correlation, $r = 0.680$, $p = 0.004$, $n = 16$) and lower air temperature (Spearman's correlation, $r = 0.676$, p = 0.004, n = 16).

Similarly, the water chemistry of the forest lakes was distinct from the park lakes. The forest lakes had significantly lower conductivity than the urban park lakes (Kruskal Wallis, Chi-square = 13.277, p = 0.004; Table 1) with Ampang lake having the lowest conductivity. This suggests that urbanization caused an input of pollutants such as dissolved salts and inorganic materials into the lake.

The substrates of the forest lakes had significantly smaller sized particles (mud/silt and sand) compared to the park lakes which had more gravel and boulders (Kruskal Wallis, Chi-square = 8.422, $p = 0.038$; Table 1). The substrate was seen to influence the establishment of flora in and around the lakes: a strong negative relationship was observed between substrates and both macrophytes (Spearman's correlation, $r = -0.705$, $p = 0.002$, $n = 16$) and vegetation cover (Spearman's correlation, $r = -0.739$, $p = 0.001$, n = 16), because these grew better in fine sediment than among cobbles and boulders.

Composition of chironomid communities

Species richness

A total of 19 Chironomidae species from the subfamilies Chironominae (10 species), Tanypodinae (7 species) and Orthocladiinae (2 species) were collected (Table 2). Shah Alam lake recorded the most species (14), followed by Ampang (10 species), Kota Damansara (9 species) and the lowest was Subang Jaya (8 species). However, chironomid species richness among the lakes was not significantly different (ANOVA, $F_{3,12} = 0.357$, $p = 0.785$). Chironominae was the most diverse subfamily in Ampang, Subang Jaya and Shah Alam lakes compared to Kota Damansara lake where Tanypodinae dominated. *Monopelopia* sp., *Procladius* sp. and *Corynoneura* sp. were only found in forested lakes whereas *Cladotanytarsus* sp., *Conochironomus* sp., *Dicrotendipes* sp., *Kiefferulus tainanus*, *Parachironomus* sp., *Clinotanypus* sp., *Tanypus* sp. and *Nanocladius* sp. were only found in urban lakes, particularly Shah Alam lake.

Species richness had a strong positive relationship with leaf litter cover (which was highest in the forest lakes – particularly Ampang Lake: Spearman's correlation, $r = 0.677$, p = 0.004, n = 16) and a moderate positive relationship with vegetation cover at bank (Spearman's correlation, $r = 0.544$, p = 0.029, n = 16),

Table 2 The diversity, abundance (in brackets) and functional feeding groups of Chironomidae collected from different lakes

Species	Location			
	Ampang	Kota Damansara	Subang Jaya	Shah Alam
Chironominae				
Chironomus javanus	CG (20)	–	CG (8)	CG (13)
Cladotanytarsus sp.	–	–	–	CG (12)
Conochironomus sp.	–	–	CG (19)	CG (2)
Dicrotendipes sp.	–	–	–	CG (14)
Kiefferulus tainanus	–	–	–	CG (18)
Parachironomus sp.	–	–	–	CG (10)
Polypedilum leei	CG (786)	CG (102)	CG (37)	CG (237)
Stenochironomus sp.	S (3)	S (1)	S (1)	–
Tanytarsus formosanus	CG (328)	CG (635)	CG (8)	CG (5)
Zavreliella marmorata	CG (735)	–	CG (36)	–
Tanypodinae				
Ablabesmyia sp.	P (15)	G, P (10)	G, P (44)	P (11)
Clinotanypus sp.	–	–	P (9)	P (6)
Monopelopia sp.	–	P (18)	–	–
Paramerina sp.	P (74)	P, G (41)	–	P (3)
Procladius sp.	P (140)	G, P (483)	–	–
Tanypus sp.	–	–	–	P (3)
Zavrelimyia sp.	P (17)	G, P (28)	–	P (2)
Orthocladinae				
Corynoneura sp.	CF (13)	CF (14)	–	–
Nanocladius sp.	–	–	–	CG (2)

CG collector-gatherer, *CF* collector-filterer, *G* grazer, *P* predator, *S* shredder, − not found

Abundance

The abundance of chironomids was significantly different among the lakes (Kruskal Wallis, Chi-square = 9.640, p = 0.022). Tukey's post-hoc test indicated that the chironomid abundance in forested lakes was higher than park lakes (Table 3). Chironominae represented more than 50% of larvae from all lakes – mostly *Polypedilum leei*, *Tanytarsus formosanus* and *Zavreliella marmorata*. Although Shah Alam lake had the highest diversity of Chironominae, the abundance was usually low (<20 per species) with the exception of *P. leei*. In contrast, *Procladius* sp. was the most abundant Tanypodinae (>100 larvae) whereas Orthocladiinae was the least abundant with *Corynoneura* sp. having the highest count of 14. Overall, *Stenochironomus* sp. and *Nanocladius* sp. were rare everywhere (never >3).

