Bhutan Journal of Animal Science (BJAS)
Special Issue, Page 1-10, October 2022

POST-MONSOON COMPOSITION OF ICHTHYOFAUNA ALONG THE PUNATSHANGCHHU AND ITS TRIBUTARIES AT THE HYDROPOWER PROJECTS AREA

GOPAL PRASAD KHANAL[1], CHANGLU[1], PEMA TSHERING[2], PEMA GYELPO[2], PEMO[2], SANGAY DOLMA[3], TASHI DORJI[4] AND DAWA DOLI SHERPA[4]

[1] National Research and Development Centre for Riverine and Lake Fisheries, Haa 15001.
[2] Mahseer Conservation and Fish Monitoring Centre (National Research and Development Centre for Riverine and Lake Fisheries, Haa), Taksa, Wangdue Phodrang 14001.
[3] Environment Wing, Punatshangchhu - I Hydroelectric Project Authority (PHPA – I), Wangdue Phodrang 14001.
[4] Environment Wing, Punatshangchhu - II Hydroelectric Project Authority (PHPA – II), Wangdue Phodrang 14001.

Author for correspondence: gpkhanal@moaf.gov.bt

ABSTRACT: Hydropower promotors in Bhutan are mandated to address impacts on aquatic biodiversity through proper conservation and management plans formulated through regular monitoring of impacted areas. This assessment presents findings from post-monsoon monitoring of mainstem Punatshangchhu and its tributaries within the Punatshangchhu Hydropower Project area (PHPP – I & II) from November 22nd – 26th, 2021. Though Kruskal-Wallis test and multiple pairwise comparison the study recorded significant differences ($p<.05$) in physiochemical properties such as pH, dissolved oxygen (DO) and total dissolved solids (TDS) within the mainstem Punatshangchhu and its tributaries, all accessed variables were found within the permissible limits for fisheries and surface water. The differences in catch per unit effort (CPUE) among the downstream, impacted (future dewatered) and upstream zones of Punatshangchhu were not statistically significant. Lower CPUE, abundance and size observed during present monitoring compared to the post-monsoon monitoring conducted in 2018 and 2019 indicated possible changes in population structure of *Schizothorax richardsonii*, the dominant fish along the Punatshangchhu. However, nonstandard sampling adopted over years makes comparison among years unreliable requiring adoption of consistent assessment approaches during the subsequent monitoring for comprehensive realization of conservation goals.

Keywords: Catch per unit effort (CPUE); monitoring; *Schizothorax richardsonii*.

1. INTRODUCTION

Hydropower is among major source of revenue for Bhutan through the export of electricity and plays an important role in socio-economic development. The techno-economically feasible hydropower potential of Bhutanese rivers is estimated to be 26,760 megawatt (MW) (NORAD 2017). On contrast, only 2,326 MW from six major hydro power projects (HPPs) (> 25 MW) and 8.342 MW from 24 small and mini/micro plants (<25 MW) are presently harnessed. This gives opportunities to further accelerate the hydropower development for socio-economic benefits. As a consequences development of numerous hydropower projects are under pipeline. The 1200 MW Punatshangchhu - I Hydropower Project (PHPP – I) and the 1020 MW Punatshangchhu - II Hydropower Project (PHPP – II) are the major run-of-river (ROR) scheme under construction-phase at Punatshangchhu River, Wangdue Phodrang.

Hydropower developments are among the major threat to global aquatic biodiversity and needs immediate attention (Dudgeon et al. 2006; Reid et al. 2019). The dam acts as a barrier for upstream and downstream migration of fishes. The dam traps sediments and changes downstream sediment transport regime altering the habitat conditions and productivity. The impoundment of water alters the flow regime within the dewatered stretch and changes the limnological properties of water within the impoundment and dewatered stretches. These changes in hydromorphological conditions alters the diversity, distribution and composition of fishes by negatively influencing the survival, growth, migration, reproduction and recruitment characteristics of fishes. The construction phase triggers changes in morphological characteristics (substrate homogenization by washed off excavated debris), hydromorphological characteristics (from the extraction of boulder, gravel and sand) and limnological conditions (from the discharge of effluents and sediments). The fragmentation of longitudinal connectivity by diversion tunnel triggers initial impacts on the migratory fishes.

Considering the vulnerability of aquatic ecosystems to anthropogenic alterations, hydropower developers in Bhutan are required to address adverse impacts on aquatic biodiversity, and fishes in particular (Water Regulation of Bhutan, 2014). Two mitigation measures are recommended by the regulation: (i) implementation of science-based environmental flows (e-flows) and (ii) operation of fishways or initiation of river ranching of native species through hatchery operations. Adequate information on the diversity, abundance and population structure of fishes within the project area through regular monitoring are important for the implementation of these conservation measures. The present post-monsoon monitoring is therefore aimed to access (i) basic water quality parameters, and (ii) the composition of ichthyofauna at Punatshangchhu River (henceforth referred as Punatshangchhu) and its tributaries within the Punatshangchhu Hydropower Projects area (PHPP – I & II). Such monitoring program is necessary to access short and long-term impacts on the aquatic ecosystems and to meet environmental obligations through adequate implementation of conservation and mitigation plans.

2. MATERIALS AND METHOD

2.1 Study area

The study covers the Punatshangchhu and its tributaries (Figure 1, Table 1) at Wangdue Phodrang located within the vicinity of Punatshangchhu Hydropower Projects (PHPA – I & II), which are currently under construction. The sampling sites across mainstem Punatshangchhu (~ 40.574 km river length) extends from Taksa (Figure 1, Table 1 - Sl. No. 1) till Hesothangkha (Figure 1, Table 1 - Site No.

