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Research Article

Physicochemical Parameters and Fish Assemblages in the Downstream River of a Tropical Hydroelectric Dam Subjected to Diurnal Changes in Flow

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The downstream river of the tropical Batang Ai Dam is experiencing diurnal flow fluctuation due to power generation operation. Three samplings were conducted to collect the water quality and fish assemblage data and one sampling was conducted to study the hydrological characteristics of the downstream river. The results show that the downstream river is extremely shallow and moves slowly when the power generation is halted and no water is discharged from the powerhouse. Significant correlations between river flow and pH, dissolved oxygen (DO), total suspended solids (TSS), and five-day biochemical oxygen demand (BOD_5) indicated that those parameters were influenced by the water discharge regulation. Fish abundance was low in upstream segment but it gradually increased as distance from the dam increased and was significantly correlated with DO. Fish diversity in the downstream river was influenced by the river depth and chlorophyll *a* concentration. The most abundant fish species, *Cyclocheilichthys apogon*, exhibited a negative allometric growth pattern, while *Hampala macrolepidota* and *Hemibagrus planiceps* exhibited an isometric growth pattern. Fulton's condition factor (K) values for 89.4% of *H. planiceps* were ≤1, indicating poor to extremely poor conditions.

1. Introduction

Impoundment of a river often causes dramatic changes in the physicochemical characteristics and biological structure of its downstream river [1–5]. Studies have shown that connectivity disruptions coupled with erratic flow pattern change the morphology and physicochemical characteristics of a river [6–11]. Domination of fish species that is well adapted to the new environment and elimination of sensitive species could alter the composition of fish assemblages and lower the fish diversity in the downstream river [12, 13].

In Malaysia, about 80 dams have been built and hydropower dams are the most common in the state of Sarawak [14]. As more hydroelectric dams are being planned in the state of Sarawak, there has been an increased effort to understand the impacts of hydroelectric dams on the tropical aquatic ecosystem. It is also of scientific importance to investigate and evaluate the hydrological and physicochemical characteristics of a downstream river induced by river impoundment and operation of hydroelectric dam, which could have an impact on the fish community. In addition, knowledge on fish assemblages in the regulated downstream river of a dam coupled with growth pattern and well-being of fishes in the stream is also crucial for ecosystem conservation and management.

The Batang Ai Dam is the oldest dam built for electricity supply in the state of Sarawak, Malaysia. The reservoir has been impounded for more than 30 years. Several studies on water quality of the reservoir have been conducted [15–18]. However, knowledge on its downstream river below the powerhouse is scarce. The influence of the impoundment and the erratic discharge of the reservoir water during power generation on its downstream river remain unknown. Hence, this study aimed to establish the baseline data on hydrological