Chironomid abundance had a strong negative relationship with conductivity (Spearman's correlation, $r = -0.740$, p = 0.001, n = 16), moderate positive relationship with macrophytes, (Spearman's correlation, $r = 0.598$, $p = 0.014$, n = 16), moderate positive relationship with vegetation cover at banks (Spearman's correlation, $r = 0.527$, $p = 0.036$, n = 16), and strong negative relationship with substrates (Spearman's correlation, $r = -0.689$, $p = 0.003$, n = 16).

Chironomid community structure

NMDS showed that the composition of Chironomidae communities differed between each of the lakes, and there was a marked separation between forested and urban lakes (Fig. 2). The community composition of the forested lakes was more similar to each other than the urban lakes which exhibited greater differences.

Dietary analysis

Collector-gatherers consuming FPOM were the most diverse and abundant feeding group in all lakes (Table 2). These were all Chironominae apart from one Orthocladiinae (*Nanocladius* sp.). Predators (all Tanypodinae) occurred in all lakes, with prey body parts, such as head capsules of other Chironomidae, clearly visible in their guts. In addition, *Paramerina* sp. from Ampang lake consumed circular objects that appeared to be eggs of other aquatic invertebrates, suggesting a predatory diet. Interestingly, some Tanypodinae such as *Ablabesmyia* sp., *Paramerina* sp., *Procladius* sp. and *Zavrelimyia* sp. from Kota Damansara and Subang Jaya lakes also consumed a large quantity of blue-green algae, indicating a dietary shift.

Table 3 The mean abundance (±SE) per sample of chironomids in each lake by subfamily

Lakes	Chironominae	Tanypodinae	Orthocladiinae	Total Abundance
Ampang	463.50 ± 108.51	61.50 ± 10.51	3.25 ± 1.89	2111^{a}
Kota Damansara	184.50 ± 127.84	145.00 ± 64.89	3.50 ± 1.66	1332^{a}
Shah Alam	77.50 ± 36.92	6.75 ± 4.96	0.50 ± 0.29	339^{b}
Subang Jaya	27.25 ± 7.25	13.25 ± 4.77	0.00 ± 0.00	162^{b}

Any groups in a category sharing a common lower-case letter are not significantly different at $P < 0.05$ (Tukey HSD test)

Shredders (*Stenochironomus* sp.) and collector-filterers (*Corynoneura* sp.) were the least diverse and abundant larvae.

Discussion

The origins of the lakes and their subsequent development has influenced factors such as the substrates, establishment of aquatic vegetation, supply of allochthonous detritus and water chemistry. The coarser, rocky substrates of Subang Jaya and parts of Shah Alam lake (the dam wall) prevent the establishment of macrophytes, unlike the finer substrates of the forest lakes which provide good anchorage for macrophytes (Handley and Davy 2002; Li et al. 2012) (Table 1). Furthermore, the local authorities frequently remove the littoral vegetation around the urban park lakes. This management practice clearly has adverse effects on the chironomid fauna (and other aquatic fauna as well: unpublished data) and it should be avoided. Aquatic vegetation not only provides aesthetic value, it also has the potential to mediate the water quality of the lakes e.g. through uptake of heavy metals, filtration, and oxygenation via photosynthesis (Harada et al. 2013). It is recommended that more trees should be planted in the catchments and riparian zones of the urban park lakes. Riparian trees supply leaf litter and shade (reducing temperatures and photosynthesis by autotrophs) and minimize wind turbulence, which will influence the mixing of lake water (Joniak et al. 2000; Mokany et al. 2008; Spyra 2011). Coupled with the reduced water mixing, decomposition of leaf litter and submerged wood in the forested lakes could lead to a lower O_2 content and an increase in dissolved CO_2 (Dodds and Whiles 2010; Earl and Semlitsch 2013). Subsequently, the pH of the forest lakes also decreased possibly due to the association of dissolved carbon dioxide and leaching of organic acids from leaf litter (Sand-Jensen and Staehr 2007) The higher pH of the park lakes could also be