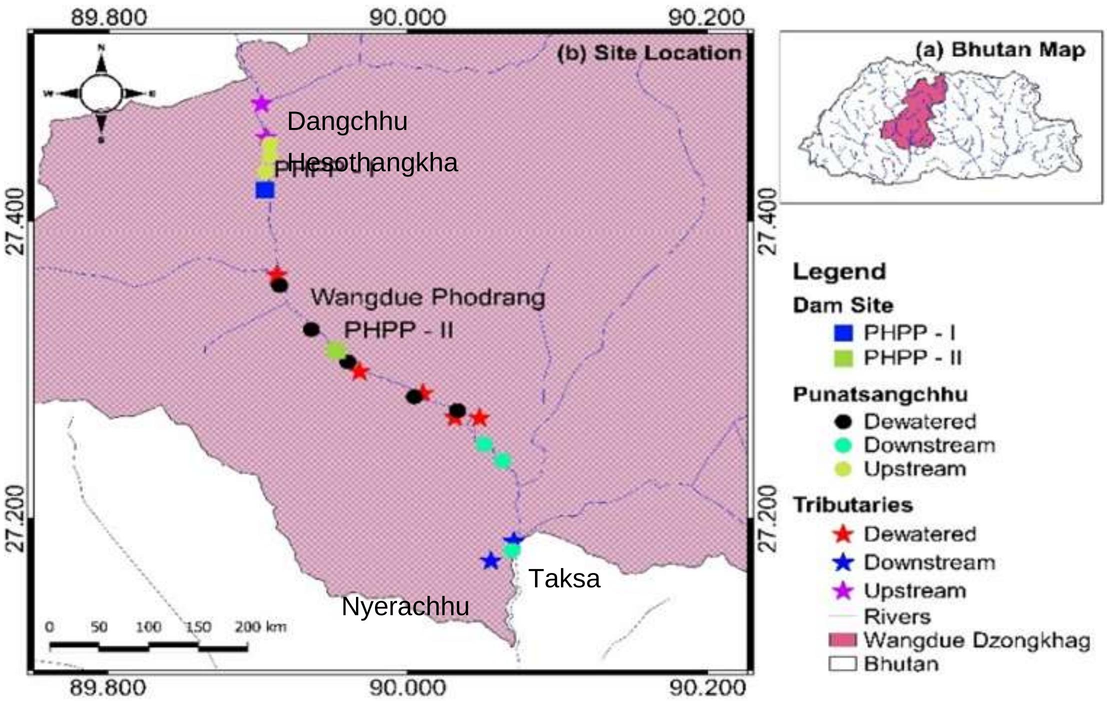

Figure 1: The location of study area and sampling sites: (a) a map of Bhutan showing the location of Wangdue Phodrang, and (b) the location of sampling sites along mainstem Punatsangchhu and its tributaries at the Punatsangchhu Hydropower Project area (PHPP – I and II).

11). Tributaries sampled (from downstream) are - Nyerachhu, Harachhu, Dikchhu, Kamerongchhu, Phenrechhu, Baychhu, Basochhu, Nahichhu (Hesothangkhachhu) and Dangchhu.

2.2 Sampling design

A total of 20 sampling sites were identified across Punatshangchhu and its tributaries within an altitudinal gradient of 627 m. The 11 sampling sites along mainstem Punatshangchhu ranges from 36 – 181 m changes in elevation as the accessibility was issues to establish sites with approximately uniform altitudinal drop. The mainstem Punatshangchhu were categorized into three zones: *downstream zone* (~ 9.957 km river length from TRT outfall of PHPP – II to Taksa), the impacted site and the future dewatered reaches, referred henceforth as *dewatered zone* (~ 27.023 km river length between outlet of PHPP – I diversion tunnel and TRT outfall of PHPP – II) and *upstream zone* (~ 3.588 km upstream from intake of PHPP – I diversion tunnel). The sampled river length along the mainstem Punatshangchhu is 5.941 km: 1.645 km along the downstream zone, 1.848 km along the dewatered zone and 2.448 km along the upstream zone. The 9 tributaries are further categorized into three zones based on their location with respect to the zones of Punatshangchhu: *downstream tributaries* (Nyerachhu and Harachhu), future *dewatered tributaries* (Dikchhu, Kamerongchhu, Phenrechhu, Baychhu, Basochhu) and *upstream tributaries* (Nahichhu and Dangchhu).

2.3 Sample collection

The fishes were sampled during the post-monsoon season (November 22nd – 26th, 2021) using cast net along mainstem Punatshangchhu sites and Dangchhu, and with electrofisher (Model: ELT62-2D; Grassl, Germany; DC 3KV) across other tributaries. The sampling effort (hours) was recorded at Punatshangchhu and Dangchhu, whereas standard sampling effort of 20 minutes of electrofishing was performed along the tributaries (except Dangchhu). The cumulative sampling efforts applied across different zones of mainstem Punatshangchhu ranges from 2 – 3 hours and a hour cast netting at Dangchhu. The fishes were released after taking length (accuracy of ± mm) and weight (Model: I-2000, Newpro Electronics, China). Some specimens are preserved in 70 % ethanol after fixation with 10 % formalin and are maintained at Mahseer Conservation and Fish Monitoring Centre (MCFMC), Taksa. Triplicates of basic water quality parameters such as dissolved oxygen (DO), pH, temperature, total dissolved solids (TDS) and electrical conductivity (EC) were recorded using a multi-parameter probe

Table 1: Geographical details of sampling sites of Punatsangchhu rivers and its tributaries at the Punatsangchhu Hydropower Project area (PHPP - I & II), Wangdue