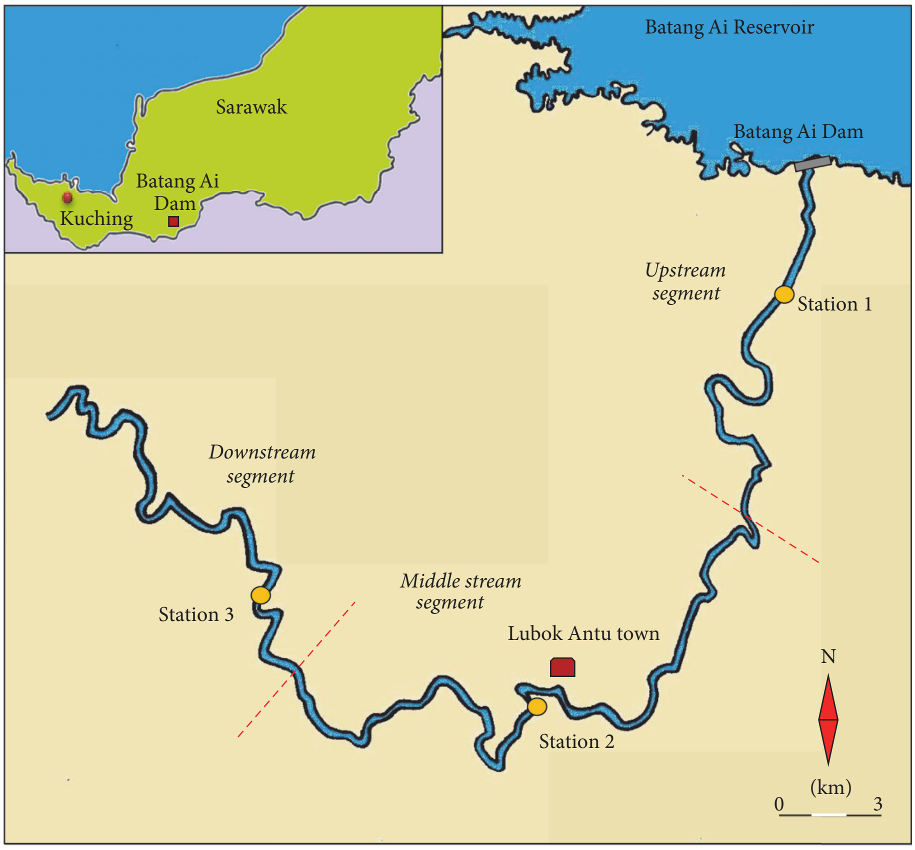

FIGURE 1: Location of the three segments and sampling stations in the study area.

characteristics, physicochemical parameters of water, and fish fauna composition in the downstream river, which was subjected to diurnal discharge of reservoir water during power generation. Additionally, the length-weight relationship and Fulton's condition factor of the three most dominant fish species in the downstream river were determined.

2. Materials and Methods

2.1. Study Area and Sampling Location. The present study was conducted in the downstream river of the Batang Ai Dam located in Lubok Antu, Sarawak, Malaysia, approximately 250 km southeast of Kuching (Figure 1). The Batang Ai Dam was constructed across Batang Ai (Batang means large river) and was commissioned in 1985. It serves as a hydropower dam and the reservoir is also used for aquaculture and tourism activities. The stretch of the river that was studied started at the powerhouse and stretched 30 km downstream from it. This stretch was divided into three segments, namely, upstream segment, middle stream segment, and downstream segment. Each segment covered a distance of about 10 km. The river was subjected to diurnal fluctuation of flow, where the discharge through turbines mainly occurs during daytime. Subsistence agricultural activities and settlements in longhouses are located along the river. In addition, the middle stream segment of the river passes through a small town, Lubok Antu, as well as a road.

2.2. Field Samplings and Laboratory Analysis. Data on fish fauna and water quality were collected in October 2014, January 2015, and February 2017. The hydrological characteristics for each segment were studied in February 2017. The width, depth, and velocity of the river were measured at three different time frames in a day by using a range finder (Bushnell Elite 1500), a depth finder (Speedtech), and a flow meter (Flowatch FL-03), respectively.

pH, temperature, electrical conductivity, dissolved oxygen (DO), and turbidity were measured in triplicate by using a pH meter with a temperature probe (SDL100 Extech Instrument), a conductivity meter (Lutron CD-4303), a DO meter (SDL150 Extech Instrument), and a turbidity meter (TU-2016 Lutron), respectively. Triplicate water samples were taken for the analyses of total suspended solids (TSS), five-day biochemical oxygen demand (BOD_5), and chlorophyll *a* (chl *a*) following the procedure of Jenkins et al. [19]. TSS was calculated as the difference between the initial weight and final weight of the 0.7 μm retention glass microfibre filter (Advantec) after the filtration of one liter of water sample and drying to constant weight at 105°C. BOD_5 was determined as the difference between the initial and final DO concentrations after a five-day long incubation of the sample at 20°C. Chl *a* was determined from samples filtered through a 0.45 μm retention glass microfibre filter (Sartorius) and extracted for 24 h using 90% (v/v) acetone.

Fish samples were collected using two types of gill nets, namely, monofilament gill net and three-layered gill net. The

Table 1: Hydrological characteristics in the three segments of Batang Ai below the dam.