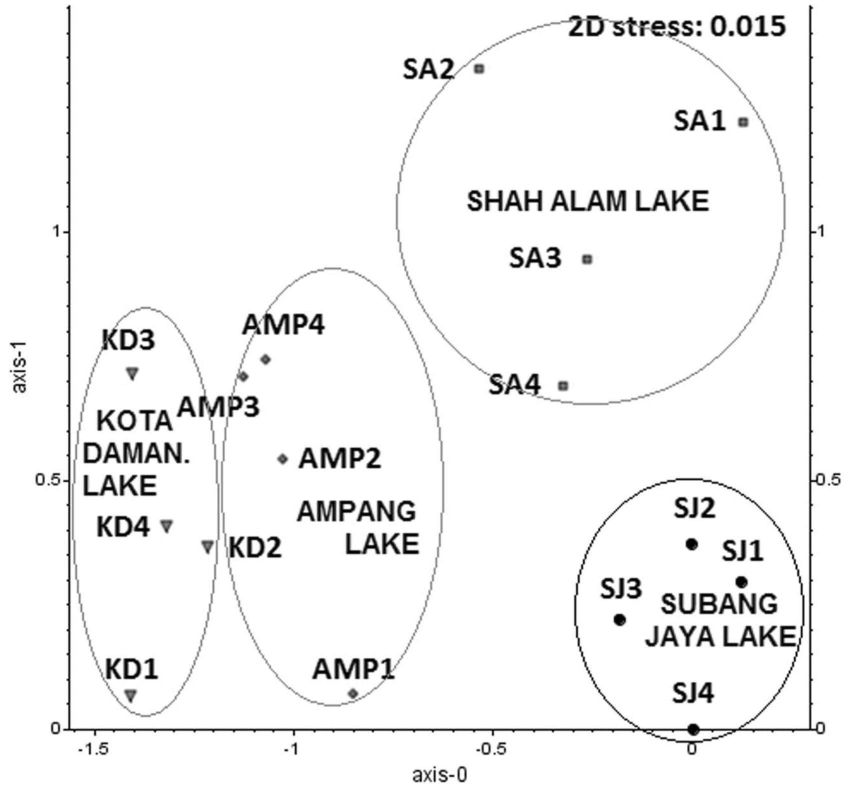

Fig. 2 MDS ordination plot of Chironomidae species composition among each site of the different lakes

a result of the contribution of inflow of polluted water from stormwater drains, especially mineral salts that contribute to the increase in alkalinity as well as conductivity which was highest in the urban park lakes and slightly elevated in Kota Damansara lake due to stormwater inflow (Table 1). It is recommended that polluted stormwater should not be directed to urban park lakes without adequate treatment. The catchment of Ampang Lake lay in pristine forest and so it had no polluted inflow. High rainfall events caused temporary elevations in naturally derived sediment and turbidity.

Chironominae and Tanypodinae are typically more abundant in warm tropical waters compared to Orthocladiinae (Eggermont and Heiri 2012) which could explain the low abundance and diversity of orthoclads in this study (Table 2). Shah Alam Lake was particularly warm (range 29.0–38.1 °C), while water temperature was significantly lower in the forested Ampang lake (25.9–28.4 °C) where chironomid abundance was highest, than the three urban lakes due to forest shading and lack of urban run-off (Table 1). Although high water temperatures may cause higher metabolic rates, denaturation of body enzymes or even death (Eggermont and Heiri 2012), Shah Alam lake had higher chironomid diversity than the other lakes. This could possibly be due to the greater tolerance of the chironomids to high temperatures and pollution compared to their potential predators and competitors such as hemipterans, coleopterans and odonates.

Macrophytes, leaf litter cover and substrate all create structural heterogeneity in the littoral zones and thus influence the community structure in the lakes (Dinakaran et al. 2008; Burdett and Watts 2009; Spyra 2011). In this study, the presence of macrophytes was shown to have a significant positive influence on chironomid abundance, supporting previous studies (Weatherhead and James 2001; Joniak et al. 2007; Takamura et al. 2009). Macrophytes provide a refuge from predation especially large predators such as fish (Tolonen et al. 2003). They also provide food directly (for grazers), as detritus (for shredders and collectors) (Spyra 2011; Iwai et al. 2012) and as a site for periphyton growth (for grazers), and they leach nutrients and organic matter (Joniak et al. 2007; Burdett and Watts 2009; Bazzanti et al. 2010; Taylor and Batzer 2010). The presence of macrophytes may be one of the interacting factors (together with cooler, cleaner water temperatures and higher oxygen content) that influence the presence of *Corynoneura* sp. in the two forested lakes (Boggero et al. 2006; Żbikowski and Kobak 2007; Bazzanti et al. 2010). Macrophytes and other vegetation along the lake banks may have indirect effects on chironomid abundance and species richness through the provision of oviposition sites for some taxa. Adult midges may aerially deposit egg masses on the water surface or deposit them near the water's edge on macrophytes, stones or leaf litter (Armitage et al. 1995). The high abundance of chironomids in forested lakes could possibly be influenced by the provision of abundant, protected oviposition sites.