Sl. No.	River/Streams	Segment	Zone	Date	Latitude (DD)	Longitude (DD)	Altitude (m)	Sampling method
1	Punatsangchhu	Mainstem	Downstream	22-11-21	27.178979	90.069548	480	Cast net
2	Punatsangchhu	Mainstem	Downstream	22-11-21	27.239184	90.063304	529	Cast net
3	Punatsangchhu	Mainstem	Downstream	22-11-21	27.250228	90.051111	579	Cast net
4	Punatsangchhu	Mainstem	Dewatered	23-11-21	27.272908	90.033036	632	Cast net
5	Punatsangchhu	Mainstem	Dewatered	23-11-21	27.282269	90.004215	683	Cast net
6	Punatsangchhu	Mainstem	Dewatered	23-11-21	27.305624	89.960029	775	Cast net
7	Punatsangchhu	Mainstem	Dewatered	23-11-21	27.327490	89.935570	882	Cast net
8	Punatsangchhu	Mainstem	Dewatered	23-11-21	27.357047	89.914206	993	Cast net
9	Punatsangchhu	Mainstem	Upstream	24-11-21	27.433392	89.904877	1174	Cast net
10	Punatsangchhu	Mainstem	Upstream	24-11-21	27.443759	89.907695	1210	Cast net
11	Punatsangchhu	Mainstem	Upstream	24-11-21	27.452496	89.907497	1364	Cast net
12	Nyerachhu	Tributaries	Downstream	26-11-21	27.171713	90.055340	581	Electrofisher
13	Harachhu	Tributaries	Downstream	26-11-21	27.184690	90.070680	480	Electrofisher
14	Dikchhu	Tributaries	Dewatered	26-11-21	27.267790	90.047780	661	Electrofisher
15	Kamerongchhu	Tributaries	Dewatered	25-11-21	27.268198	90.031306	668	Electrofisher
16	Phrenchu	Tributaries	Dewatered	26-11-21	27.284460	90.010070	716	Electrofisher
17	Baychhu	Tributaries	Dewatered	25-11-21	27.299090	89.967680	755	Electrofisher
18	Basochhu	Tributaries	Dewatered	25-11-21	27.363890	89.912410	1004	Electrofisher
19	Nahichhu	Tributaries	Upstream	25-11-21	27.456600	89.905120	1186	Electrofisher
20	Dangchhu	Tributaries	Upstream	24-11-21	27.479191	89.902049	1197	Cast net

(MODEL: 98194; Hanna Instruments, Romania).

2.4 Data analysis

The biological variables considered are Shannon diversity index (*H*), evenness (*J*), species richness (*S*), species composition (by abundance and weight) and catch per unit effort (CPUE). The comparison was done within the groups of mainstem Punatshangchhu (downstream zone, future dewatered zone and upstream zone) and within groups of tributaries (downstream tributaries, future dewatered tributaries, and upstream tributaries). Kruskal-Wallis test was performed to ascertain significant differences ($p = 0.05$) in the biological variables and water quality parameters after subjecting the data to normality test and homogeneity of variance test. Wherever applicable, multiple pairwise comparison ($p = 0.05$) was performed to see the differences among the groups (i.e., zones). Among the biological variables, only CPUE from mainstem Punatshangchhu was subjected to Kruskal-Wallis test. Other biological variables for mainstem Punatshangchhu and tributaries did not qualify for statistical inferences because of nonstandard sampling of fishes (i.e., cast netting at Dangchhu and electrofishing at other tributaries; sampling with different efforts at sites across mainstem Punatshangchhu). All the statistical analysis was performed with R statistical software.

3. RESULTS AND DISCUSSION

3.1 Basic water quality parameters

Five basic water quality parameters were accessed along the mainstem Punatshangchhu and its tributaries (Figure 2, 3, Table 2). Optimum water quality conditions are necessary to support diverse communities of aquatic organisms. Any anthropogenic activities along the riparian corridors may influence the water quality parameters in rivers. Among different zones of mainstem Punatshangchhu statically significant variation was observed for pH (Figure 2b, Table 2, χ^2 (2) = 21.398, p = 2.256e-05) and temperature (Figure 2c, Table 2, χ^2 (2) = 27.862, p = 8.911e-07). Across the tributaries zone, significant differences were observed for dissolved oxygen (Figure 3a, Table 2, χ^2 (2) = 12.502, p = 0.0019), temperature (Figure 3c, Table 2, χ^2 (2) = 7.029, p = 0.0297), TDS (Figure 3d, Table 2, χ^2 (2) = 16.718, p = 0.0002) and EC (Figure 3e, Table 2, χ^2 (2) = 15.531, p = 0.0004). However, the observed DO and pH across all the sites and zones of Punatshangchhu and their tributaries are within the water quality requirements for the propagation of wildlife and fisheries (Class D) as per Indian standards (CPCB 2008). The observation (on DO and pH) also classifies all the zones under the Class I category as per the United Nations Economic Commission for Europe (UNECE) standard of surface freshwater quality for the maintenance of aquatic life (UNECE 1994). Generally, a pH range of 6 – 9 are satisfactory on a long-term basis for freshwater aquatic organisms and freshwater ecosystems with pH from 6.5 to 8.5 are generally regarded to support healthy, diverse and productive fish and macroinvertebrate communities (NAS 1972; Albaster and Lloyd 1982). Dissolved oxygen is an important component of aquatic ecosystem health. Albaster and Lloyd (1982) suggested a minimum DO concentration of 5 ppm to satisfactorily support life stages of most aquatic fauna. However, *Schizothorax richardsonii* prefers highly oxygenated waters and under natural conditions waters with 8 – 10 ppm of DO and pH of 7.2 – 8.2 (comparable to our findings) are known to provide excellent conditions for spawning (Chandra et al. nd). Temperature influences

Table 2: Summary of basic water quality parameters (mean ± SD) sampled from downstream, dewatered and upstream zones of Punatsangchhu and its tributaries.

Segment	Zone	DO (ppm)	pH	Temperature (°C)	TDS (ppm)	EC (mS/cm)
Punatsangchhu	Downstream	10.61 ± 0.25	8.59 ± 0.19	13.87 ± 0.22	44.33 ± 3.50	0.09 ± 0.00
Punatsangchhu	Dewatered	10.87 ± 0.21	8.26 ± 0.15	13.07 ± 0.11	42.53 ± 1.60	0.09 ± 0.00
Punatsangchhu	Upstream	10.95 ± 0.38	8.40 ± 0.03	12.11 ± 0.20	43.66 ± 0.50	0.09 ± 0.00
Tributaries	Downstream	11.65 ± 0.21	8.57 ± 0.37	15.24 ± 0.27	64.00 ± 22.88	0.13 ± 0.13
Tributaries	Dewatered	10.64 ± 0.86	8.09 ± 0.15	15.16 ± 2.18	22.60 ± 10.16	0.04 ± 0.04
Tributaries	Upstream	10.61 ± 0.15	8.47 ± 0.41	13.73 ± 0.21	48.33 ± 24.83	0.10 ± 0.10

metabolism and other physiochemical process of fishes. It is general trend for water temperature to increase along the longitudinal gradient, i.e., from upstream to downstream (Figure 2c, 3c).

