Effects of water temperature, dissolved oxygen and total suspended solids on juvenile *Barbonymus schwanenfeldii* (Bleeker, 1854) and *Oreochromis niloticus* (Linnaeus, 1758)

[1]Lee Nyanti, [1]Chen-Lin Soo, [1]Nona-Nabilah Ahmad-Tarmizi, [1]Nik-Nurul-Kamila Abu-Rashid, [1]Teck-Yee Ling, [1]Siong-Fong Sim, [2]Jongkar Grinang, [3]Tonny Ganyai, [3]Karen-Suan-Ping Lee

[1] Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia; [2] Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia; [3] Research and Development Department, Sarawak Energy Berhad, 93050 Kuching, Sarawak, Malaysia. Corresponding author: L. Nyanti, lnyanti@unimas.my

Abstract. The aim of the present study was to investigate the effects of water temperature, dissolved oxygen (DO), and total suspended solids (TSS) in water on an indigenous fish species, *Barbonymus schwanenfeldii* (Bleeker, 1854), and an exotic fish species, *Oreochromis niloticus* (Linnaeus, 1758) in Malaysia. The survival rate, growth performance, and feed conversion ratio (FCR) of juvenile fish were tested in different water quality conditions for 30 days. The water temperature of 30°C, DO value of less than 4 mg L^{-1}, and TSS content of 1000 mg L^{-1} are believed to be harmful to fish life. The result indicates that the *O. niloticus* juveniles are relatively tolerant of high water temperature and TSS in term of survivorship, whereas the *B. schwanenfeldii* juveniles are more vulnerable to the two parameters. Reduced DO value had influenced the survival rate of both fish species in a similar way where 100% mortality of both fish species occurred at DO value less than 2 mg L^{-1}. The growth performance of juvenile *B. schwanenfeldii* was less susceptible to the changes of water temperature and DO whereas the growth performance of juvenile *O. niloticus* was influenced by the two parameters. The results show that the FCR of both fish increased with high water temperature and TSS. The juvenile *B. schwanenfeldii* was able to sustain its growth by consuming additional food in high water temperature. Increased DO value significantly improved the FCR of *O. niloticus* juvenile but not of *B. schwanenfeldii* juvenile.

Key Words: turbidity, hypoxia, survival rate, growth performance, feed conversion ratio, exotic species, native species.

Introduction. Anthropogenic activities resulting in degradation of aquatic habitats are increasing in Sarawak (Ling et al 2013; Gandaseca et al 2014; Nagarajan et al 2015; Ling et al 2016; Soo et al 2016). Most anthropogenic activities generally raise the temperature of receiving waters, cause sedimentation and eutrophication which leads to the turbid environment and depletion of dissolved oxygen (DO) content in water column (Moehansyah et al 2002; Moore et al 2005; Cooke et al 2011). Those physicochemical water quality parameters determine the distribution and abundance of fish and affect the survival and growth of fish (Freund & Petty 2007; Bilotta & Brazier 2008; Ice 2008; Gupta et al 2012; Flint et al 2015; Kjelland et al 2015; Jeppesen et al 2018). The effects of water temperature upon life of fish which is a poikilotherm are profound (Durham et al 2006; Bartolini et al 2014). DO in water is also considered one of the most revealing factors in water quality where hypoxia is a common cause of fish kills around the world (Flint et al 2015; Jeppesen et al 2018). High suspended solids in water can cause physical damage to gill structure of fish and clogging which leads to respiratory failure (Au et al 2004). The turbid condition also decreases anti predator behavior, foraging efficiency, and hatching rate of fish (Gray et al 2012; Li et al 2013; Kimbell & Morrell 2015).

In addition to the degradation of ecosystem by human activities, freshwater ecosystems can be impacted by exotic species. The greater tolerance of exotic fishes to environmental stressors was the major contributor of the invasion success of exotic species. The large interspecific variation in the temperature tolerance of exotic fish species had ease the establishment of exotic species in the Rhine river that subjected to thermal pollution, thus limit the full recovery of native fish fauna and increases competition between native and exotic species (Leuven et al 2011). Butler et al (2010) stated that the ability of exotic fish to acquire oxygen from its environment is a key to its survival compared to native species. Nyanti et al (2017) studied the acidification tolerance between native and exotic fish species in Malaysia. The exotic fish *Oreochromis niloticus* is found to be more acidic tolerant than the native fish *Barbonymus schwanenfeldii* demonstrating the vulnerability of Malaysian native fish in natural environment that facing water acidification problem due to human activities.

Understanding of the environmental stressors tolerance of fishes and how this varies among native and exotic species can play an important role in estimating fish ecological distribution and making predictions about which organisms are particularly threatened by environmental change. All of which could provide a better information for aquatic management and conservation. Yet, tolerance of Malaysian native and non-native fish species exposed to high temperature, low DO, and high TSS concentration has not been investigated. Hence, this study aims to study the effects of water quality on survival, growth performance, and feed conversion ratio of the indigenous fish species of *B. schwanenfeldii* and compared with the exotic fish species of *O. niloticus* in Malaysia.

Material and Method. The experimental setup in Nyanti et al (2017) was followed in the present study with minor modification. The experiment was conducted from October to November 2013 in Universiti Malaysia Sarawak, Kota Samarahan, Malaysia. Three experiments were conducted to study the effect of water temperature, DO, and total suspended solids (TSS) on *B. schwanenfeldii* and *O. niloticus* juveniles. Rectangular fiberglass tanks (2.1 m x 1.3 m x 0.6 m) with small compartments (39 cm x 49 cm x 67 cm) made from polyvinyl chloride (PVC) frame and net were used. Capacity of each compartment was approximately 70 L and served as one replicate for each treatment. The *B. schwanenfeldii* and *O. niloticus* juveniles were obtained from the Department of Agriculture, Serian and PM Aquaculture Sdn. Bhd., Kota Sentosa, respectively. The fish were acclimatized for three days before the experiment. All the fish were active and no mortality was occurred prior to the experiment.

Two water temperature levels (24°C and 30°C) were selected and maintained by using an immersion thermostatic heater (Tianrun, W-500HG). Five levels of DO (0, 2, 4, 7, and 8.5 mg L^{-1}) were selected in the present study. The low DO values (0, 2, 4 mg L^{-1}) were adjusted by using sodium sulphite while the high DO values (7 and 8.5 mg L^{-1}) were maintained by aeration. The temperature and DO values of each tank were monitored and maintained daily throughout the experiment. Five levels of TSS (0, 500, 1000, 5000, and 10000 mg L^{-1}) were investigated. Sediment sample collected from the banks of Sarawak River was used to prepare different TSS concentrations. The sediment sample was first sterilized at 125°C by using an oven (ESCO Isotherm, Isocide). Then, a selected weight of sediment was added into each tank to attain the four TSS concentrations. Tank without sediment addition has served as a control. The water in tank was stirred to obtain a homogenous distribution of sediment in tank. TSS value was monitored and maintained weekly throughout the experiment.

