Research Article

Patterns of Fish Assemblage, Growth, and Diet Composition in a Tropical River between Two Cascading Hydropower Dams

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Construction of cascade dams has been shown to have impacts on fish assemblages and biodiversity. Yet, there is no literature on fish assemblages in the Murum River that connects the cascading Bakun and Murum dams in Sarawak, Malaysia. Hence, study on this modified ecosystem is necessitated to better understand the effects of the cascade dam construction on fish fauna. For this, fish samples were caught at five stations located along the river during both dry and wet seasons. Environmental parameters were taken concurrently with fish sampling. Length-weight relationship, condition factors, and diet composition of selected fish species in the river were also determined. The present study demonstrated that there are indications of the impact of cascading dams on the formation of a complex ecosystem in the Murum River, that is, changing from the shallow downstream of the Murum Dam to the deep transitional and inundated zone of the Bakun reservoir. The transitional zone in the Murum River exhibited the lowest fish species diversity, richness, and evenness during the dry season due to low pH and DO coupled with high turbidity. The biological indices improved when the water quality improved during the wet season. On the contrary, the diversity and evenness indices at the inundated tributary station decreased remarkably during the wet season, likely due to the migration of fish during the onset of the rainy season. This study showed that *Barbonymus schwanenfeldii* has a wider feeding habit which contributes to its higher distribution and abundance in the Murum River. The growth patterns of *B. schwanenfeldii, Cyclocheilichthys apogon*, *Hampala macrolepidota, Lobocheilos ovalis,* and *Osteochilus enneaporos* were better during wet than dry season. Overall, the condition factor of all native fish species in the Murum River was in poor to fair condition, whereas the exotic species, *Oreochromis mossambicus*, exhibited excellent condition (K value > 2) for both seasons. The increase in the number of *O. mossambicus* coupled with its high condition factor indicates biological intrusion and a potential threat to the native fish species in the Murum River. Continuous monitoring is essential to detect in-time risk issues associated with environmental degradation and biological invasion in this regulated and inundated river ecosystem.

1. Introduction

Physical structures such as dams and reservoirs were made to fulfil man's needs for the purposes of power generation, flood control, recreation, agriculture, and industry. Dam impoundment inevitably modifies the natural regime of its downstream rivers and has resulted in environmental degradation [1–3]. The fluctuations of flow and environmental conditions could lead to alteration of aquatic biodiversity in the downstream river [4]. Nyanti [5] demonstrated that the downstream river of the tropical Batang Ai Dam is extremely shallow and slow flowing when the power generation is halted, and no water is discharged from the powerhouse, which has subsequently reduced the fish abundance in the river. In addition, seasonal changes in the hydrology of the downstream river could also lead to differences in fish assemblages [6].

Studies have been conducted on the impacts of cascade dam construction since the implementation of the extensive cascade hydropower plant [7, 8]. The construction of cascade dams in a river caused a repeated segment of the river being divided into a series of inundated areas. The effects of cascading dams on the environment are more complex than the effects of a single dam due to the cumulative effects of the cascading dams [7]. Xie et al. [9] demonstrated that the development of cascade hydropower and continued dam construction had exerted a major influence on the fish species composition, where the endemic headwater species had declined in the upper reaches of the Yellow River, China, due to habitat alteration.

In Sarawak, two large hydroelectric dams, namely, the Murum hydroelectric dam and the Bakun hydroelectric dam, are both located upstream of the Rajang River. The Murum hydroelectric dam with a catchment area of $2750 \, \text{km}^2$ is located on the Murum River, a tributary of the uppermost part of the Rajang River. Less than 100 km downstream is the Bakun hydroelectric dam with a catchment area of $14,750 \, \text{km}^2$ located on the Rajang River [10]. These cascading hydroelectric dams are connected by a segment of the Murum River which possesses a complex ecosystem as it is not only influenced by the regulated flow from the Murum Dam but also by the transitional zone and inundated area of the Bakun reservoir.

To date, no study has been conducted on the fish assemblages along the Murum River between the two cascade dams after their impoundment. As more hydroelectric dams are planned to be constructed in the region [10], a study on the effects of the cascade dam construction on this tropical ecosystem is warranted. Therefore, this study aimed to investigate the patterns of fish assemblages in the Murum River that connects the two dams during the dry and wet seasons. In addition, the growth pattern and diet composition of selected fish species in the Murum River were also studied.

2. Materials and Methods

2.1. Field Collection and Laboratory Analysis.
Two sampling trips were made in July and October 2016 during the dry and wet seasons, respectively. Both samplings were conducted at five stations along the Murum River located between Murum hydroelectric dam and the Bakun hydroelectric dam, as shown in Figure 1. The sampling station was determined according to the zonation commonly occurring in the reservoir along the downstream gradient. Station 1 and station 2 were located at the downstream of the Murum Dam which is part of the riverine zone of the Bakun hydroelectric reservoir. The Murum Hydroelectric Powerhouse was located in between the two stations. Station 3 was located at the transitional zone of the Bakun hydroelectric reservoir, whereas station 5 was located at the inundated area of the Bakun Dam. Lastly, station 4 was located at the Temaju River, a tributary of the Murum River.