TDS in water influences osmotic pressure and are supposed to remain < 1000 ppm in freshwater ecosystems (Figure 2d, 3d) despite the ability of many freshwater organisms to tolerate > 5000 ppm TDS (Boyd 2020). High TDS will reduce water clarity, decreases algae production and increases water temperature. Electrical conductivity (Figure 2e, 3e) provides estimate of total dissolved solids in aquatic ecosystems (Figure 2d vs 2e, Figure 3d vs 3e).

3.2 Species diversity, composition and size distribution

The present monitoring recorded a total of eight species from the entire sampling area and two species from mainstem Punatshangchhu (Table 3). *Schizothorax richardsonii* (IUCN Status: Vulnerable) was only the threatened species encountered from all the sites during present sampling season. *Salmo trutta*, an invasive species was encountered only from the Dangchhu.

However, the present study could not record *Schizothorax progastus* and *Garra gotyla* from the mainstem Punatshangchhu, *Glyptothorax* sp., *Parachiloglanis* sp. and *Barilius* sp. from the tributaries which were recorded during the earlier sampling expeditions. Higher Shannon diversity index (Figure 4a) and species richness

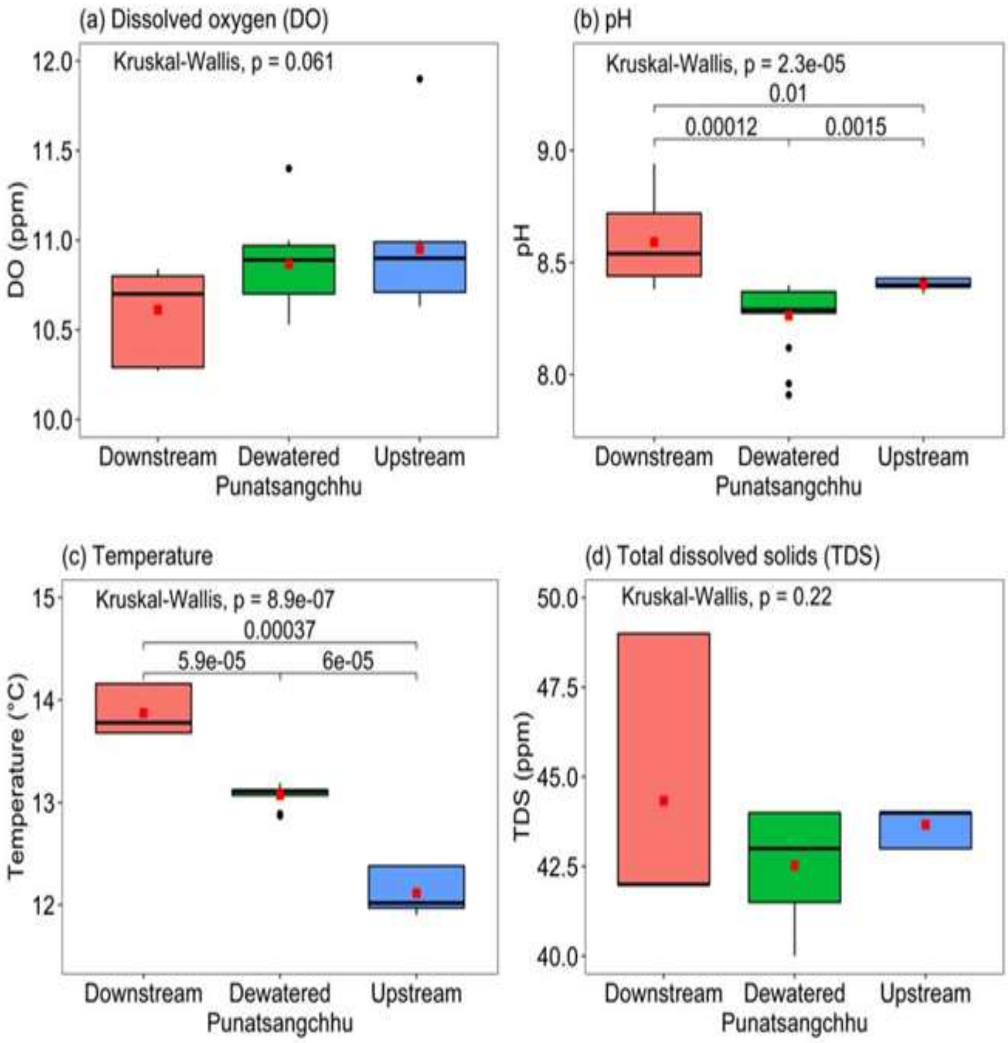

Figure 2: Box plots of basic water quality parameters sampled from the downstream, dewatered and upstream zones of mainstem Punatsangchhu and the results of the Kruskal–Wallis test and multiple comparisons tests. Red square denotes group means (Table 2).

Table 1*:* Summary of species recorded from Punatshangchhu and its tributaries at PHPP area.