At each treatment, all water quality parameters were maintained as constant value and monitored weekly except for the studied parameter (Table 1). Temperature, pH, and DO were measured by using a pH meter with temperature probe (Hanna, HI8424) and a DO meter (Hanna, H19142), respectively. TSS was determined as the difference between the initial and final weight of the 0.45 µm glass fibre filter (Whatman GF/C), after filtration of an adequate sample volume and drying at 105°C. Weekly water sample was also taken from each tank for total ammoniacal nitrogen (TAN) and nitrite-nitrogen (NO_2-N) analyses using HACH method (HACH 2012). Water was changed when the concentrations of TAN and NO_2-N were high.

Table 1

Water quality during the three experiments, and initial total length (TL) and body weight (BW) of fish used in the present study

Experiment	*Water quality*					*Barbonymus schwanenfeldii*		*Oreochromis niloticus*	
	Temperature (°C)	*DO (mg L^{-1})*	*pH*	*TAN (mg L^{-1})*	*NO_2-N (mg L^{-1})*	*Initial TL (cm)*	*Initial BW (g)*	*Initial TL (cm)*	*Initial BW (g)*
Temperature (°C)									
24	24	7.6±0.2	7.5±0.1	0.03±0.03	0.01±0.00	2.8±0.2	0.2±0.0	2.8±0.3	0.3±0.1
30	30	7.6±0.1	7.6±0.0	0.07±0.02	0.01±0.00	2.8±0.2	0.2±0.0	2.8±0.3	0.3±0.1
DO (mg L^{-1})									
0	25.4±0.3	0	6.9±0.5	0.80±0.03	0.02±0.01	3.2±0.5	0.3±0.1	3.2±0.2	0.5±0.0
2	26.0±0.5	2	7.0±0.5	0.80±0.03	0.02±0.01	3.2±0.5	0.3±0.1	3.2±0.2	0.5±0.0
4	25.5±0.4	4	7.2±0.4	0.84±0.07	0.02±0.01	3.2±0.5	0.3±0.1	3.2±0.2	0.5±0.0
7	25.3±0.2	7	7.4±0.4	0.80±0.04	0.02±0.01	3.2±0.5	0.3±0.1	3.2±0.2	0.5±0.0
8.5	25.6±0.0	8.5	7.0±0.0	0.37±0.41	0.02±0.01	3.2±0.5	0.3±0.1	3.2±0.2	0.5±0.0
TSS (mg L^{-1})									
0	25.8±1.0	7.9±0.4	7.4±0.3	0.80±0.05	0.01±0.01	3.9±0.3	0.5±0.1	3.1±0.4	0.3±0.1
500	26.0±1.0	7.6±0.2	7.2±0.3	0.85±0.05	0.02±0.01	3.9±0.3	0.5±0.1	3.1±0.4	0.3±0.1
1000	26.0±1.0	7.7±0.3	7.0±0.5	0.80±0.04	0.02±0.01	3.9±0.3	0.5±0.1	3.1±0.4	0.3±0.1
5000	26.0±1.1	7.8±0.3	7.0±0.5	0.77±0.03	0.02±0.01	3.9±0.3	0.5±0.1	3.1±0.4	0.3±0.1
10000	26.0±1.0	7.8±0.3	6.9±0.5	0.82±0.05	0.02±0.01	3.9±0.3	0.5±0.1	3.1±0.4	0.3±0.1

Twenty individuals from each species were used for each treatment. Each treatment was conducted in triplicate. The initial total length (TL) and body weight (BW) of *B. schwanenfeldii* and *O. niloticus* juveniles were measured to the nearest centimeter and to the nearest gram by using a measuring board (Wildco, 118) and a weighing balance (Adventurer, Dhaus), respectively. Since the temperature, DO, and TSS experiments were three independent experiments, the fishes used in each experiment were chosen as long as they were in juvenile stage. Table 1 summarizes the initial TL and BW of fish used in each treatment. The fish were fed twice daily at 5% BW with pelleted fish feed throughout the experiment. Daily fish mortality was recorded and dead fish was replaced immediately with fish receiving the same treatment to maintain the density of fish in each compartment. At the end of the experiment, the TL and BW of fish for each treatment were measured. The survival rate, growth performance, and food conversion ratio (FCR) of fish were calculated as:

$$\text{Survival rate (\%)} = N_i/N_0*100;$$
$$\text{Body weight gain (BWG)} = W_i - W_0;$$
$$\text{Total length gain (TLG)} = TL_i - TL_0;$$
$$\text{Specific growth rate (SGR)} = (\ln W_i - \ln W_0)/t*100;$$
$$FCR = Df/(W_i - W_0).$$

Where N_i = number of fish at the end of the experiment, N_0 = initial number of fish, W_i = weight of fish at the end of the experiment (g), W_0 = initial weight of fish (g), TL_i = total length of fish at the end of the experiment (cm), TL_0 = initial total length of fish (cm), t = experiment time (day), Df = dry feed (g).

The survival rate, TLG, BWG, SGR, and FCR of fish exposed to different water temperature, DO, and TSS were compared using the ANOVA test followed by Turkey test at $p < 0.05$. Independent t-test was used to compare the aforementioned parameters between the two species. All the statistical analyses were carried out by using the Statistical Software for Social Sciences (SPSS Version 22, SPSS Inc. 1995).

Results

Temperature. Figure 1 illustrates that survival rate, TLG, BWG, and SGR of *B. schwanenfeldii* and *O. niloticus* juveniles were relatively lower at 30°C than those at 24°C. No mortality of fish was observed at 24°C, but survival rate of *B. schwanenfeldii* juvenile significantly decreased ($p < 0.05$) to 75±5.0% at 30°C. The survival rate of *O. niloticus* juvenile also decreased to 88.3±11.5% but it was not statistically significant ($p > 0.05$). No significant differences ($p > 0.05$) in the TLG and BWG of *B. schwanenfeldii* and *O. niloticus* juveniles when they were exposed to different water temperature. However, *O. niloticus* juvenile showed significantly lower ($p < 0.05$) SGR at 30°C (2.71±0.30%) than that at 24°C (3.67±0.50%). The FCR of both fish was significantly higher at 30°C (≈ 2.84) than that at 24°C (≈ 2.00). When both fish were exposed to high water temperature, the survival rate, growth performance, and FCR of *B. schwanenfeldii* juvenile were not significantly different ($p > 0.05$) from *O. niloticus* juvenile. Yet, the *O. niloticus* juvenile grew better than *B. schwanenfeldii* juvenile at 24°C where it's BWG and SGR were significantly higher ($p < 0.05$) than those of *B. schwanenfeldii* juvenile.