Gill nets of various mesh sizes (2.54 cm, 5.08 cm, 6.35 cm, and 7.62 cm) and three-layered gill nets (14 cm-4 cm-14 cm) were used for fish sampling at each station for a duration of three days and two nights. During this period, the nets were left overnight and retrieved on the next day. Fish were counted and grouped according to their respective species in the field. Taxonomy keys [11, 12] were used for fish species identification. The taxonomic status was also confirmed with the latest literature [13–15] and online global database of fish species [16, 17]. Fish that cannot be identified in the field were preserved by using 10% formalin for approximately 72 hours followed by preservation in 70% ethanol. The total length (L) and body weight (W) of fishes were recorded by using a ruler and a portable balance (Shimadzu, ELB200) to the nearest 0.1 cm and 0.01 g, respectively. Environmental parameters were taken concurrently with the fish sampling. Water depth was measured at each station using a depth finder (Speedtech Instruments 67505). *In situ* water quality parameters including dissolved oxygen (DO), temperature, pH, turbidity, and conductivity were taken by using YSI Multiparameter Water Quality Sonde (YSI 6920). Triplicate measurements were taken from subsurface (0.5 m) and bottom (3 to 5 m) water columns. The data were then pooled for subsequent analysis at each station.

The top four abundant fish species from the family Cyprinidae were selected for stomach content analysis. The samples were analysed by pooling the data from the two trips due to the limited number of samples. Each individual was dissected to obtain its stomach by using a dissecting kit (Gold Cross) and was fixed in 5% formalin for further analysis. For the stomach content analysis, the fish stomach was cut longitudinally, and the stomach content was sorted according to the food type under a stereomicroscope (Olympus SZ51) and weighed to the nearest 0.001 g by using a balance (Shimadzu BL-220H).

2.2. Data and Statistical Analysis.
Shannon–Weiner's diversity index (H) [18], Pielou's evenness index (J) [19], and Margalef's species richness index (D) [20] were used to determine the species diversity, richness, and evenness indices at each station and the whole study area. The biological indices were calculated using formulae (1)–(3).

Shannon–Weiner's diversity index (H):

$$H = \sum \frac{N_i}{N} \log e \frac{N_i}{N}. \tag{1}$$

Pielou's evenness index (J):

$$J = \frac{H}{\log eS}. \tag{2}$$

Margalef's index of species richness (D):

$$D = \frac{S - 1}{\log eN}, \tag{3}$$

where N = sample size, N_i = number of specimens per species, and S = total number of species.

The stomach content of fish was analysed by using the frequency of occurrence (FO) and mass method (MM) [21]. The FO was used to calculate how frequently the food type occurs in each individual using
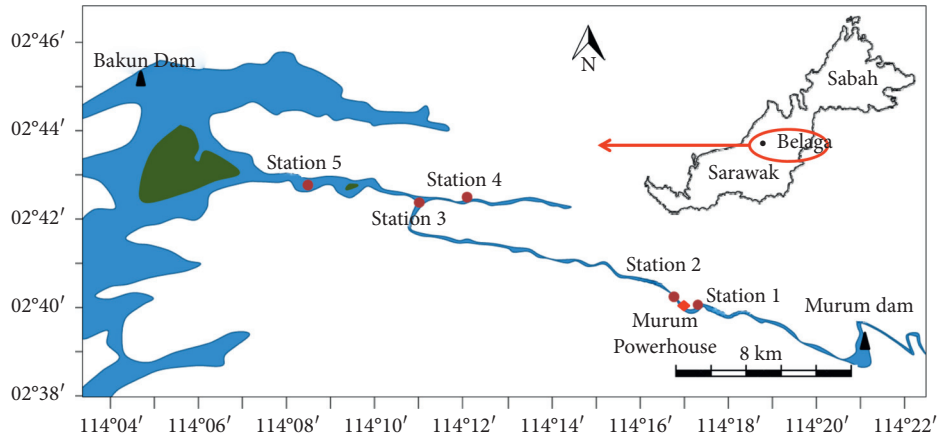
FIGURE 1: The location of sampling stations at the study area.

$$\% FO_i = \frac{N_i}{N} \times 100, \tag{4}$$

where FO_i = frequency of occurrence of food item i, N_i = the number of stomachs in which the given item i occurs, and N = the total number of stomachs examined with food.

The MM was used to determine the diet composition of the species by using

$$\% MM_i = \frac{m_i}{m_t} \times 100, \tag{5}$$

where $\%MM_i$ = the mass percentage of food item i, m_i = the mass of food item i, and m_t = the total mass of food (gut content).

Length-weight relationship (LWR) [22] of selected fish species was expressed using

$$W = aL^b. \tag{6}$$

The constants a and b were estimated using linear regression as

$$\log W = \log a + b \log L, \tag{7}$$

where W is the weight of the fish (g), L is the length of the fish (cm), $\log a$ is the intercept, and b is the regression coefficient. The growth of the fish was indicated by the b value, where $b = 3$ indicates an isometric growth rate, $b > 3$ is a positive allometric growth, and $b < 3$ is a negative allometric growth.