Study area	Species (*S*)	Species (IUCN status, ecological status)
Punatshangchhu and tributaries	8	*Garra arupi* (**NE, I**), *Garra gotyla* (**LC, I**), *Neolissochilus hexagonolepis* (**NT, I**), *Pseudecheneis sulcata* (**LC, I**), Psilorhynchus *homaloptera* (**LC, I**), *Salmo trutta* (**LC, E**), *Schizothorax richardsonii* (**VU, I**), *Schizothorax* sp. (**-, I**)
Punatshangchhu (mainstream)	2	*Schizothorax richardsonii* (**VU, I**), *Schizothorax* sp. (**-, I**)
Punatshangchhu (Downstream)	2	*Schizothorax richardsonii* (**VU, I**), *Schizothorax* sp. (**-, I**)
Punatshangchhu (Dewatered)	2	*Schizothorax richardsonii* (**VU, I**), *Schizothorax* sp. (**-, I**)
Punatshangchhu (Upstream)	2	*Schizothorax richardsonii* (**VU, I**), *Schizothorax* sp. (**-, I**)
Tributaries (Downstream)	6	*Garra arupi* (**NE, I**), *Garra gotyla* (**LC, I**), Neolissochilus *hexagonolepis* (**NT, I**), *Pseudecheneis sulcata* (**LC, I**), *Psilorhynchus homaloptera* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Nyerachhu	6	*Garra arupi* (**NE, I**), *Garra gotyla* (**LC, I**), *Neolissochilus hexagonolepis* (**NT, I**), *Pseudecheneis sulcata* (**LC, I**), *Psilorhynchus homaloptera* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Harachhu	3	*Garra gotyla* (**LC, I**), *Psilorhynchus homaloptera* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Tributaries (Dewatered)	6	*Garra arupi* (**NE, I**), *Garra gotyla* (**LC, I**), *Neolissochilus hexagonolepis* (**NT, I**), *Pseudecheneis sulcata* (**LC, I**), *Psilorhynchus homaloptera* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Dikchhu	6	*Garra arupi* (**NE, I**), *Garra gotyla* (**LC, I**), *Neolissochilus hexagonolepis* (**NT, I**), *Pseudecheneis sulcata* (**LC, I**), *Psilorhynchus homaloptera* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Kamerongchhu	3	*Garra gotyla* (**LC, I**), *Neolissochilus hexagonolepis* (**NT, I**), *Schizothorax richardsonii* (**VU, I**)
Phrenchu	5	*Garra gotyla* (**LC, I**), *Neolissochilus hexagonolepis* (**NT, I**), *Pseudecheneis sulcata* (**LC, I**), *Psilorhynchus homaloptera* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Baychhu	4	*Garra gotyla* (**LC, I**), *Neolissochilus hexagonolepis* (**NT, I**), *Pseudecheneis sulcata* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Basochhu	4	*Garra gotyla* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Tributaries (Upstream)	5	*Garra gotyla* (**LC, I**), *Pseudecheneis sulcata* (**LC, I**), *Salmo trutta* (**LC, E**), *Schizothorax richardsonii* (**VU, I**), *Schizothorax* sp. (**-, I**)
Nahichhu	5	*Garra gotyla* (**LC, I**), *Pseudecheneis sulcata* (**LC, I**), *Schizothorax richardsonii* (**VU, I**)
Dangchhu	2	*Salmo trutta* (**LC, E**), *Schizothorax* sp. (**-, I**)

IUCN status: ***VU*** = Vulnerable, ***NT*** = Near threatened, ***LC*** = Least concern, ***NE*** = Not evaluated.
Ecological status: ***I*** = Indigenous, ***E*** = Exotic. - = Uncertain, need identification at species level.

Table 4: Summary of CPUE as kg/hr (mean ± SD) of fish sampled from downstream, dewatered and upstream zones of Punatsangchhu and its tributaries during the post-monsoon season (2018, 2019, 2021).

Stretch	Year	Punatsangchhu		
		Downstream	Dewatered	Upstream
Punatsangchhu	2021	2.200 ± 3.583	0.681 ± 0.756	0.617 ± 0.916
Punatsangchhu	2019	2.825	1.801 ± 3.112	2.463
Punatsangchhu	2018	4.31	1.870 ± 1.852	1.987
Tributaries	2021	1.812 ± 0.525	1.930 ± 1.112	0.859 ± 0.055

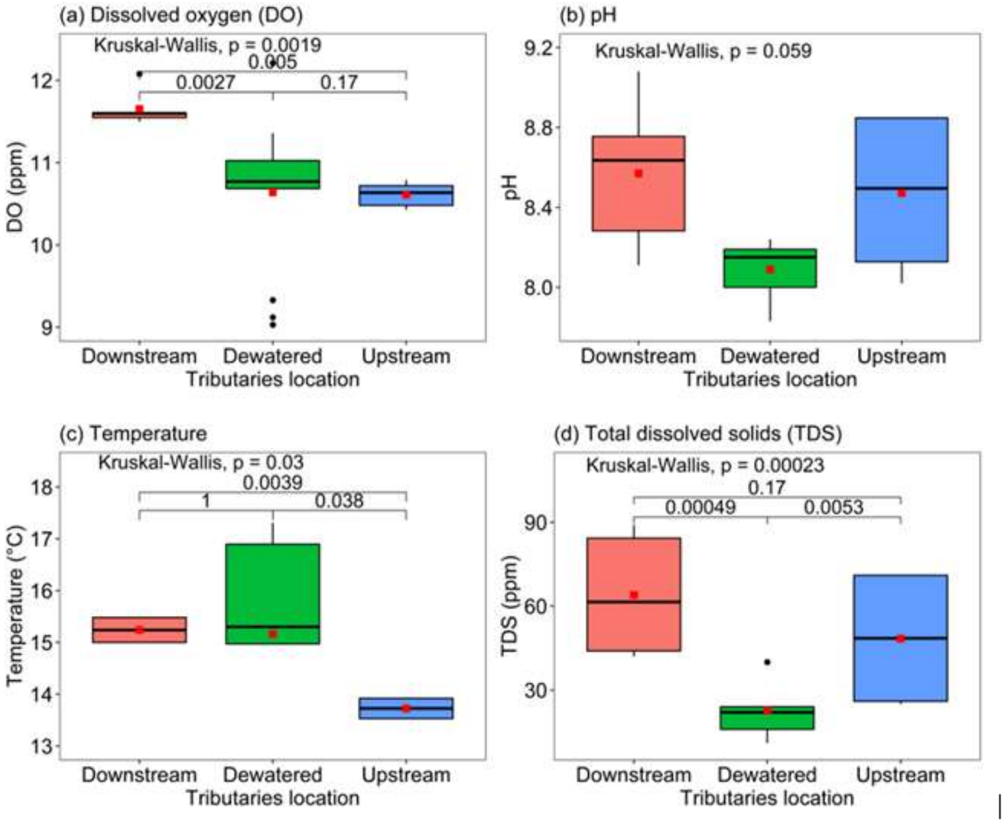

Figure 3: Box plots of basic water quality parameters sampled from the tributaries located at the downstream, dewatered and upstream zones of mainstem Punatsangchhu and the results of the Kruskal–Wallis test and multiple comparisons tests. Red square denotes group means (Table 2).