Parameter	Upstream			Middle stream			Downstream		
	0840	1500	2000	0740	1020	1806	0940	1222	1530
Mean depth, m	0.55	0.90	0.96	1.22	0.89	2.17	0.79	0.96	0.72
Mean velocity, m/s	0.07	0.50	1.00	0.22	0.37	0.88	0.68	0.80	0.60
Flow, m^3/s	1.90	26.23	53.50	15.25	18.56	86.14	17.29	25.30	13.74

monofilament gill net consisted of four different mesh sizes (2.5 cm, 5.1 cm, 7.2 cm, and 10.2 cm) and each had a length of 45.0 m. The three-layered gill net had mesh sizes of 14.0 cm, 4.0 cm, and 14.0 cm with a length of 65.0 m. For each sampling trip, equal numbers of nets were placed and left for two nights in each segment and the nets were checked twice daily during daytime. The fish specimens collected were fixed in 10% formalin and later transferred into 70% ethanol for preservation. Fish specimens were sorted and enumerated according to sampling station and species identified according to the taxonomic keys [20, 21] and an online global database of fish species [22]. The total length (TL) and body weight (BW) of the three most abundant fish species were measured to the nearest millimeter and gram, respectively.

2.3. Data and Statistical Analysis. The flow, mean depth, and mean velocity of the river were calculated according to Chapra [23]. The water quality parameters collected in the three segments were compared by using one-way ANOVA, where the sampling trip was treated as a random effect in the analysis followed by Tukey's test, where $P \leq 0.05$ indicated significant difference. The fish data collected during the three sampling trips at each segment were pooled to calculate the fish abundance in each segment. Species diversity, evenness, and richness were calculated using the following formulas.

Shannon's diversity index (H) [24] is given as follows:

$$H = \sum \frac{N_i}{N} \log_e \frac{N_i}{N}. \quad (1)$$

Pielou's evenness (J) [25] is given as follows:

$$J = \frac{H}{\log_e S}. \quad (2)$$

Margalef's index of species richness (D) [26] is given as follows:

$$D = \frac{S-1}{\log_e N}, \quad (3)$$

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

The length-weight relationship (LWR) and the general well-being of fish expressed by Fulton's condition factor (K) of the three most abundant species were determined. The LWR of fish species was established using the formula $\mathrm{BW} = a\mathrm{TL}^n$ by expressing it in the logarithmic form as $\log \mathrm{BW} = \log a + n \log \mathrm{TL}$ [27]. The statistical significance of the relationship was determined by using linear regression analysis with $P \leq 0.05$, where the constants "a" and "n" were obtained. Fulton's condition factor (K) [28] was calculated using the following formula:

$$K = \frac{\mathrm{BW} \times 100}{\mathrm{TL}^3}. \quad (4)$$

Pearson's correlation analysis was performed to elucidate significant relationship among the biotic and abiotic parameters at $P \leq 0.10$. All the statistical analyses were carried out using the Statistical Package for Social Sciences (SPSS version 24, SPSS Inc., 1995).

3. Results and Discussion

3.1. Hydrological Characteristics of the Downstream River of Batang Ai Dam. The hydrological characteristics of the downstream river of the dam varied substantially in a day due to the regulation of water discharge through the turbines during power generation and no water was released from the spillway. Prior to the discharge in the morning, the river was shallow and moved slowly, particularly in the upstream segment, with a mean depth of 0.55 m, a mean velocity of 0.07 m/s, and an estimated discharge of 1.90 m^3/s (Table 1). The mean velocity and flow gradually increased towards the downstream direction with the highest mean velocity of 0.68 m/s and the highest flow of 17.29 m^3/s observed in the downstream segment. When the water was discharged from the reservoir into the downstream river during power generation, the mean depth, mean velocity, and flow increased substantially in the upstream and middle stream segments. The mean depth, mean velocity, and flow in the upstream segment were found to increase to 0.90 m, 0.50 m/s, and 26.23 m^3/s, respectively, at 1500 hrs. The water discharge continues to affect the mean velocity and flow in the upstream segment, where they increased up to 1.00 m/s and 53.50 m^3/s, respectively, at 2000 hrs. In middle stream segment, the impact of the water discharge was observed at around 1800 hrs, where the mean depth, mean velocity, and flow increased up to 2.17 m, 0.88 m/s, and 86.14 m^3/s, respectively. There was no noticeable variation in the hydrological characteristics of the downstream segment as the discharge had not reached the downstream segment yet.