Finally, the condition of the selected fish species was determined by using Fulton's condition factor (K) [23]:

$$K = 100 \, W/L^3. \tag{8}$$

One-way ANOVA followed by Tukey post hoc test was used to determine the significant difference of each water quality parameter among stations at each trip, while independent-sample T-test was used to determine if there is a significant difference between trips at each station. Pearson's correlation analysis was performed to elucidate the significant relationships between biological indices and water quality parameters. All statistical analyses were significant at $p \leq 0.05$ carried out using the Statistical Package for Social Sciences (SPSS version 24, SPSS Inc., 1995).

3. Results and Discussion

3.1. Fish Composition in the Murum River during Dry and Wet Seasons. Figure 2 shows that a total of four and seven families were caught during the first trip (dry season) and the second trip (wet season) in the Murum River, respectively. A total of 360 individuals comprising of 18 species were caught during the dry season, while 267 individuals from 20 species were collected during the wet season. The family Cyprinidae dominated the Murum River in both seasons, constituting 88.6% (319 individuals) and 83.1% (222 individuals) of the total catch during the dry and wet seasons, respectively. This is similar to a previous study in the two tributaries of the Murum River located upstream of the Murum Dam reservoir, where it was reported that Cyprinidae was the most dominant family (62.1%) [24]. Nyanti [5] also demonstrated that the most dominant family in the downstream river of the Batang Ai Dam was Cyprinidae (67.9%). The dominance of cyprinids is shown throughout the Southeast Asian region [25–27]. Numerous studies have also reviewed that cyprinids are the most common freshwater fish family in Malaysia [28, 29]. Beamish et al. [25] explained that cyprinids are dominant compared to other fish families as they are able to inhabit a broad range of environments due to their adaptive stomach, genetic modification, and intestine adaptation efforts.

During the dry season, the second dominant family caught was Bagridae (7.8%), followed by Cichlidae (3.1%) and Siluridae (0.6%). During the wet season, Cichlidae was recorded as the second dominant family (10.1%), followed by Bagridae (4.9%) and Siluridae (0.7%). Meanwhile, Cobitidae, Mastacembelidae, and Pangasiidae were the least dominant families where only one individual was caught for each family. According to Sapis et al. [24], the presence of introduced species, specifically cichlids in the Murum River, may be due to the accidental release of cultured fish from community ponds during the dam impoundment. The present study demonstrated that cichlids have overtaken the bagrids during the wet season because they are hardier and
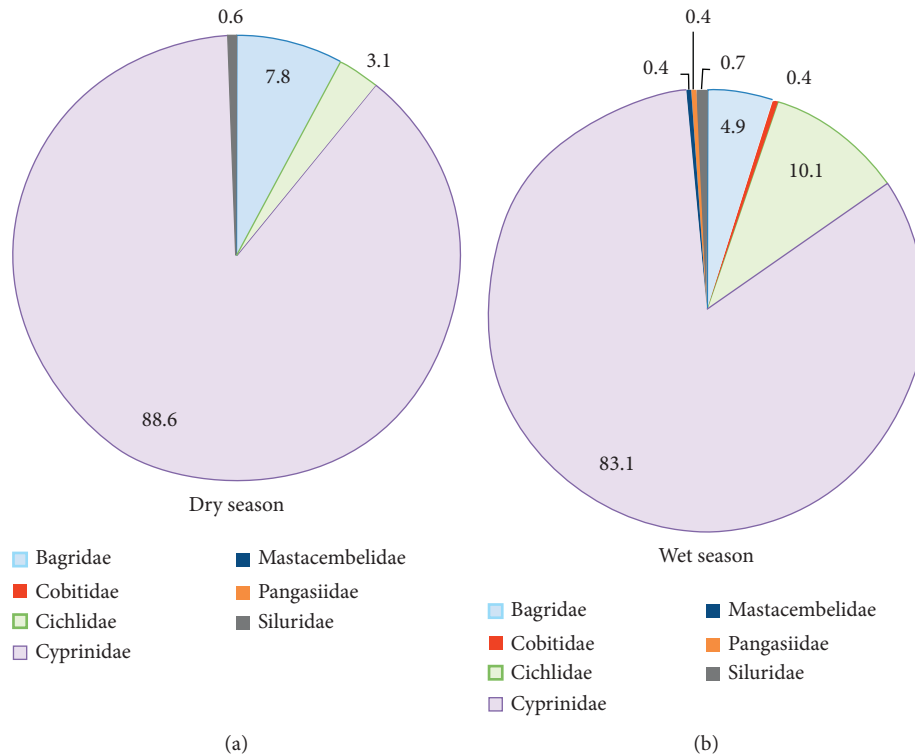
FIGURE 2: The overall percentage of the fish family recorded in the study area.

more tolerant to a wide range of environmental conditions than the Malaysian native species [30–32]. The increase of cichlid abundance in the Murum River over time might be an early warning sign of biological invasion, which could pose a serious threat to the native species in the river as well as the functioning of the ecosystem [33].