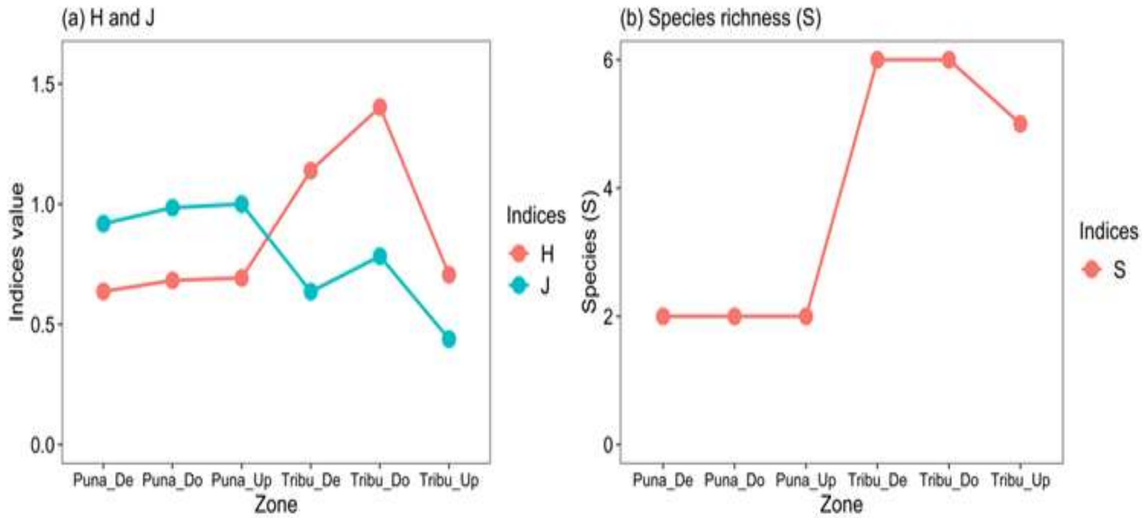

Figure 4: Line graph showing the diversity indices of fish sampled from downstream, dewatered and upstream zones of Punatsangchhu and its tributaries (a) *H* and *J*, (b) = *S*. **Note: Zone:** Tribu_Up = Tributaries (upstream), Tribu_Do = Tributaries (downstream), Tribu_De = Tributaries (dewatered), Puna_Up = Punatsangchhu (upstream), Puna_Do = Punatsangchhu (downstream), Puna_De = Punatsangchhu (Dewatered).

(Figure 4b) were observed from the tributaries as compared to mainstem Punatshangchhu. In general, *Schizothorax richardsonii* was the most dominant species across all the zones of Punatshangchhu and its tributaries, both by abundance (Figure 5a) and by weight (Figure

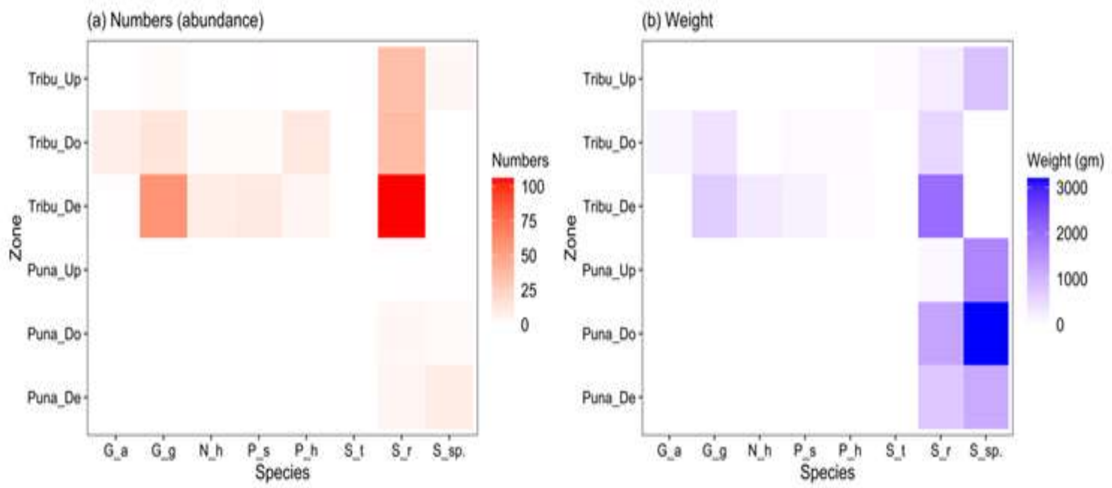

Figure 5: Heat map showing species-wise catch composition of fishes recorded from downstream, dewatered and upstream zones of Punatsangchhu and its tributaries by: (a) abundance and (b) weight. **Note: Zone:** Tribu_Up = Tributaries (upstream), Tribu_Do = Tributaries (downstream), Tribu_De = Tributaries (dewatered), Puna_Up = Punatsangchhu (upstream), Puna_Do = Punatsangchhu (downstream), Puna_De = Punatsangchhu (Dewatered). **Species:** G_a = *Garra arupi*, G_g = *Garra gotyla*, N_h = *Neolissochilus hexagonolepis*, P_s = *Pseudecheneis sulcata*, P_h = *Psilorhynchus homaloptera*, S_t = *Salmo trutta*, S_r = *Schizothorax richardsonii*, S_sp. = *Schizothorax* sp.