3.2. Physicochemical Parameters of the Water of the Downstream River of Batang Ai Dam. Water quality at the downstream river was significantly different ($P \leq 0.05$) among segments along the river (Table 2). The lowest pH value of 6.4 was recorded in the upstream segment and significantly increased ($P \leq 0.05$) to 6.8 in the middle stream and downstream segments. The pH value was classified as Class II according to the Water Quality Index (WQI) of Malaysia [29]. The lower pH value in the upstream segment is due to the

Table 2: Means and standard deviations of the physicochemical characteristics of the downstream river of Batang Ai.

Parameter	Upstream	Middle stream	Downstream
pH	$6.4^{a} \pm 0.2$	$6.8^{b} \pm 0.2$	$6.8^{b} \pm 0.4$
Temperature	$29.0^{c} \pm 1.4$	$28.0^{b} \pm 1.6$	$26.8^{a} \pm 0.7$
Conductivity	$23.9^{b} \pm 5.3$	$25.4^{c} \pm 5.0$	$21.8^{a} \pm 5.7$
DO	$5.9^{a} \pm 1.7$	$6.2^{b} \pm 1.5$	$6.3^{c} \pm 1.4$
Turbidity	$3.8^{a} \pm 0.8$	$4.6^{a} \pm 1.3$	$15.4^{b} \pm 14.9$
TSS	$4.4^{a} \pm 0.5$	$11.7^{ab} \pm 13.9$	$12.4^{b} \pm 11.6$
BOD_5	$3.5^{b} \pm 0.2$	$2.6^{a} \pm 1.4$	$2.6^{a} \pm 1.2$
Chl *a*	$2.5^{a} \pm 0.9$	$2.1^{a} \pm 0.4$	$2.4^{a} \pm 1.4$

Mean followed by different letters indicated significant difference at $P \leq 0.05$.

intake of lower pH water from hypolimnion of the reservoir during power generation. In Batang Ai Dam, the water intake for power operation is about 14 m below the surface, where the pH is predominantly acidic [15]. The increase in pH value at middle stream and downstream segments is attributable to dilution effect [30]. Water temperature ranged from 26.8 ± 0.7°C to 29.0 ± 1.4°C, where it decreased significantly ($P \leq 0.05$) with distance from the dam. Changes in water temperature of the downstream river of a hydropower plant occurred when warmer or colder water of a reservoir was being released into its downstream river [31, 32]. Bobat [31] stated that the downstream water of dams and hydropower plants was generally warmer than upstream water because of the passing of water from pipelines, penstock, turbine, and cooling system into the downstream river. However, Ling et al. [16] showed that the water temperature of river located at outflow of the Batang Ai reservoir was colder than the reservoir water. Hence, it is hypothesized that warm water in upstream segment in the present study is due to direct solar radiation in the shallow and exposed river. As river depth increased in middle stream and downstream segments, the heat capacity per unit surface area increased and thus a decrease in water temperature was observed [33].

Mean conductivity values at the segments ranged from 21.8 ± 5.7 μS/cm to 25.4 ± 5.0 μS/cm and they were significantly different ($P \leq 0.05$) (Table 2). The highest value of conductivity was observed in the middle stream segment. Similar to pH value, the DO values in the downstream river also increased significantly with distance from the dam ($P \leq 0.05$), that is, from 5.9 ± 1.7 mg/L in upstream segment to 6.3 ± 1.4 mg/L in downstream segment. The increase in DO value further from the powerhouse indicates that the DO content was first impacted by the low DO from the reservoir but was later diluted by river water with higher DO content as well as reaeration due to faster water flow along the river. The mean DO values met the minimum requirement for healthy sensitive aquatic organisms (5 mg/L) at all segments and are classified as Class II. However, low DO values of less than 5 mg/L were observed occasionally in the downstream river during samplings. This is due to the lower value of DO from deeper water column of the reservoir. At the water intake depth of 14 m, DO has been reported to be 3.92 mg/L [15]. Factors responsible for the large variations in DO value among trips were seasonal variations in precipitation, which resulted in changes in river flow rate and the differences in discharge during power generation. This is further supported by the significant correlation ($r = +0.993$; $P \leq 0.10$) between DO and flow observed in the present study.