Table 1 shows the list of fish composition at each station in the Murum River during the dry and wet seasons. *Barbonymus schwanenfeldii* ($n = 76$) and *Cyclocheilichthys apogon* ($n = 76$) were the most abundant species in the Murum River during the dry season, followed by *Osteochilus hasseltii* ($n = 54$) and *Parachela oxygastroides* ($n = 34$). During the wet season, *B. schwanenfeldii* ($n = 118$) was recorded as the most abundant species, followed by *C. apogon* ($n = 29$) and *P. oxygastroides* ($n = 29$). The dominance of *B. schwanenfeldii* in the present study differed with the fish assemblages at the downstream river of the Batang Ai Dam where fish species were low in abundance ($\approx 1.4\%$), although both rivers downstream of the dam were abundant in *C. apogon* [5]. This could be due to the complex ecosystem of the Murum River that is changing from the shallow downstream of the Murum Dam to the deep transitional and inundated zone of the Bakun reservoir, which favours *B. schwanenfeldii* as it moves into inundated areas during the wet season to feed and spawn [34]. This is also in agreement with the present result whereby the abundance of *B. schwanenfeldii* was higher during the wet season than that during the dry season, particularly at the inundated area (station 4). On the contrary, the abundance of *C. apogon* was lower during the wet season than the dry season, while *O. hasseltii* was not found in the river during the wet season. The lower abundance or complete absence of fish species during the wet season could be due to the migration behaviour of the fish [34] or the removal of fish species due to the modification of habitat in the river [4]. The variations in abundance and occurrence of fish species indicates that restructuring of fish communities in this river is still ongoing as the river is just recently been modified. Therefore, continuous and long-term monitoring is necessary for a better understanding of fish composition and distribution patterns in the regulated river.

Table 2 shows the fish biological indices in the Murum River and at each station during the dry and wet seasons. Overall, the diversity index value of 2.3 during the dry season was higher than that during the wet season (2.0), whereas the species richness index was higher during the wet season (3.4) than that during the dry season (2.9). The diversity and richness indices decreased towards the downstream direction from station 1 to station 3 during both seasons. In the present study, the species richness was significantly (p value ≤ 0.05) and highly correlated with pH ($R^2 = +0.799$) and DO ($R^2 = +0.755$) as shown in Table 3. The highest values of pH (6.8) and DO (8.2 mg/L) were observed at station 1 and were significantly higher (p value ≤ 0.05) than those at other stations (Table 4). The water pH value dropped significantly to 5.8 (p value ≤ 0.05) at station 2 which is located below the Murum Hydroelectric Powerhouse and continued to deteriorate at station 3 which is located further down at the transitional zone; but, the water pH value improved at stations 4 and 5 which are inundated. Deterioration of water quality, particularly water pH and DO, is commonly observed in a river located downstream of a

TABLE 1: The list of fish composition in the Murum River during the dry (trip 1) and wet (trip 2) seasons.

Family	Species	Trip 1						Trip 2					
		St1	St2	St3	St4	St5	Murum River	St1	St2	St3	St4	St5	Murum River
Bagridae	*Hemibagrus fortis*	2	—	1	—	—	3	—	—	—	—	—	—
	Hemibagrus capitulum	2	—	5	1	2	10	4	—	3	1	4	12
	Mystus singaringan	4	—	1	3	7	15	—	—	—	1	—	1
Cobitidae	*Syncrossus hymenophysa*	—	—	—	—	—	—	—	—	—	1	—	1
Cichlidae	*Oreochromis mossambicus*	—	—	—	2	9	11	—	2	21	—	4	27
Cyprinidae	*Barbonymus schwanenfeldii*	11	4	4	11	46	76	10	2	16	57	33	118
	Cyclocheilichthys apogon	24	1	44	2	5	76	—	7	13	4	5	29
	Cyclocheilichthys armatus	—	—	—	—	—	—	—	1	—	—	1	2
	Hampala bimaculata	4	4	—	—	—	8	—	1	—	—	—	1
	Hampala macrolepidota	1	—	1	11	1	14	1	—	1	1	8	11
	Labiobarbus festivus	2	1	—	—	—	3	—	—	—	—	—	—
	Lobocheilos ovalis	4	1	8	4	8	25	5	1	2	1	1	10
	Lobocheilos cf. *falcifier*	—	—	—	—	—	—	—	—	1	1	2	4
	Osteochilus borneensis	1	—	—	—	—	1	—	—	—	—	—	—
	Osteochilus enneaporos	11	—	—	—	—	11	7	1	1	—	—	9
	Osteochilus hasseltii	44	1	2	3	4	54	—	—	—	—	—	—
	Osteochilus schlegelii	1	—	—	—	—	1	—	—	—	—	—	—
	Parachela oxygastroides	1	—	—	21	12	34	5	6	2	1	15	29
	Puntioplites waandersi	—	2	2	4	7	15	1	—	1	2	—	4
	Rasbora argyrotaenia	—	—	—	—	—	—	2	2	—	—	—	4
	Tor tambra	—	—	—	—	1	1	1	—	—	—	—	1
Mastacembelidae	*Mastacembelus erythrotaenia*	—	—	—	—	—	—	—	—	—	—	1	1
Pangasiidae	*Pangasius macronema*	—	—	—	—	—	—	1	—	—	—	—	1
Siluridae	*Kryptopterus cryptopterus*	—	—	—	—	—	—	—	—	—	1	—	1
	Kryptopterus lais	—	—	—	—	—	—	1	—	—	—	—	1
	Kryptopterus limpok	—	—	—	2	—	2	—	—	—	—	—	—
	N	112	14	68	64	102	360	38	23	61	71	74	267

n = number of individuals; St = station.