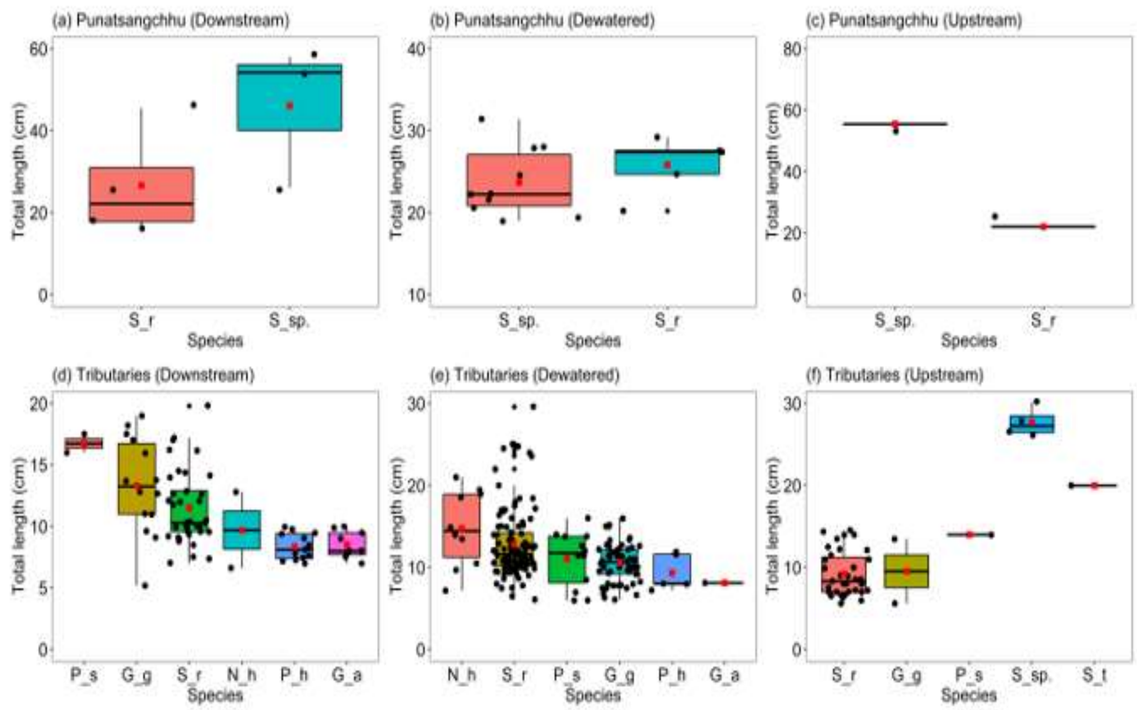

Figure 6: Box plots of species-wise total length (cm) of fish sampled from downstream, dewatered and upstream section of Punatsangchhu (a, b, c) and its tributaries (d, e, f). ■ = group means. **Note: Species:** G_a = *Garra arupi*, G_g = *Garra gotyla*, N_h = *Neolissochilus hexagonolepis*, P_s = *Pseudecheneis sulcata*, P_h = *Psilorhynchus homaloptera*, S_t = *Salmo trutta*, S_r = *Schizothorax richardsonii*, S_sp. = *Schizothorax* sp.

5b). The Common snow trout (*Schizothorax richardsonii*) are usually the most dominant species in the Himalayan rivers, including the Punatshangchhu. Larger size (total length, weight) and higher abundance of *Schizothorax spp.* was encountered from mainstem

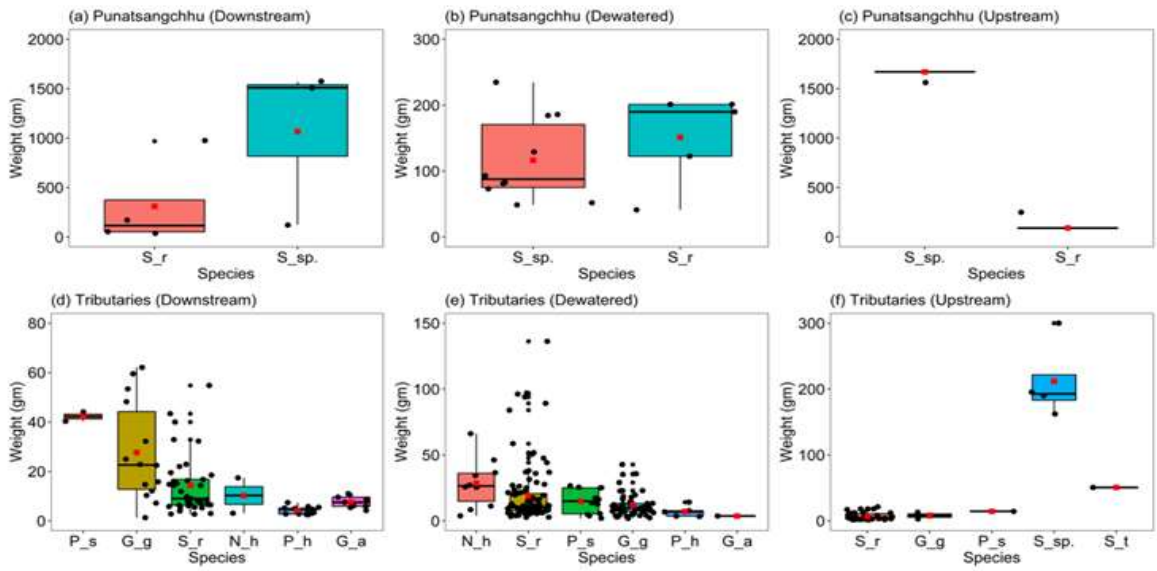

Figure 7: Box plots of species-wise weight (gm) of fish sampled from downstream, dewatered and upstream section of Punatsangchhu (a, b, c) and its tributaries (d, e, f). Red square denotes group means. **Note: Species:** G_a = *Garra arupi*, G_g = *Garra gotyla*, N_h = *Neolissochilus hexagonolepis*, P_s = *Pseudecheneis sulcata*, P_h = *Psilorhynchus homaloptera*, S_t = *Salmo trutta*, S_r = *Schizothorax richardsonii*, S_sp. = *Schizothorax* sp.