Turbidity and TSS values were low in the downstream river, ranging from 3.8 ± 0.8 NTU to 15.4 ± 14.9 NTU and from 4.4 ± 0.5 mg/L to 12.4 ± 11.6 mg/L, respectively. Both parameters were classified as Class I and/or Class II according to WQI. The low turbidity and TSS values in the present study were different from the high turbidity and TSS values observed in the downstream river of a new hydroelectric dam [30]. However, they are consistent with low turbidity (2–15 NTU) and TSS values (2–7 mg/L) recorded in the Batang Ai reservoir at 10 and 20 m depths [17], as suspended solids have settled at this 30-year-old reservoir [16]. Among the segments studied, turbidity and TSS values were significantly higher ($P \leq 0.05$) in downstream segment than in upstream segment. TSS was significantly and positively correlated ($r = +0.999$; $P \leq 0.05$) with flow (Table 3), indicating resuspension of sediment under higher flow rate in downstream segment, which was likely the cause of higher turbidity and TSS values in the downstream segment.

BOD_5 showed an opposite trend with turbidity and TSS values, where the mean decreased significantly from 3.5 mg/L in upstream segment to 2.6 mg/L in middle stream and downstream segments. BOD_5 concentration was classified as Class III in upstream segment and Class II in middle stream and downstream segments. The gradual decrease of BOD_5 concentration further downstream indicates that BOD_5 was most probably contributed by the reservoir water as high BOD_5 concentration (6.33 mg/L) had been reported in the outflow of the reservoir [16]. This is further supported by the significant and negative correlation ($r = -0.993$; $P \leq 0.10$) between BOD_5 and flow. Chl *a* concentration was relatively constant along the river with a mean value of 2.3 mg/m^3 as the analysis shows that there was no significant difference ($P > 0.05$) among the segments.

3.3. Fish Assemblage of the Downstream River of the Batang Ai Dam. A total of 436 fish individuals belonging to eight families, 13 genera, and 17 species were captured in the downstream river of Batang Ai (Table 4). The results show that the most dominant family is Cyprinidae (67.9%) followed by Bagridae (11.2%). The three most dominant species were *Cyclocheilichthys apogon* (48.2%) and *Hampala macrolepidota* (11.0%) from the family Cyprinidae and *Hemibagrus planiceps* (10.8%) from the family Bagridae. Shannon's diversity index of 1.9 and the richness index of 2.6 show that fish diversity and species richness in the downstream river were low [34].

Table 3: Correlation between abiotic and biotic parameters at downstream river of Batang Ai ($N = 3$).

	pH	Temp.	Cond.	Turb.	DO	TSS	BOD_5	Chl *a*	Flow	Mean depth	Abundance	*H*	*D*
pH	1.000												
Temp.	−0.839	1.000											
Cond.	−0.096	0.623	1.000										
Turb.	0.553	−0.917	−0.883	1.000									
DO	0.971	−0.945	−0.332	0.737	1.000								
TSS	0.997^{**}	−0.879	−0.174	0.617	0.987^{*}	1.000							
BOD_5	-1.000^{**}	0.839	0.096	−0.553	−0.971	-0.997^{**}	1.000						
Chl *a*	−0.693	0.189	−0.651	0.218	−0.500	−0.634	0.693	1.000					
Flow	0.993^{*}	−0.899	−0.217	0.650	0.993^{*}	0.999^{**}	-0.993^{*}	−0.600	1.000				
Mean depth	0.774	−0.304	0.556	−0.100	0.599	0.721	−0.774	-0.993^{*}	0.691	1.000			
Abundance	0.920	−0.985	−0.478	0.835	0.987^{*}	0.948	−0.920	−0.356	0.961	0.464	1.000		
H	0.713	−0.216	0.630	−0.190	0.524	0.656	−0.713	-1.000^{**}	0.622	0.996^{*}	0.382	1.000	
D	0.531	0.017	0.793	−0.413	0.312	0.462	−0.531	−0.979	0.423	0.947	0.156	0.973	1.000

$^{*}P \leq 0.10$; $^{**}P \leq 0.05$.