Dissolved oxygen. Figure 2 illustrates that none of the fish survived when they were exposed to DO values of 0 mg L^{-1} and 2 mg L^{-1}. The survival rate of *B. schwanenfeldii* and *O. niloticus* juveniles significantly increased ($p < 0.05$) to 76.7±2.9% and 83.3±7.6%, respectively, when DO value was increased to 4 mg L^{-1}. More than 90% and 100% survival rates were recorded for both species at DO value of 7 mg L^{-1} and 8.5 mg L^{-1}, respectively. There was no significant difference ($p > 0.05$) in survival rate between the two species that were exposed to different DO value. The highest TLG of *B. schwanenfeldii* juvenile (1.20±0.11 cm) and *O. niloticus* juvenile (1.17±0.25 cm) was observed at DO value of 8.5 mg L^{-1}. The TLG of both fish was significantly lower ($p < 0.05$) when DO value decreased. The BWG, SGR, and FCR of *B. schwanenfeldii* juvenile were not significantly different when exposed to different DO value, with a mean of 0.55

g, 4.44%, and 1.05, respectively. On the other hand, the highest BWG (1.09±0.10 g) and SGR (4.00±0.21%) of *O. niloticus* juvenile were observed at DO value of 8.5 mg L^{-1} and decreased significantly ($p < 0.05$) as DO decreased. The FCR of *O. niloticus* juvenile significantly increased ($p < 0.05$) from 1.26 to 2.39 as DO value was decreased. The BWG, SGR, and FCR of *O. niloticus* juvenile were significantly higher ($p < 0.05$) than *B. schwanenfeldii* juvenile at DO values of 4 and 7 mg L^{-1}. When exposed to DO value of 8.5 mg L^{-1}, the BWG of *O. niloticus* juvenile was significantly higher ($p < 0.05$) than *B. schwanenfeldii* juvenile, but there was no significantly different ($p > 0.05$) in SGR and FCR between the two fish.

Total suspended solids. Figure 3 illustrates that the survival rate, TLG, BWG, and SGR of *B. schwanenfeldii* and *O. niloticus* juveniles decreased as TSS concentration increased while their FCR exhibited an opposite trend. When they were exposed to 1000 mg L^{-1} of TSS and above, their survival rate (≈ 67.5%) was significantly lower ($p < 0.05$) than those in the control (≈ 89.2%). There was no significant difference ($p > 0.05$) in survival rate between the two species when they were exposed to TSS concentration up to 5000 mg L^{-1}. However, survival rate of *O. niloticus* juvenile (43.3±7.6%) was significantly higher than *B. schwanenfeldii* juvenile (13.3±2.9%) when they were exposed to 10000 mg L^{-1} of TSS.

The TLG and BWG of *B. schwanenfeldii* juvenile steadily decreased from 0.46±0.03 cm and 0.81±0.13 g to 0.21±0.05 cm and 0.28±0.01 g, respectively, when the fish was exposed to increasing TSS concentration. The TLG and BWG of *B. schwanenfeldii* juvenile that exposed to 1000 mg L^{-1} of TSS was significantly lower ($p < 0.05$) than those in control. Similarly, the TLG and BWG of *O. niloticus* juvenile decreased from 0.61±0.03 cm to 0.29±0.14 cm and from 0.93±0.01 g to 0.33±0.14 g, respectively, when TSS concentration was increased. The TLG and BWG of *O. niloticus* juvenile exhibited different responses when it was exposed to different concentrations of TSS. The TLG and BWG of *O. niloticus* juvenile were significantly lower ($p < 0.05$) than those in control when it was exposed to 5000 and 500 mg L^{-1} of TSS, respectively. The TLG of *B. schwanenfeldii* juvenile was significantly lower ($p < 0.05$) than *O. niloticus* juvenile when they were exposed to TSS concentrations of 0 and 500 mg L^{-1}. However, their TLG became not significantly different ($p > 0.05$) when they were exposed to a higher TSS concentration at 1000 mg L^{-1} of TSS and above. On the other hand, the BWG of both fish was not significantly different ($p > 0.05$) at all treatments.

The SGR of *B. schwanenfeldii* and *O. niloticus* juveniles decreased from 4.39±0.02% and 3.02±0.30% to 2.21±0.67% and 1.36±0.04%, respectively. The SGR of juvenile fish of both species was significantly lower ($p < 0.05$) than that in control when they were exposed to 500 mg L^{-1} of TSS. The SGR of *B. schwanenfeldii* juvenile was significantly lower ($p < 0.05$) than *O. niloticus* juvenile when exposed to TSS concentration ranging from 0 to 5000 mg L^{-1}. However, the difference in SGR became not significant ($p > 0.05$) when they were exposed to 10000 mg L^{-1} of TSS. In contrast, the FCR of *B. schwanenfeldii* juvenile (2.04-5.91) was significantly higher than *O. niloticus* juvenile (0.96-2.38) at all treatments. The FCR of *B. schwanenfeldii* and *O. niloticus* juveniles was significantly higher ($p < 0.05$) than that in control when they were exposed to 5000 and 10000 mg L^{-1} of TSS, respectively.