TABLE 2: Fish biological indices in the Murum River during the dry (trip 1) and wet (trip 2) seasons.

Station	Species diversity (*H*)		Species richness (*D*)		Species evenness (*J*)	
	Trip 1	Trip 2	Trip 1	Trip 2	Trip 1	Trip 2
1	1.9	2.1	2.8	2.7	0.7	0.9
2	1.7	1.9	2.3	2.6	0.9	0.9
3	1.3	1.7	1.9	2.2	0.6	0.7
4	2.0	0.9	2.4	2.3	0.8	0.4
5	1.8	1.7	2.2	2.1	0.8	0.7
Murum River	2.3	2.0	2.9	3.4	0.8	0.7

hydroelectric dam [2]. The modification of the physicochemical states of the habitat downstream of the powerhouse could remove certain species that are vulnerable to physicochemical fluctuations, thus the decrease in species richness. Abiotic parameters of water quality have been known to have great impacts on species richness [35]. The lowest fish abundance was also consistently observed at station 2, which was located below the powerhouse (Table 1). The DO values at all stations located below the powerhouse were significantly lower (p value ≤ 0.05) than station 1 (upstream of the powerhouse), ranging from 2.1 mg/L to 4.1 mg/L and from 2.7 mg/L to 4.2 mg/L, during the dry and wet seasons, respectively (Table 4). The lowest DO value was also observed at stations 2 and 3 during the dry season but

improved significantly (p value ≤ 0.05) during the wet season. The significant improvement in DO during the wet season at stations 2 and 3 might also be the reason for the higher species richness at those stations during the wet season. Noticeable changes in biological indices between dry and wet seasons were observed at stations 3 and 4, which were located at the transitional zone and the tributary of the Murum River, respectively. Station 3 had the lowest diversity, richness, and evenness indices during the dry season. These lowest biological indices coincided with the worst water quality indicated by the lowest pH (5.5) and DO (2.1 mg/L) values and the highest turbidity (60.5 NTU), the parameters of which were known for their detrimental effects on fishes [30–32]. However, during the wet season, the

TABLE 3: Correlation between *in situ* water quality and fish biological indices at the Murum River.

	Depth (m)	Temp (°C)	pH	DO (mg/L)	Cond (μS/cm)	Turbidity (NTU)
Diversity	−0.395	−0.032	+0.405	+0.401	−0.330	−0.089
Richness	−0.450	−0.059	+0.799 **	+0.755 *	−0.413	−0.330
Evenness	−0.479	−0.379	+0.147	+0.058	−0.009	+0.097

* p value ≤ 0.05.

TABLE 4: *In situ* water quality of the Murum River during the dry (trip 1) and wet seasons (trip 2).

Parameter	Sampling	Station				
		1	2	3	4	5
Depth (m)	Trip 1	4.1 ± 0.3^{a1}	6.6 ± 0.2^{b1}	12.6 ± 0.1^{c2}	28.1 ± 0.1^{e2}	23.3 ± 0.1^{d2}
	Trip 2	5.2 ± 0.1^{a2}	6.7 ± 0.1^{b1}	10.8 ± 0.1^{c1}	27.2 ± 0.2^{e1}	19.4 ± 0.1^{d1}
Temp (°C)	Trip 1	28.7 ± 0.0^{b2}	25.0 ± 0.1^{a1}	25.5 ± 0.0^{a1}	29.6 ± 0.1^{c1}	30.2 ± 0.5^{c1}
	Trip 2	27.7 ± 0.0^{b1}	24.9 ± 0.0^{a1}	28.6 ± 0.4^{c2}	29.6 ± 0.2^{d1}	30.3 ± 0.3^{d1}
pH	Trip 1	6.8 ± 0.0^{e2}	5.7 ± 0.0^{b1}	5.5 ± 0.0^{a1}	5.8 ± 0.0^{c1}	6.0 ± 0.0^{d1}
	Trip 2	6.7 ± 0.0^{d1}	5.9 ± 0.0^{b2}	5.6 ± 0.0^{a2}	6.0 ± 0.0^{c2}	6.0 ± 0.0^{c1}
DO (mg/L)	Trip 1	8.2 ± 0.0^{d1}	2.1 ± 0.0^{a1}	2.1 ± 0.0^{a1}	4.1 ± 0.1^{c1}	3.3 ± 3.0^{b1}
	Trip 2	8.2 ± 0.0^{d1}	2.8 ± 0.0^{a2}	4.2 ± 0.1^{c2}	4.2 ± 0.3^{c1}	3.5 ± 2.7^{b1}
Cond (μS/cm)	Trip 1	33.8 ± 0.0^{a2}	53.2 ± 0.5^{e2}	46.3 ± 0.0^{c2}	49.4 ± 0.0^{d2}	44.6 ± 0.4^{b2}
	Trip 2	28.4 ± 0.0^{a1}	46.8 ± 0.1^{d1}	37.5 ± 0.3^{b1}	45.5 ± 0.6^{c1}	37.1 ± 0.2^{b1}
Turbidity (NTU)	Trip 1	10.4 ± 0.1^{a2}	44.6 ± 0.6^{b2}	60.5 ± 0.2^{c2}	57.0 ± 3.6^{c2}	8.3 ± 1.0^{a1}
	Trip 2	6.6 ± 0.0^{a1}	36.1 ± 0.4^{d1}	20.5 ± 2.0^{c1}	14.6 ± 1.8^{b1}	7.8 ± 2.0^{a1}