Table 4: Summary of the fish assemblages at the downstream river of Batang Ai.

Family	Species	Upstream		Middle stream		Downstream		Total	
		Count	%	Count	%	Count	%	Count	%
Bagridae	*Hemibagrus nigriceps*	0	0	2	1	0	0	2	0.5
	Hemibagrus planiceps	15	17	16	10	16	8	47	10.8
Channidae	*Channa striata*	1	1	6	4	1	1	8	1.8
Clariidae	*Clarias batrachus*	3	3	2	1	2	1	7	1.6
Cyprinidae	*Barbonymus schwanenfeldii*	3	3	1	1	2	1	6	1.4
	Cyclocheilichthys apogon	45	52	70	46	95	48	210	48.2
	Cyclocheilichthys armatus	1	1	2	1	0	0	3	0.7
	Hampala macrolepidota	5	6	16	10	27	14	48	11.0
	Osteochilus enneaporos	0	0	0	0	1	1	1	0.2
	Osteochilus schlegelii	0	0	1	1	0	0	1	0.2
	Osteochilus waandersii	0	0	6	4	4	2	10	2.3
	Puntius binotatus	3	3	2	1	5	3	10	2.3
	Rasbora caudimaculata	3	3	4	3	0	0	7	1.6
Eleotridae	*Oxyeleotris marmorata*	5	6	5	3	8	4	18	4.1
Mastacembelidae	*Mastacembelus erythrotaenia*	0	0	5	3	3	2	8	1.8
Osphronemidae	*Osphronemus goramy*	3	3	14	9	23	12	40	9.2
Toxotidae	*Toxotes microlepis*	0	0	1	1	9	5	10	2.3
Total number of species		11	100	16	100	13	100	17	100
Total number of fish caught		87		153		196		436	
Shannon's diversity index, *H* (*e*)		1.7		1.9		1.7		1.9	
Margalef's richness index, *D* (*e*)		2.2		3.0		2.3		2.6	
Pielou's evenness index, *J* (*e*)		0.7		0.7		0.7		0.7	

The highest diversity and species richness were found in the middle stream segment. In the downstream river, an evenness index of 0.7 shows that the fish compositions are considered to be more evenly distributed [25].

The present study shows that fish abundance increased with an increasing distance from the dam. A total of 87, 153, and 194 individuals were caught in the upstream, middle stream, and downstream segments, respectively. Reduced biotic abundance, diversity, and productivity in tail water may be due directly to flow variation or indirectly to factors related to flow variation such as changes in river depth and temperature [35]. In the present study, fish abundance was significantly and positively correlated with DO ($r = +0.987$; $P \leq 0.10$). This indicates that lower DO content in the upstream segment plays a significant role in the reduction of fish abundance in that segment. The fish abundance increased when DO improved in the downstream direction. As DO was influenced by the river flow, fish abundance in the study area was indirectly influenced by the flow as well. However, there is no strong relationship found between fish abundance and flow in the present study. Similarly, Growns [12] reported that the abundance of individual fish species was only weakly correlated with the index of flow deviation and river hydrology and thus explained only a small part of variation in fish assemblage structure. The species diversity was found to be significantly and positively correlated with the river mean depth ($r = +0.996$; $P \leq 0.10$). The result indicates that fish assemblage in a shallow river in the upstream segment is less diverse than a deeper river in middle stream and downstream segments.

Table 5 summarizes the LWR analysis conducted on the three most dominant species in the downstream river of

TABLE 5: Summary of regression analyses of length-weight relationships of the three most abundant species in the downstream river of Batang Ai.