Punatshangchhu than from the tributaries (Figure 6 & 7). Although, large size class of fishes are generally associated with large rivers, the differences in abundance can be from different sampling gears used for the mainstream Punatshangchhu and its tributaries (refer sample collection in materials and methods).

3.3 Catch per unit effort (CPUE) and species richness

The differences in CPUE observed across different zones of Punatshangchhu during the present monitoring season were not statistically

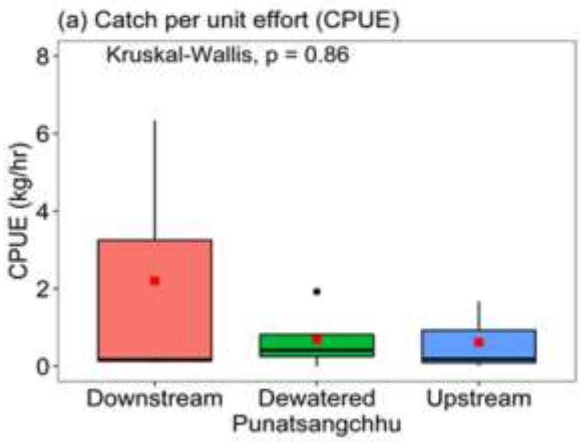

Figure 8: Box plots of CPUE of fishes sampled from downstream, dewatered and upstream section of Punatsangchhu and the result of Kruskal-Wallis test. Red square denotes group means (Table 4). Statistical comparison only applicable for CPUE at mainstem Punatsangchhu and not to other zones because of issues of standardized sampling

significant (Figure 8a, Table 4, χ^2 (2) = 0.304, p = 0.859). However, the CPUE observed across all zones of Punatshangchhu during the present monitoring was lower than the CPUE observed during the post-monsoon monitoring of 2018 and 2019 (Table 4, note: CPUE was adopted only during post-monsoon sampling of 2018 and used for post-monsoon sampling of 2019. CPUE was not considered during post-monsoon sampling of 2020 and all the sampling preceding post-monsoon 2018). The abundance of *Schizothorax richardsonii* during the present sampling from the future dewatered stretch (n = 15) was lower than those observed during post-monsoon sampling in 2018 (n = 79) with lower mean total length and small variation in total length (post-monsoon 2018 = 30.54 ± 10.16 cm vs prost-monsoon 2021 = 25.38 ± 3.58). This indicates possible changes in population structure of *Schizothorax richardsonii*, the dominant fish in Punatshangchhu.

Schizothorax richardsonii is a short-mid distance migratory fish and the fragmentation of habitats by diversion tunnels of PHPP – I and II are likely to block upstream migration. In addition, the disturbances from the hydropower construction coupled with extreme flooding events may impact fishes within the project area (e.g., increase in velocity immediately downstream of diversion tunnel outlet during extreme and untimely flooding events results in fish kill and destruction of fish habitats). Although the impacts of hydropower construction on fishes are gradual, and becomes pronounced in the long-run, inconsistencies in sampling methods makes comparison among years difficult to access short-term consequences and if applicable, the results will be unreliable for concrete interpretation of impacts. In consideration of this, consistent sampling approaches are recommended for any future assessment. Over years, through the opportunities provided by the hydropower developers, there has been improvement in the assessment approaches for hydropower projects. Subsequent monitoring, both during construction and operational-phase with consistent sampling are therefore crucial for comprehensive assessment of the impacts of PHPP – I & II on Punatshangchhu.

4 CONCLUSIONS & RECOMMENDATION

The spatial differences in basic water quality parameters and the catch per unit effort (CPUE) along the mainstem Punatshangchhu are not alarming, at least considering the results of present monitoring. However, considering inconsistent sampling approaches, implementation of standardized long-term monitoring is recommended during future assessment for comprehensive spatio-temporal comparison of monitoring data.

FUNDING

The funding for the current monitoring program was jointly supported by the Punatshangchhu - I Hydroelectric Project Authority (PHPA – I) and Punatshangchhu - II Hydroelectric Project Authority (PHPA – II).

REFERENCES

Alabaster JS and Lloyd R. (1981). Water quality criteria for freshwater species. Food and Agricultural Organization of the United Nations, London, Butterworth Scientific publication. 360 pp.

Boyd CE. (2020). Dissolved Solids. In: Water Quality: An introduction, Boyd CE., 83 – 118 Springer, Cham.

Chandra S, Pandey NN and Giri AK. (nd). Snow trout (Schizothorax richardsonii Gray, 1832). https://www.google.com/search?client=firefoxbd&q=SNOW+TROUT+PH+7.4+TO+8.2+CFRI. Accessed 30 January 2022.

CPCB. (2008). Guidelines for water quality monitoring. Central Pollution Control Board, Ministry of Environment and Forests, India. 35 pp.

Dudgeon D, Arthington AH, Gessner MO, Kawabata ZI, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ and Sullivan CA. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews, 81(2): 163 – 182.

NAS. (1972). Water Quality Criteria. A report of the Committee on Water Quality Criteria. National Academy of Sciences and National Academy of Engineering.

NORAD. (2017). Norwegian Energy Cooperation with Bhutan: A summary report. https://www.norad.no/en/toolspublications/publications/2017/norwegian-energy-cooperation-with-bhutan/. Norwegian Agency for Development Cooperation. Accessed 26 January 2022.

Reid et al. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. Biological Reviews, 94(3): 849–873.

UNECE. (1994). Standard statistical classification of surface freshwater quality for the maintenance of aquatic life. In: Readings in International Environment Statistics, United Nations Economic Commission for Europe, United Nations, New York and Geneva., 53 – 64.