The mean followed by the same letter in the same row indicates no significant difference between stations, whereas the mean followed by the same number at each station for each parameter indicates no significant difference between trips (p value > 0.05).

biological indices at station 3 improved when these water quality parameters improved significantly (p value ≤ 0.05) (Table 4). On the contrary, the diversity and evenness indices at station 4 during the wet season were the lowest among stations and lower than those during the dry season as well, although species richness remained similar during both seasons. Unlike station 3, the diversity and evenness indices at station 4 decreased remarkably even though pH and turbidity improved significantly (p value ≤ 0.05) during the wet season (Table 4). This phenomenon demonstrated that the fish assemblage at the inundated tributary station was less influenced by the water quality parameters than the transitional zone at the main river. Instead, the low diversity and evenness index at station 4 during the wet season are most probably due to the migration of the fish to the upstream of Sungai Temaju where station 4 is located during the onset of the rainy season, and thus the dominance of *Barbonymus schwanenfeldii* which has demonstrated upriver breeding migratory behaviour [36].

The river depth in the present study increased significantly (p value ≤ 0.05) from station 1 at upstream (4.7 m) to station 4 (27.7 m) and station 5 (21.4 m) at the inundated area (Table 4). Depth is one of the important habitat variables in determining fish distribution in a river, yet river depth in the present study was not significantly correlated with fish biological indices (p value > 0.05). Nyanti [5] found that fish species diversity was significantly and positively correlated with the mean depth of a river located downstream of the Batang Ai Dam. The author demonstrated that the fish assemblage in a shallow river in the upstream segment is less diverse than a deeper river in the middle

stream and downstream segments. The lack of correlation between river depth and fish biological indices in the present study might be due to very deep water at the downstream stations as they were located in the inundated area of the Bakun Dam reservoir.

3.2. Length-Weight Relationship and Condition Factor.
Table 5 shows the length-weight relationship (LWR) for selected fish species with the coefficient of determination (R^2) greater than 0.80 in the Murum River. The results indicated that the growth patterns of five fish species including *Barbonymus schwanenfeldii*, *Cyclocheilichthys apogon*, *Hampala macrolepidota*, *Lobocheilos ovalis*, and *Osteochilus enneaporos* were better during the wet season than those during the dry season. This could be due to the rising of the water level during the wet season which inundated the larger area and thus increasing food supplies to the fish [34]. The growth patterns of the three fish species were the same during both seasons where *Parachela oxygastroides* and *Hemibagrus capitulum* showed positive allometric growth, while *Oreochromis mossambicus* showed negative allometric growth for both seasons. The LWR for *Mystus singaringan*, *Osteochilus hasseltii,* and *Puntioplites waandersi* was determined at the dry season only due to the low number of individuals caught during the wet season. *O. hasseltii* exhibited isometric growth ($b = 3.007$), while *M. singaringan* ($b = 3.555$) and *P. waandersi* ($b = 3.162$) exhibited positive allometric growth.

The condition factor (K) for all selected species ranged from 0.61 to 2.04 and from 0.62 to 2.19 during the dry and

TABLE 5: Summary of regression analyses of the length-weight relationship (LWR) of selected species in the Murum River during the dry (trip 1) and wet (trip 2) seasons.