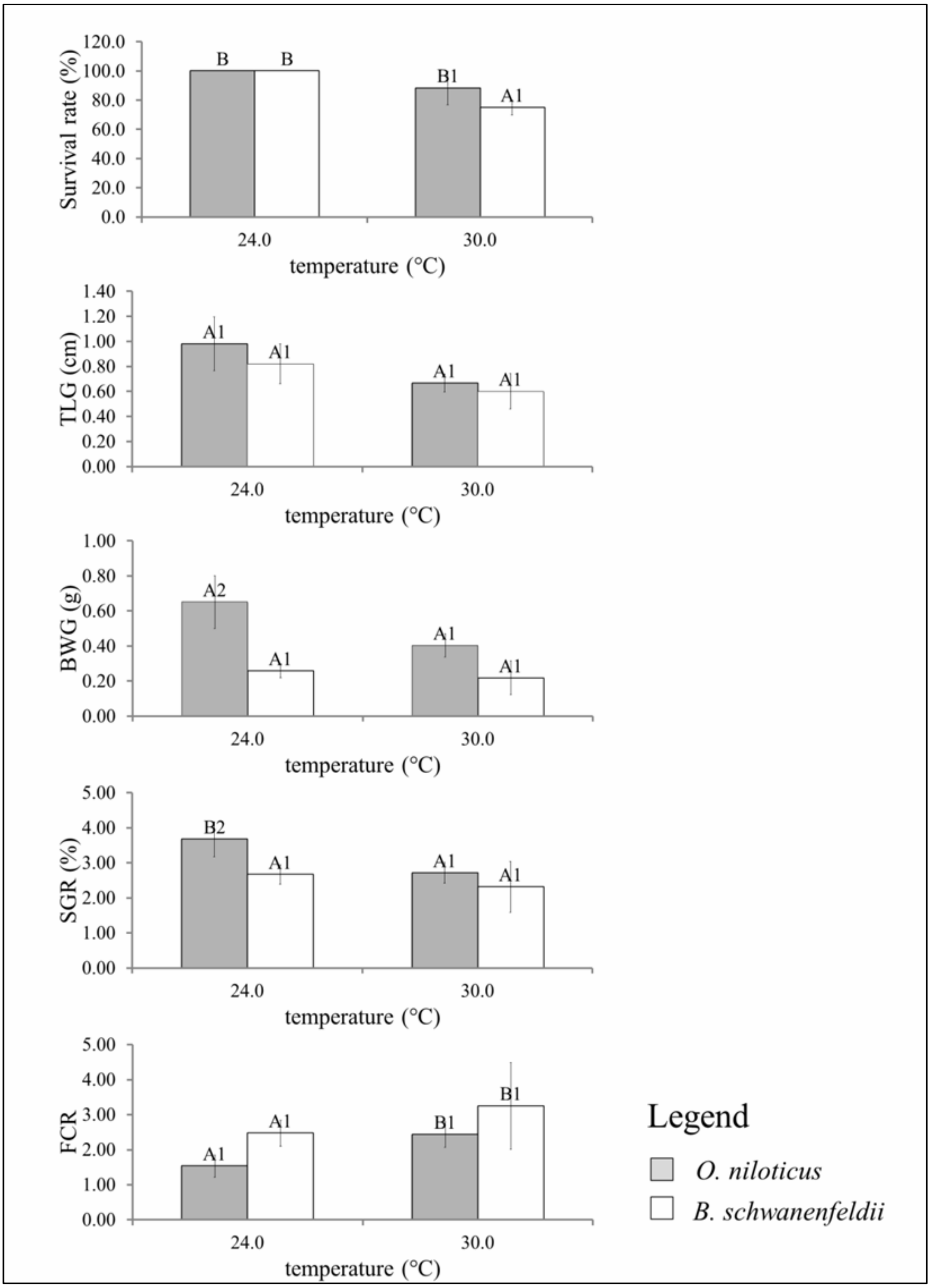

Figure 1. Survival rate, growth performance (TLG, BWG, and SGR), and FCR of *Oreochromis niloticus* and *Barbonymus schwanenfeldii* juveniles subjected to different water temperature for 30 days. Different letters indicate significant difference between treatments whereas different numbers indicate significant difference between fish at $p < 0.05$.

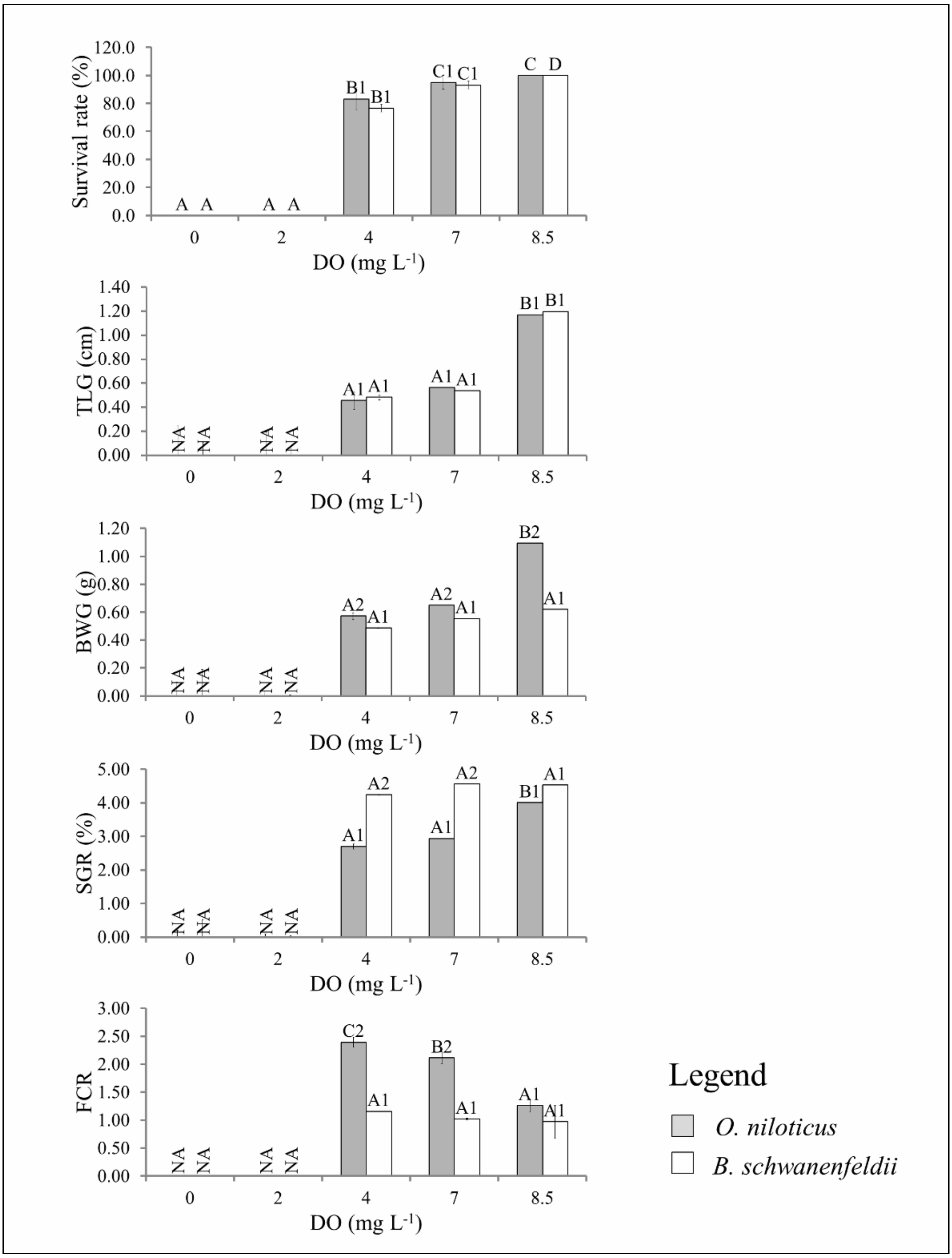

Figure 2. Survival rate, growth performance (TLG, BWG, and SGR), and FCR of *Oreochromis niloticus* and *Barbonymus schwanenfeldii* juveniles subjected to different DO for 30 days. Different letters indicate significant difference between treatments whereas different numbers indicate significant difference between fish at $p < 0.05$. NA = data not available due to 100% mortality of fish.

