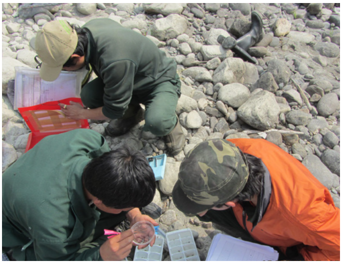
AQUATIC BIODIVERSITY ASSESSMENT

A baseline study in Mangdechhu, Central Bhutan



Center for Water, Climate and Environmental Policy

UGYEN WANGCHUCK INSTITUTE FOR CONSERVATION AND ENVIRONMENTAL RESEARCH

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ACRONYMS

CI	Confidence Interval
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organisation
GNHC	Gross National Happiness Commission
H’	Shannon Diversity Index
HKH	Hindu Kush Himalayan
IUCN	International Union for Conservation of Nature
MHPA	Mangdechhu Hydroelectric Power Authority
M	Mean
masl	Meters Above Sea Level
mg/l	Milligram per liter
MW	Mega Watt
NEC	National Environment Commission
NTU	Nephelometric Turbidity Units
p	Probability
ppm	Parts Per Million
SD	Standard Deviation
SPSS	Statistical Package for the Social Science
TDS	Total Dissolved Solids
UWICER	Ugyen Wangchuck Institute for Conservation and Environmental Research
WCP	Wangchuck Centennial Park
WWF	World Wildlife Fund
µS	Microsiemens
µm	Micrometer

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SUMMARY

The growing number of hydropower in the country has posed immense impacts on aquatic biodiversity. None of the hydropower plants in the country has the baseline information on aquatic biodiversity. This study was initiated to generate baseline information on aquatic biodiversity during the ongoing construction of Mangdechhu Hydropower Plant. The study area stretches from Bjezam in Trongsa to Tingtibe in Zhemgang, covering the ongoing construction area and downstream. This report accounts 10 orders, 44 species of macroinvertebrates at the family level and 4 species of fish from 14 sampling sites. The samples were enumerated from a total of 33 replicates (pools, riffles, cascades and rapids). There was no significant differences in diversity between the far and nearby plots from the construction site however, as the plot descended from the construction site we observed increasing diversity, compared to the construction reach. The higher number of individuals were recorded from the riffles than other microhabitats.

To get an estimate of biodiversity richness, an in-depth study is crucial covering four seasons with equal representatives from the microhabitats. For understanding the pre and post monsoon status of freshwater diversity, we suggest the pre-survey must be conducted way before the commencement of construction. Macroinvertebrates and fishes are very sensitive to alteration of habitats and flow fluctuation, indicating the impacts on the health of freshwater ecosystems. This report serves as the baseline information and we suggest further in-depth studies with increased sampling efforts, covering upstream sampling reach and tributaries.

Headwaters of Mangdechhu. Picture: Tshering Dendup

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1. INTRODUCTION

Surface freshwater habitats hold around 0.01% of world's water and covers 0.08% of earth surface (Dudgeon et al. 2006). Around 50,000 to 100,000 freshwater species are expected to live in the underground water (Dudgeon et al. 2006). Freshwater biodiversity contributes a wide range of services. However, they are the most vulnerable to extinction as a consequence of anthropogenic activities and infrastructure development that are further challenged by climate change impacts. In Bhutan, infrastructure development along and across the water bodies are growing rapidly, where physical threats are evident but not measured. Hydropower development that involves the construction of a dams are the main threats that changes the mainstream of river continuum (Allen, Molur & Daniel, 2010). Mangdechhu hydropower is one of the mega projects in central Bhutan, which is under construction. This report provides an baseline assessment of macroinvertebrates and fish diversity surveyed during the ongoing construction of the Mangdehchhu hydropower plant.

1.1 Importance of freshwater biodiversity and threats

Irrigation alone uses about 69% of the total freshwater withdrawal for food production excluding groundwater, and 23% for industries and municipalities are returned to water bodies (FAO, 2006; Gleick, 2000). Only 8% of freshwater is for human use (Gleick, 2000). Biodiversity of vertebrate and invertebrate plays an integral role in ecosystem services of which some are irreplaceable (Dudgeon et al. 2006). The value of biodiversity has several components, its direct contribution comprises of food, medicine and minerals while indirect contribution includes storehouse for genetic information, insurance during unexpected disasters, recreational and tourism (Dudgeon et al. 2006; WCP, 2012).