Family	Species	Trip	Log BW = log a + b log TL			Parameter estimates		SE	p value	LWR: $W = aL^b$	Growth pattern
			n	R^2	p value						
Barigdae	*Mystus singaringan*	1	12	0.805	**0.001**	Log a	−6.857	1.748	**0.003**	$W = 0.0011L^{3.555}$	A+
						b	3.555	0.553	**0.001**		
		2	NA								
	Hemibagrus capitulum	1	10	0.955	**0.001**	Log a	−5.333	0.843	**0.001**	$W = 0.0048L^{3.129}$	A+
						b	3.129	0.240	**0.001**		
		2	12	0.983	**0.001**	Log a	−6.473	0.491	**0.001**	$W = 0.0015L^{3.457}$	A+
						b	3.457	0.143	**0.001**		
Cichlidae	*Oreochromis mossambicus*	1	11	0.961	**0.001**	Log a	−3.170	0.525	**0.001**	$W = 0.0420L^{2.744}$	A−
						b	2.744	0.185	**0.001**		
		2	13	0.948	**0.001**	Log a	−2.545	0.531	**0.001**	$W = 0.0785L^{2.562}$	A−
						b	2.562	0.181	**0.001**		
Cyprinidae	*Barbonymus schwanenfeldii*	1	72	0.899	**0.001**	Log a	−3.571	0.314	**0.001**	$W = 0.0281L^{2.686}$	A−
						b	2.686	0.108	**0.001**		
		2	118	0.947	**0.001**	Log a	−4.496	0.181	**0.001**	$W = 0.0112 L^{3.004}$	I
						b	3.004	0.066	**0.001**		
	Cyclocheilichthys apogon	1	74	0.920	**0.001**	Log a	−4.610	0.290	**0.001**	$W = 0.0100L^{3.048}$	I
						b	3.048	0.106	**0.001**		
		2	29	0.972	**0.001**	Log a	−6.043	0.305	**0.001**	$W = 0.0024L^{3.614}$	A+
						b	3.614	0.117	**0.001**		
	Hampala macrolepidota	1	12	0.874	**0.001**	Log a	−3.056	0.895	**0.007**	$W = 0.0471L^{2.481}$	A−
						b	2.481	0.298	**0.001**		
		2	11	0.994	**0.001**	Log a	−5.136	0.240	**0.001**	$W = 0.0059 L^{3.192}$	A+
						b	3.192	0.085	**0.001**		
	Lobocheilos ovalis	1	24	0.893	**0.001**	Log a	−4.558	0.653	**0.001**	$W = 0.0105L^{2.933}$	A−
						b	2.933	0.216	**0.001**		
		2	6	0.848	**0.009**	Log a	−11.665	3.380	**0.026**	$W = 0.0000 L^{5.408}$	A+
						b	5.408	1.145	**0.009**		
	Osteochilus enneaporos	1	11	0.882	**0.001**	Log a	−4.355	1.049	**0.002**	$W = 0.0128L^{2.900}$	A−
						b	2.900	0.354	**0.001**		
		2	9	0.922	**0.001**	Log a	−5.969	1.155	**0.001**	$W = 0.0026L^{3.436}$	A+
						b	3.436	0.378	**0.001**		
	Osteochilus hasseltii	1	53	0.869	**0.001**	Log a	−4.650	0.481	**0.001**	$W = 0.0096L^{3.007}$	I
						b	3.007	0.163	**0.001**		
		2	NA								
	Parachela oxygastroides	1	27	0.814	**0.001**	Log a	−5.916	0.914	**0.001**	$W = 0.0027L^{3.306}$	A+
						b	3.306	0.316	**0.001**		
		2	24	0.831	**0.001**	Log a	−6.706	0.870	**0.001**	$W = 0.0012L^{3.571}$	A+
						b	3.571	0.310	**0.001**		
	Puntioplites waandersi	1	14	0.986	**0.001**	Log a	−5.006	0.360	**0.001**	$W = 0.0067L^{3.162}$	A+
						b	3.162	0.110	**0.001**		
		2	NA								

n, number of individuals; R^2, coefficient of determination; SE, standard error; SD, standard deviation; A+, positive allometry; A−, negative allometry; I, isometric. Significant values (p value < 0.05) are indicated in bold.

wet seasons, respectively (Table 6). There are no noticeable changes in fish condition factor in the two different seasons except for *L. ovalis* where the condition factor of fish was better during the wet season. Almost half of the selected species in the Murum River scored a K value of less than 1.0, signifying poor fish condition and unsuitable environment for fish growth [37]. The exotic species *O. mossambicus* had the highest K value (>2) in the present study, indicating that fish is in excellent condition and thriving better in the Murum River compared to the Malaysian native species. This serves as a warning sign of the potential biological intrusion and threat to the native species.

The growth patterns of fish in the present study were dissimilar compared to those in the downstream river of the Batang Ai Dam where Nyanti [5] reported that *C. apogon* exhibited negative allometric growth, whereas *H. macrolepidota* and *H. capitulum* exhibited isometric growth. The author also showed that the condition factor value gradually decreased from the most abundant species *C. apogon* to the third most abundant species *H. capitulum* at the downstream river of the Batang Ai Dam [5] which is similar with the present study where the K value of *C. apogon* was the highest among the three species, followed by *H. macrolepidota* and *H. capitulum*. Nevertheless, the

TABLE 6: The condition factor (K) of the selected species in the Murum River during dry (trip 1) and wet (trip 2) seasons.

Family	Species	Trip 1		Trip 2	
		n	$K \pm SD$	n	$K \pm SD$
Bagridae	*Mystus singaringan*	12	0.61 ± 0.09	—	—
	Hemibagrus capitulum	10	0.78 ± 0.18	12	0.76 ± 0.17
Cichlidae	*Oreochromis mossambicus*	11	2.04 ± 0.15	13	2.19 ± 0.31
Cyprinidae	*Barbonymus schwanenfeldii*	72	1.14 ± 0.22	118	1.16 ± 0.34
	Cyclocheilichthys apogon	74	1.14 ± 0.09	29	1.18 ± 0.20
	Hampala macrolepidota	12	1.01 ± 0.16	11	1.01 ± 0.15
	Lobocheilos ovalis	24	0.86 ± 0.08	6	1.06 ± 0.19
	Osteochilus enneaporos	11	0.96 ± 0.11	9	0.97 ± 0.09
	Osteochilus hasseltii	53	0.99 ± 0.14	—	—
	Parachela oxygastroides	27	0.65 ± 0.05	24	0.62 ± 0.13
	Puntioplites waandersi	14	1.14 ± 0.14	—	—

n, number of individuals; K, condition factor; SD, standard deviation.