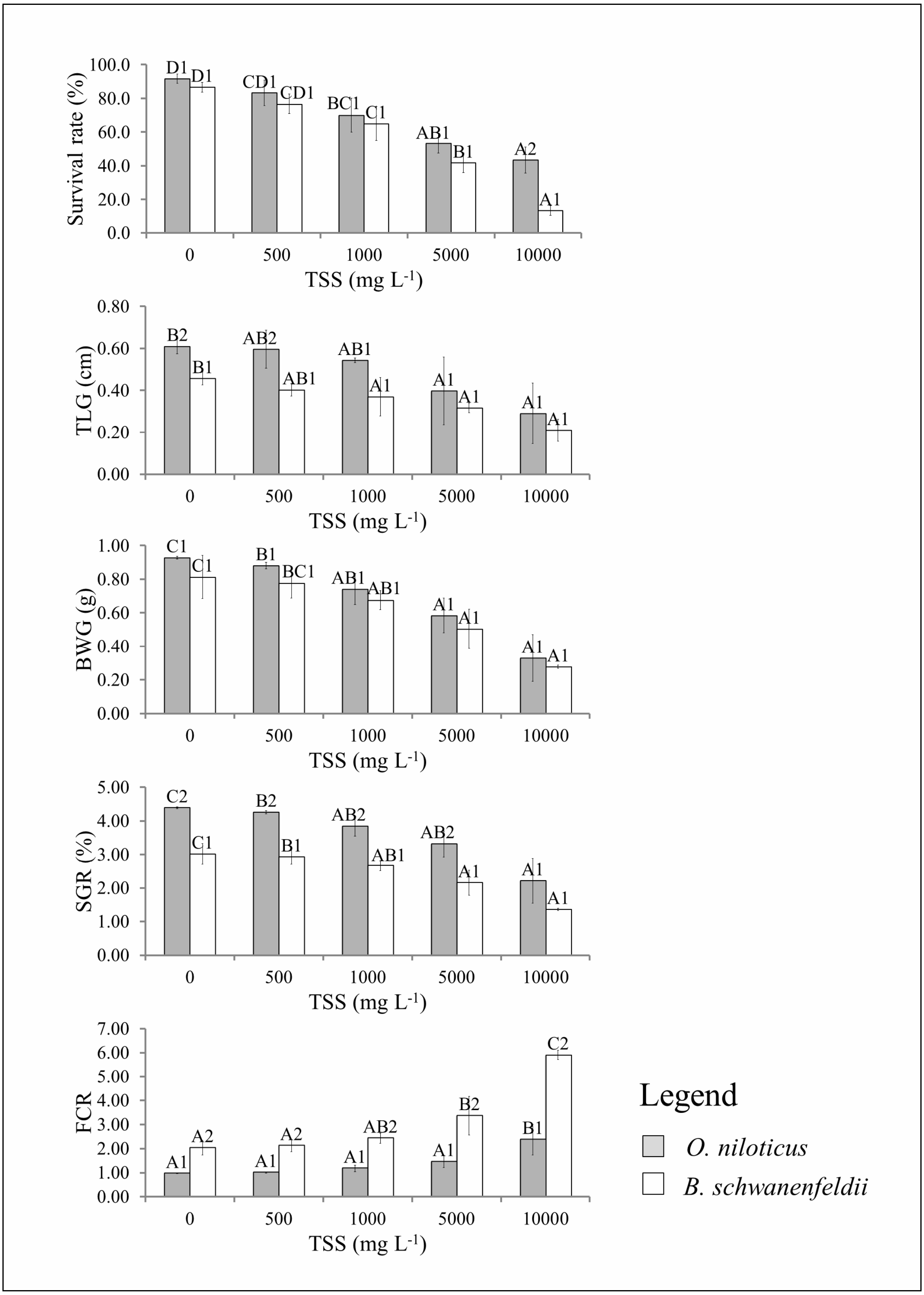

Figure 3. Survival rate, growth performance (TLG, BWG, and SGR), and FCR of *Oreochromis niloticus* and *Barbonymus schwanenfeldii* juveniles subjected to different TSS for 30 days. Different letters indicate significant difference between treatments whereas different numbers indicate significant difference between fish at $p < 0.05$.

Discussion. Increased water temperature had influenced mostly the survival rate and FCR of *B. schwanenfeldii* and *O. niloticus* juveniles. The impact of increased water temperature is more profound on *B. schwanenfeldii* juvenile than *O. niloticus* juvenile where its survival rate decreased significantly ($p < 0.05$) at 30°C. Comparatively, the thermal tolerance of *Labeo rohita* fry and *Barbus barbus* larvae are wider than the two test organisms in the present study where nearly 100% of fish survived at temperature ranging from 26 to 36°C, and from 21 to 30°C, respectively (Das et al 2005; Kaminski et al 2013). Besides, El-Sherif & El-Feky (2009) and Pandit & Nakamura (2010) reported 100 and 95% of survival rate of *O. niloticus* fingerlings reared at 30 and 35°C, respectively. The lower survival rate of *O. niloticus* juvenile (88.3%) in the present study when compared to those studies was probably due to different fish size used in the test. Body size often affects fish tolerance to extreme environment condition due to ontogenetic difference in physiology where thermal tolerance decreased among successive stages (Komoroske et al 2014; Moyano et al 2017).

An increment of 6°C in the present study significantly increased ($p < 0.05$) the FCR of both fish species. Higher FCR at higher temperature is expected as elevated temperature increases the metabolism and respiration of fish, resulting in increased FCR. The *O. niloticus* fingerlings (Pandit & Nakamura 2010) and *L. rohita* fry (Das et al 2005) exhibited a similar trend as that for *B. schwanenfeldii* and *O. niloticus* juveniles. However, the increment of 6°C in the present study did not have a significant impact ($p > 0.05$) on the TLG, BWG, and SGR of *B. schwanenfeldii* juvenile albeit the values were lower at 30°C. The result indicates that *B. schwanenfeldii* juvenile was able to maintain growth at higher temperature through consume additional food. On the other hand, the TLG and BWG of *O. niloticus* juvenile did not differ significantly ($p > 0.05$) when water temperature increased, yet its SGR was significantly lower ($p < 0.05$) at 30°C than that at 24°C. This demonstrates that the growth of *O. niloticus* juvenile is impaired at elevated water temperature. Similar trend was also found in *O. niloticus* fingerlings and *L. rohita* fry, which exhibited a decrease in growth when temperature was increased (Das et al 2005; Pandit & Nakamura 2010).