Species	log BW = log a + n log TL			Parameter estimates		Standard error	P	95% confidence interval		LWR: $W = aL^n$
	N	R^2	P					Lower bound	Upper bound	
Cyclocheilichthys apogon	208	0.844	**0.001**	log a	−1.482	0.092	**0.001**	−1.663	−1.302	$W = 0.033L^{2.678}$
				n	2.678	0.080	**0.001**	2.520	2.836	
Hampala macrolepidota	46	0.875	**0.001**	log a	−1.916	0.211	**0.001**	−2.341	−1.490	$W = 0.012L^{3.014}$
				n	3.014	0.172	**0.001**	2.668	3.361	
Hemibagrus planiceps	47	0.901	**0.001**	log a	−2.119	0.191	**0.001**	−2.503	−1.734	$W = 0.008L^{3.039}$
				n	3.039	0.150	**0.001**	2.737	3.341	

Significant values ($P \leq 0.05$) are indicated in bold.

TABLE 6: Summary of Fulton's condition factor (K) of the three most abundant species in the downstream river of Batang Ai.

Species	N	Fulton's condition factor (K)				Percentage of individuals					
		Min	Max	Mean	SD	≤0.8	$0.8 < x \leq 1$	$1 < x \leq 1.2$	$1.2 < x \leq 1.4$	$1.4 < x \leq 1.6$	>1.6
Cyclocheilichthys apogon	208	0.77	3.09	1.48	0.53	0.5	1.4	23.1	46.2	12.5	16.3
Hampala macrolepidota	46	0.89	4.05	1.35	0.59	0.0	21.7	45.7	8.7	8.7	15.2
Hemibagrus planiceps	47	0.66	1.41	0.86	0.15	46.8	42.6	6.4	2.1	2.1	0.0

the Batang Ai Dam. Significant linear regressions with R^2 close to the value of one show that TL and BW of each species fitted the linear model well. The LWRs for *C. apogon*, *H. macrolepidota*, and *H. planiceps* are expressed as $W = 0.033L^{2.678}$, $W = 0.012L^{3.014}$, and $W = 0.008L^{3.039}$, respectively. The most dominant species, *C. apogon*, exhibited a negative allometric growth (coefficient "n" value < 3), whereas *H. macrolepidota* and *H. planiceps* exhibited an isometric growth as indicated by the "n" values of 3.

Fulton's condition factor (K) value gradually decreased from the most abundant species, *C. apogon* (1.48 ± 0.53), to the third most abundant species, *H. planiceps* (0.86 ± 0.15) (Table 6). Around 46.2% of the K values of *C. apogon* were found in the range of 1.2–1.4, which indicates that nearly half of the fish in this species were in good condition. On the other hand, 45.7% of *H. macrolepidota* scored K values between 1.0 and 1.2, indicating that nearly half of this species caught were in fair condition. However, most of the K values of *H. planiceps* (89.4%) were ≤1, indicating poor to extremely poor conditions [36]. Food availability and environmental condition are most likely the reasons for the well-being of those species. The most abundant fish species, *C. apogon*, thrived better in the downstream river of Batang Ai compared to other species.

4. Conclusions

The present study shows that water discharge regulation of the Batang Ai Dam affected the hydrological characteristics, physicochemical parameters of water, and fish assemblages of its downstream river. The downstream river was extremely shallow and moved slowly but the mean depth, velocity, and flow of the river increased substantially when water was discharged from the dam during power generation. Physicochemical parameters of water, particularly pH, DO, TSS, and BOD_5 concentrations, were impacted by the dam water discharge as indicated by the significant correlation between those parameters and flows. The three most abundant fish species were *C. apogon* (48.2%) and *H. macrolepidota* (11.0%) of family Cyprinidae followed by *H. planiceps* (10.8%) of family Bagridae. Fish abundance was low in upstream segment but gradually increased in the downstream direction, away from the dam. Fish abundance was significantly correlated with DO, whereas the fish diversity was influenced by the river depth. Length-weight relationship analyses show that *C. apogon* exhibited negative allometric growth, whereas *H. macrolepidota* and *H. planiceps* exhibited isometric growth.

Conflicts of Interest

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

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