TABLE 7: The stomach content analysis of four selected species by using the frequency occurrence of food and mass method.

Species	n	Type of food item	Frequency of occurrence (%)	Mass method (%)
Barbonymus schwanenfeldii	53	Insect	92.5	15.7
		Oligochaetes	26.4	0.1
		Seeds	24.5	1.5
		Plant parts	24.5	8.5
		Detritus	100.0	74.2
Cyclocheilichthys apogon	27	Insect	66.7	4.3
		Oligochaetes	3.7	0.1
		Plant parts	14.8	0.6
		Detritus	92.6	95.0
Parachela oxygastroides	40	Insect	87.5	20.3
		Plant parts	5.0	0.2
		Detritus	100.0	79.5
Hampala macrolepidota	13	Crustaceans	92.3	9.4
		Plant parts	7.7	0.1
		Detritus	100.0	90.5

condition factors of these fish species were higher at the downstream river of the Batang Ai Dam compared to the present study, likely due to being in a regulated lotic environment compared to the lentic environment.

3.3. Stomach Content Analysis. Table 7 shows the stomach content of *Barbonymus schwanenfeldii, Cyclocheilichthys apogon, Parachela oxygastroides,* and *Hampala macrolepidota* by using the frequency of occurrence (FO) and mass method (MM). The stomach content of *B. schwanenfeldii* ($n = 53$) comprised insects, oligochaetes, seeds, plant parts, and detritus. The highest FO of food in *B. schwanenfeldii* was detritus (100.0%), followed by insects (92.5%), oligochaetes (26.4%), seeds (24.5%), and plant parts (24.5%). In % mass, detritus contributed 74.2% of the total mass of stomach content, followed by insects (15.7%), plant parts (8.5%), seeds (1.5%), and oligochaetes (0.1%). The diet composition of *C. apogon* ($n = 27$) comprised insects, oligochaetes, plant parts, and detritus. Detritus had the highest FO (92.6%), followed by insects (66.7%), plant parts (14.8%), and oligochaetes (3.7%). Detritus also had the highest % mass with

95.0% of the total mass of *C. apogon* stomach content, followed by insects (4.3%), plant parts (0.6%), and oligochaetes (0.1%). The stomach content of *P. oxygastroides* ($n = 40$) comprised insects, plant parts, and detritus with a FO of 87.5%, 5.0%, and 100.0%, respectively. Mass method showed that the stomach content of *P. oxygastroides* was also highly composed of detritus which was 79.5% of the total mass of stomach content, followed by insects (20.3%) and then plant parts with only 0.2% of the total mass of stomach content. The FO of detritus (100.0%) and crustaceans (92.3%) was high, while the FO of plant parts was low (7.7%) in *H. macrolepidota* ($n = 13$). In % mass, detritus, crustaceans, and plant parts contributed 90.5%, 9.4%, and 0.1% of the total mass of stomach content, respectively.

Among the selected species, *B. schwanenfeldii* had the most diverse food items observed during the analyses, indicating a wider feeding habit which contributes to its higher distribution and abundance in the Murum River. Hamid et al. [38] described *C. apogon* as omnivorous and found that the stomach content of *C. apogon* mainly consisted of Oligochaeta, Chironomidae, and detritus. The finding was consistent with the type of food found in *C. apogon* in the

present study. Makmur et al. [39] documented that *H. macrolepidota* is a carnivorous fish species, which is in agreement with the present study where the stomach content of fish was high in crustaceans (FO > 90%). Nevertheless, plant parts were also found in the stomach contents of *P. oxygastroides* and *H. macrolepidota*, although the FO (≈6.4%) and MM (≈0.2%) were low. This shows that these fish species can modify their diet by feeding on plant materials during the limitation of preferred food [40].

4. Conclusions

The present study showed that cascade dams influenced the fish assemblage and biological indices in the Murum River that is located between the two cascading dams of Bakun and Murum. The Murum Hydroelectric Powerhouse had exerted a major influence on the fish abundance, species diversity, and richness due to the deterioration of water quality, particularly water pH and DO. The most profound impact on species diversity, richness, and evenness was observed at the transitional zone of the Bakun reservoir, particularly during the dry season. The family Cyprinidae was the most dominant family during the dry and wet seasons, while the abundant species varied between seasons, which is attributable to the migration behaviour of fish during the onset of the rainy season and ongoing restructuring of fish communities as the river has just been recently modified. The present study also demonstrated a potential threat of biological invasion on native species in the river as indicated by the increase of fish abundance coupled with the high condition factor of the exotic species, *Oreochromis mossambicus*. All native fish species in the river were in poor to fair condition, although some of the species exhibited better growth patterns during the wet season. Therefore, continuous and long-term monitoring of fish fauna is necessary to better understand the fish composition and distribution patterns in the newly modified river to improve long-term forecasts and to develop invasion species management plan for conservation of the native species in the river.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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