Decreased of DO value to anoxic and hypoxia conditions had a detrimental effect on survival of *B. schwanenfeldii* and *O. niloticus* juveniles where 100% mortality of both fish species occurred when they were exposed to 0 and 2 mg L^{-1} of DO. The survival rate of *O. niloticus* juvenile in the present study was lower than the study of Abdel-Tawwab et al (2015) where high survival rate (> 95%) of *O. niloticus* was reported in low DO water (1.0 to 1.5 mg L^{-1}). This is most probably due to the smaller fish size used in the present study (≈ 0.3 g) compared to the study of Abdel-Tawwab et al (2015) where a small fish size of 3.7 g and a large fish size of 12.8 g were used. The juvenile fish have a higher metabolic rate than larger fish rendering them more vulnerable in anoxic condition. In that study, the authors also noticed that larger fish tolerated low DO better than the small ones where the highest mortality was observed in smaller fish at low DO.

The oxygen requirements and DO tolerances of the two species were similar as there was no significant difference ($p > 0.05$) on survival rate between the two species at different DO value. This indicates that the exotic species *O. niloticus* juvenile did not possess a significant advantage upon the native species of *B. schwanenfeldii* juvenile at anoxic and hypoxia conditions. On the other hand, Butler et al (2010) studied the DO tolerances of native and exotic freshwater fish species of North Queensland and found that the exotic fishes have significantly greater DO tolerances than most native fish species. The authors attributed the low DO tolerance of Australian native fish to a shorter evolutionary history in hypoxia freshwater. In addition, most of the exotic fish of North Queensland belong to families that are capable of breathing oxygen directly from the air in hypoxic waters and can stay out of water for considerable periods, whereas most of the freshwater fish native to northern Australia does not possess this capability. Flint et al (2015) also demonstrated that juvenile barramundi (*Lates calcarifer*) and rainbowfish (*Melanotaenia splendida splendida*) that attempted to perform aquatic surface respiration in hypoxia condition were more tolerant of severe hypoxia than was sooty grunter (*Hephaestus fuliginosus*) that did not perform aquatic surface respiration.

In the present study, the BWG, SGR, and FCR of *B. schwanenfeldii* juvenile were not significantly different ($p > 0.05$) at DO value ranged from 4 to 8.5 mg L^{-1}. The results indicate that DO in that range did not have significant effects on the growth and feed efficiency of *B. schwanenfeldii* juvenile. On the other hand, exposure of *O. niloticus* juvenile in high DO water considerably improves its growth performance and feed efficiency. The TLG, BWG, and SGR of *O. niloticus* juvenile significantly increased ($p < 0.05$) whereas its FCR significantly decreased ($p < 0.05$) when it was exposed to 8.5 mg L^{-1} of DO. Similar result was demonstrated in the study of Abdel-Tawwab et al (2015) where fish growth and feed intake were adversely affected by low DO. The low feed intake and low growth observed in fish at low DO conditions were due to fish appetite and digestibility was reduced (Tran-Duy et al 2012). Thus, the high growth of *O. niloticus* juvenile in the present study under high DO condition could be attributed to better feed consumption and nutrient digestibility.

Exposure of *B. schwanenfeldii* and *O. niloticus* juveniles to high TSS influence their survival rate, growth performance, and FCR. The survival rate, TLG, BWG, and SGR of both fish inversely proportional to a TSS increase. On the other hand, the FCR of both fish increased when TSS was increased. Exposure of fish in 1000 mg L^{-1} of TSS significantly reduced (p value < 0.05) their survival rate to less than 70% when compared to control (≈ 89.2%). The impact of increased TSS is more profound on *B. schwanenfeldii* juvenile than *O. niloticus* juvenile. This is evident in the fact that the survival rate of *B. schwanenfeldii* juvenile was significantly lower (p value < 0.05) than *O. niloticus* juvenile when they were exposed to extremely turbid water. Nearly half of the *O. niloticus* juvenile (43.3%) and merely 13.3% of *B. schwanenfeldii* juvenile survived when they were exposed to 10000 mg L^{-1} of TSS. The fish death could be due to the respiratory failure caused by clogging and physical damage of the gills at high TSS concentration (Buermann et al 1997). Similarly, mortality of the redbreast tilapia, *Tilapia rendalli* increased with increasing silt concentration (Buermann et al 1997). However, the TSS tolerance of *O. niloticus* juvenile in the present study was lower than *T. rendalli* juvenile where the LC_{50} value of *T. rendalli* juvenile was reported as ranging from 21 to 24 g L^{-1} (≈ 21000 to 24000 mg L^{-1}).

The present study demonstrated that a turbid environment can be stressful for fish and compromise fish growth and feeding. It has been shown that prolong exposure of high TSS in fish can cause damages to gill structure, osmoregulatory stress, and physiological stress in fish (Au et al 2004). In the present study, the SGR of both fish was significantly lower ($p < 0.05$) when they were exposed to 500 mg L^{-1} of TSS. Similarly, Suedel et al (2017) reported that the growth of smallmouth bass (*Micropterus dolomieu*) swim-up fry decreased when the fry was exposed to 100 mg L^{-1} of TSS for 72 hours. The *B. schwanenfeldii* juvenile was more susceptible to turbid environment than *O. niloticus* juvenile. The TLG and SGR of *O. niloticus* juvenile were significantly higher ($p < 0.05$) than *B. schwanenfeldii* juvenile, although it became not significantly different ($p > 0.05$) when TSS increased. Besides, the FCR of *O. niloticus* juvenile remained constant in TSS concentration ranging from 0 to 5000 mg L^{-1} of TSS. On the other hand, the FCR of *B. schwanenfeldii* juvenile was significantly increased when it was exposed to 5000 mg L^{-1} of TSS. The result indicates that the slower growth of *B. schwanenfeldii* juvenile at higher TSS may increases its mortality risk in natural environment because it remains in the vulnerable small size classes for a longer period.