Food resources are among the major factors affecting chironomid assemblages in an ecosystem. Previous studies have shown that pristine riverine communities typically have greater numbers of grazers, shredders and collector-filterers compared to predators and collector-gatherers which tend to dominate the fauna of lakes (Johnson et al. 2004; Earl and Semlitsch 2013), supporting the results in this study whereby collector-gatherers and predators dominated the four lakes (Table 1). There was an overwhelming abundance of chironomids in the forest lakes compared to urban lakes (Table 3), particularly collector-gatherers such as *Tanytarsus formosanus* and *Zavreliella marmorata.* One shredder species was recorded - *Stenochironomus*, which feeds by mining wood and vegetation (Mendes 2002; Sanseverino and Nessimian 2008; Koroiva et al. 2013). It was only recorded in lakes with submerged wood and was not collected in Shah Alam lake. There was also only one species of collector-filterer - *Corynoneura* which was only found in the two forest lakes. This genus has been associated with the presence of macrophytes, high oxygen content and lower water temperature (Boggero et al. 2006; Żbikowski and Kobak 2007; Bazzanti et al. 2010). Interestingly, *Nanocladius* sp., identified as collector-gatherer in this study has been known to be a parasite (Doucett et al. 1999) or ectosymbiont (Pennuto 2003; Hayashi and Ichiyanagi 2005) in other studies.

Chironomid larvae can exhibit generalist or opportunistic feeding behaviour depending on factors such as particle size selection, nutritional content and accessibility to food resources (Schmid and Schmid-Araya 1997; Naser and Roy 2012)(Schmid and Schmid-Araya 1997; Naser and Roy 2012). For example Tanypodinae can exhibit selective or non-selective feeding (Armitage et al. 1995). In this study, four predatory tanypod taxa, *Ablabesmyia* sp., *Paramerina* sp., *Procladius* sp., *and Zavrelimyia* sp. consumed blue-green algae and fungi in Kota Damansara and Subang Jaya lakes – both of which showed signs of pollution (Tables 1, 2). *Procladius* spp. have been reported to consume a wide range of food sources, including prey, detritus and periphyton (Vodopich and Cowell 1984; Nessimian and Sanseverino 1995; Galizzi et al. 2012). Laboratory experiments have shown that the survival and growth of *Procladius choreus* were equal regardless of the diet (Oligochaeta, Chironominae larvae and detritus) (Baker and McLachlan 1979), even though detritus has lower nutritional value than prey (Cummins and Klug 1979). Since prey have higher nutritional value due to more nitrogen content than algae (Sterner and Elser 2002), the consumption of periphyton despite high abundance of prey (i.e. Chironominae) by *Procladius* sp. in Kota Damansara lake could indicate that periphyton is abundant and more easily accessible compared to elusive small prey. The presence of prey body parts in the guts suggests that

Procladius sp. supplement their diet because periphyton alone may not be sufficient for growth (Vodopich and Cowell 1984).

Conclusions

The characteristics of the forested and park lakes clearly influenced the assemblage and diets of chironomids. The forested lakes had higher allochthonous inputs than the urban park lakes which enabled them to support more chironomids, particularly collector-gatherers. The urban park lakes, and to some extent Kota Damansara Lake, have been affected by urban runoff as indicated by the higher water conductivity compared to pristine Ampang Lake. This has resulted in abundant growths of Cyanophyta, which allowed some predatory tanypod taxa to supplement their diets with blue green algae. The presence of riparian vegetation and aquatic macrophytes clearly had a positive influence on chironomid communities by providing food, microhabitats, shade and possibly filtering pollutants and thus would be expected to be beneficial to other fauna as well. To improve the ecology of the urban lakes the municipal councils should reconsider the present maintenance regimes (removing littoral vegetation), plant more riparian vegetation (particularly trees) and address the problems of polluted inflows.

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