Reduced survival rate of *B. schwanenfeldii* juvenile at high water temperature, low DO, and turbid condition could have important long-term effects for *B. schwanenfeldii* populations in natural environment. The lower survival rate of the native species of *B. schwanenfeldii* juvenile than the exotic species of *O. niloticus* juvenile at high water temperature and turbid condition confers a disadvantage of the native species in natural environment. The water temperature of 30°C is believed to be harmful to fish life and growth as lower survival rate and SGR were observed in *B. schwanenfeldii* and *O. niloticus* juveniles, respectively. Water temperature of tropical reservoirs and forest streams subjected to logging activities can easily reach 30°C and above (Nyanti et al 2012; Ling et al 2016; Ling et al 2017a; Ling et al 2017b). Consequently, temperature profiles of aquatic habitat can profoundly influence the distribution and competitiveness of *B. schwanenfeldii* (Lessard & Hayes 2003; Cooke et al 2004; Durham et al 2006). As *B. schwanenfeldii* juvenile has low survival rate in turbid condition, the fish is vulnerable in natural environment that facing water sedimentation problem due to human activities. The greater TSS tolerance of exotic species confers a significant advantage upon these native fishes, especially as high TSS is common in Sarawak forest streams subjected to logging activities (Ling et al 2016; Ling et al 2017b). If both fish species are in these same environments that exotic species have become most abundant, it thus increases competition between native and non-native species.

Conclusions. The present study demonstrated that survival rate, growth performance, and SGR of fish are influenced by a number of water quality parameters including water temperature, DO value, and TSS concentration. Those water quality parameters influenced the fish life and growth to a different extent. The indigenous species *B. schwanenfeldii* and exotic species *O. niloticus* in Malaysia also exhibited different responses to the changes of water quality. Thermal and TSS tolerances of the indigenous species *B. schwanenfeldii* were lower than the exotic species *O. niloticus* in Malaysia; yet the DO tolerance of both fish species was similar. The growth of *B. schwanenfeldii* juvenile did not show a significant response to temperature and DO changes but it was significantly influenced by high TSS concentration. In contrast, the growth of *O. niloticus* juvenile was significantly influenced by all parameters. The FCR of both fish species was increased significantly when water temperature and TSS were increased.

Acknowledgements. The authors appreciate the financial support provided by the Sarawak Energy Berhad through Grant No. GL(F07)/SEB/6/2013(32), and the facilities provided by Universiti Malaysia Sarawak.

References

Abdel-Tawwab M., Hagras A. E., Elbaghdady H. A. M., Monier M. N., 2015 Effects of dissolved oxygen and fish size on Nile tilapia, *Oreochromis niloticus* (L.): growth performance, whole-body composition, and innate immunity. Aquaculture International 23(5):1261-1274.

Au D. W. T., Pollino C. A., Wu R. S. S., Shin P. K. S., Lau S. T. F., Tang J. Y. M., 2004 Chronic effects of suspended solids on gill structure, osmoregulation, growth, and triiodothyronine in juvenile green grouper *Epinephelus coioides*. Marine Ecology Progress Series 266:255-264.

Bartolini T., Butail S., Porfiri M., 2014 Temperature influences sociality and activity of freshwater fish. Environmental Biology of Fishes 98(3):825-832.

Bilotta G. S., Brazier R. E., 2008 Understanding the influence of suspended solids on water quality and aquatic biota. Water Research 42(12):2849-2861.

Buermann Y., Du Preez H. H., Steyn G. J., Smit L., 1997 Tolerance levels of redbreast tilapia, *Tilapia rendalli* (Boulenger, 1896) to natural suspended silt. Hydrobiologia 344(1):11-18.

Butler B., Burrows D., Morgan G., 2010 Dissolved oxygen tolerance of exotic freshwater fish species in north Queensland report 10/08 of the Australian Centre for Tropical Freshwater Research, James Cook University, Townsville, to the Marine and Tropical Sciences Research Facility. Reef and Rainforest Research Centre Limited, Cairns, 22 pp.

Cooke G. D., Welch E. B., Jones J. R., 2011 Eutrophication of Tenkiller Reservoir, Oklahoma, from nonpoint agricultural runoff. Lake and Reservoir Management 27: 256-270.

Cooke S. J., Bunt C. M., Schreer J. F., 2004 Understanding fish behavior, distribution, and survival in thermal effluents using fixed telemetry arrays: a case study of smallmouth bass in a discharge canal during winter. Environmental Management 33(1):140-150.

Das T., Pal A. K., Chakraborty S. K., Manush S. M., Sahu N. P., Mukherjee S. C., 2005 Thermal tolerance, growth and oxygen consumption of *Labeo rohita* fry (Hamilton, 1822) acclimated to four temperatures. Journal of Thermal Biology 30(5):378-383.

Durham B. W., Wilde G. R., Pope K. L., 2006 Temperature-caused fish-kill in a flowing great plains river. The Southwestern Naturalist 51(3):397-401.

El-Sherif M. S., El-Feky A. M. I., 2009 Performance of Nile tilapia (*Oreochromis niloticus*) fingerlings. II. Influence of different water temperatures. International Journal of Agriculture and Biology 11:301-305.
Flint N., Crossland M. R., Pearson R. G., 2015 Sublethal effects of fluctuating hypoxia on juvenile tropical Australian freshwater fish. Marine and Freshwater Research 66(4): 293-304.
Freund J. G., Petty J. T., 2007 Response of fish and macroinvertebrate bioassessment indices to water chemistry in a mined Appalachian watershed. Environmental Management 39(5):707-720.
Gandaseca S., Rosli N., Mustapha A., Pazi M., Arianto C. I., 2014 Effects of land use on river water quality of Awat-Awat Lawas Mangrove Forest Limbang Sarawak Malaysia. International Journal of Physical Sciences 9(17):386-396.
Gray S. M., Chapman L. J., Mandrak N. E., 2012 Turbidity reduces hatching success in threatened spotted gar (*Lepisosteus oculatus*). Environmental Biology of Fishes 94(4):689-694.
Gupta B. K., Sarkar U. K., Bhardwaj S. K., 2012 Assessment of habitat quality with relation to fish assemblages in an impacted river of the Ganges basin, northern India. Environmentalist 32(1):35-47.
HACH, 2012 Hach Water Analysis Handbook. Hach Company, 1642 pp.
Ice G. G., 2008 Stream temperature and dissolved oxygen. In: Hydrological and biological responses to forest practices. Stednick J. D. (ed), Springer-Verlag, pp. 37-54.
Jeppesen R., Rodriguez M., Rinde J., Haskins J., Hughes B., Mehner L., Wasson K., 2018 Effects of hypoxia on fish survival and oyster growth in a highly eutrophic estuary. Estuaries and Coasts 41(1):89-98.
Kaminski R., Wolnicki J., Sikorska J., Garcia V., 2013 Effects of temperature on growth, survival and body composition in larvae of barbel, *Barbus barbus* (L.). Aquaculture International 21(4):829-841.
Kimbell H. S., Morrell L. J., 2015 Turbidity influences individual and group level responses to predation in guppies, *Poecilia reticulata*. Animal Behaviour 103:179-185.
Kjelland M. E., Woodley C. M., Swannack T. M., Smith D. L., 2015 A review of the potential effects of suspended sediment on fishes: potential dredging-related physiological, behavioral, and transgenerational implications. Environment Systems and Decisions 35(3):334-350.
Komoroske L. M., Connon R. E., Lindberg J., Cheng B. S., Castillo G., Hasenbein M., Fangue N. A., 2014 Ontogeny influences sensitivity to climate change stressors in an endangered fish. Conservation Physiology 2(1):1-13.
Lessard J. L., Hayes D. B., 2003 Effects of elevated water temperature on fish and macroinvertebrate communities below small dams. River Research and Applications 19(7):721-732.
Leuven R. S. E. W., Hendriks A. J., Huijbregts M. A. J., Lenders H. J. R., Matthews J., van der Velde G., 2011 Differences in sensitivity of native and exotic fish species to changes in river temperature. Current Zoology 57(6):852-862.
Li W., Zhang T., Zhang C., Li Z., Liu J., Hicks B. J., 2013 Effects of turbidity and light intensity on foraging success of juvenile mandarin fish *Siniperca chuatsi* (Basilewsky). Environmental Biology of Fishes 96(8):995-1002.
Ling T. Y., Lee T. Z. E., Nyanti L., 2013 Phosphorus in Batang Ai hydroelectric dam reservoir, Sarawak, Malaysia. World Applied Sciences Journal 28(10):1348-1354.
Ling T. Y., Soo C. L., Sivalingam J. R., Nyanti L., Sim S. F., Grinang J., 2016 Assessment of the water and sediment quality of tropical forest streams in upper reaches of Baleh River, Sarawak, Malaysia, subjected to logging activities. Journal of Chemistry 2016:1-13.
Ling T. Y., Gerunsin N., Soo C. L., Nyanti L., Sim S. F., Grinang J., 2017a Seasonal changes and spatial variation in water quality of a large young tropical reservoir and its downstream river. Journal of Chemistry 2017:1-16.

Ling T. Y., Soo C. L., Liew J. J., Nyanti L., Sim S. F., Grinang J., 2017b Application of multivariate statistical analysis in evaluation of surface river water quality of a tropical river. Journal of Chemistry 2017:1-13.

Moehansyah H., Maheshwari B. L., Armstrong J., 2002 Impact of land-use changes and sedimentation on the Muhammad Nur Reservoir, South Kalimantan, Indonesia. Journal of Soils and Sediments 2(1):9-18.

Moore R. D., Spittlehouse D. L., Story A., 2005 Riparian microclimate and stream temperature response to forest harvesting: a review. Journal of the American Water Resources Association 41(4):813-834.

Moyano M., Candebat C., Ruhbaum Y., Álvarez-Fernández S., Claireaux G., Zambonino-Infante J. L., Peck M. A., 2017 Effects of warming rate, acclimation temperature and ontogeny on the critical thermal maximum of temperate marine fish larvae. PLoS ONE 12(7):e0179928.

Nagarajan R., Jonathan M. P., Roy P. D., Muthusankar G., Lakshumanan C., 2015 Decadal evolution of a spit in the Baram river mouth in eastern Malaysia. Continental Shelf Research 105:18-25.

Nyanti L., Ling T. Y., Grinang, J., 2012 Physico-chemical characteristics in the filling phase of Bakun hydroelectric reservoir, Sarawak, Malaysia. International Journal of Applied Science and Technology 2(6):92-101.

Nyanti L., Abu-Rashid N. N. K., Ling T. Y., Soo C. L., Sim S. F., Grinang J., 2017 Acidification tolerance of *Barbonymus schwanenfeldii* (Bleeker, 1854) and *Oreochromis niloticus* (Linnaeus, 1758) - implication of fish size. AACL Bioflux 10(4):746-753.

Pandit N. P., Nakamura M., 2010 Effect of high temperature on survival, growth and feed conversion ratio of Nile tilapia, *Oreochromis niloticus*. Our Nature 8:219-224.

Soo C. L., Ling T. Y., Lee N., Apun K., 2016 Assessment of the characteristic of nutrients, total metals, and fecal coliform in Sibu Laut River, Sarawak, Malaysia. Applied Water Science 6:77-96.

Suedel B. C., Wilkens J. L., Kennedy A. J., 2017 Effects of suspended sediment on early life stages of smallmouth bass (*Micropterus dolomieu*). Archives of Environmental Contamination and Toxicology 72(1):119-131.

Tran-Duy A., van Dam A. A., Schrama J. W., 2012 Feed intake, growth and metabolism of Nile tilapia (*Oreochromis niloticus*) in relation to dissolved oxygen concentration. Aquaculture Research 43(5):730-744.

Received: 18 November 2017. Accepted: 31 January 2018. Published online: 25 March 2018.
Authors:
Lee Nyanti, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia, e-mail: lnyanti@unimas.my
Chen-Lin Soo, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia, e-mail: qianlin1112@gmail.com
Nona-Nabilah Ahmad-Tarmizi, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia, e-mail: nonatarmizi@gmail.com
Nik-Nurul-Kamila Abu-Rashid, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia, e-mail: nick_kamila@yahoo.com
Teck-Yee Ling, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia, e-mail: tyling@unimas.my
Siong-Fong Sim, Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia, e-mail: sfsim@unimas.my
Jongkar Grinang, Institute of Biodiversity and Environmental Conservation, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia, e-mail: gjongkar@unimas.my
Tonny Ganyai, Research and Development Department, Sarawak Energy Berhad, 93050 Kuching, Sarawak, Malaysia, e-mail: tonnyganyai@sarawakenergy.com.my
Karen-Suan-Ping Lee, Research and Development Department, Sarawak Energy Berhad, 93050 Kuching, Sarawak, Malaysia, e-mail: karenLee@sarawakenergy.com.my

How to cite this article:
Nyanti L., Soo C. L., Ahmad-Tarmizi N. N., Abu-Rashid N. N. K., Ling T. Y., Sim S. F., Grinang J., Ganyai T., Lee K. S. P., 2018 Effects of water temperature, dissolved oxygen and total suspended solids on juvenile *Barbonymus schwanenfeldii* (Bleeker, 1854) and *Oreochromis niloticus* (Linnaeus, 1758). AACL Bioflux 11(2):394-406.