The global threats to freshwater biodiversity are pandemic and experts have grouped under five major groups 1) over-exploitation; 2) water pollution; 3) flow modification; 4) destruction or degradation of habitats; and 5) invasion by exotic species (Dudgeon et al. 2006). The hydropower plants are largely attributed to a wide range of threats to an aquatic ecosystem. Freshwater diversity as an indicator for water quality and health of the ecosystem, there is need to understand their status for future planning, decision making and maintaining sustainable freshwater ecosystem services. Amongst 1.3 million described invertebrates, IUCN has evaluated about 30% (9,526) of species are at risk of extinction. While 21% (1,851) of fish species were evaluated at risk of extinction in 2010 (Allen, Molur & Daniel, 2010).

1.2 Freshwater biodiversity in Bhutan

Bhutan has limited records of described freshwater biodiversity however, data on fish studies are far better. The macroinvertebrates studies in Bhutan has just picked up quite recently. Until 2004 documentation of freshwater macroinvertebrates was limited to a work by the experts from Natural History Museum, Basel (Switzerland) in 1972. Later National Environment Commission (NEC) with the help of experts from the Hindu Kush Himalayan (HKH) region initiated assessment of water quality from the year 2005 (Malicky, Karma & Moong, 2008). In recent years, several new species in the country were documented. In an annotated checklist of fish, Bhutan has 91 known species recorded for the country (Gurung et al. 2013). The collaborative research between College of Natural Resources, Bhutan and Saint Luis University, USA discovered new torrent catfish fish (*Parachiloglanis bhutanensis*) from Khalingchhu in Eastern Bhutan. With discovery of this fish, Bhutan has 93 species of fish (Tshering & Thoni, 2014; WWF, 2015). The latest publication, a preliminary nationwide fish survey stated that there are records of 109 species from 24 families, of which few of these species are yet to be described (Gurung & Thoni, 2015).

In case of inland macroinvertebrates study, small stretch of Toeberongchhu, a tributary of Punatsangchhu, Thruelpangchhu, a tributary of Mangdechhu, Kawangjangsa, a tributary of Wangchhu (Dorji, 2014; Dorji, Thinley & Jamtsho, 2014; Wangyal et al. 2011), Nikkachhu, Mangdechhu, Chamkharchhu in Wangchuck Centennial Park (Wangchuck Centennial Park, 2012), Chamkharchhu and its tributary (Wangchuk & Eby, 2013) has been partially covered. Apart from fish, macroinvertebrates are not pre-assessed in all the hydropower projects in the country. Now the habitats for the freshwater biodiversity are getting fragmented and their impacts are not known.

1.3 Hydropower in Bhutan and its impacts

Bhutan's first micro hydro plant was commissioned in 1967 in Thimphu with 360 KW (Jamthsho & Chakarvarty, 2012) though the electrification process was started a year before in 1966 with 15 KW diesel generator installed at Phuntsholing. Following the year, 10 micro and 13 mini hydropower were established to meet the energy requirement in the country (Bhutan Electricity Authority, 2014). Gradually mega hydropower projects has increased with construction of high head dams across the river system in the country.

The economy of the country largely depends on hydropower energy and is the highest important revenue generator for the country. Bhutan has potential to generate over 30,000 MW (Mega Watt) of which 23,760 MW is identified as technically and economically feasible (Jamthsho & Chakarvarty, 2012). The first mega project was conceived in Chukha with the capacity of 336 MW. Over the years Basochhu (64 MW), Tala (1,020 MW), Kurichhu (60 MW), Dagachhu (126 MW) and 23 mini-micro hydro plants (8.8 MW) was established and all together generates 1,614.8 MW of electricity (BEA, 2014). Today Punatshangchhu Phase I (1,200 MW) and Punatshangchhu Phase II (1,020 MW), Mangdechhu (720 MW), Kholongchhu (600 MW), Nikachhu (118 MW) and Wangchuk (570 MW) are under construction with projected capacity to generate about 4,228 MW. Bhutan has set a strong vision to generate 10,000 MW by the year 2020. The proposed project such as Bunachhu (180 MW), Amochhu (540 MW), Chamkharchhu (770 MW), Sunkosh (2,560 MW), Kurigongree (2,460 MW), Kurichhu I (1,125 MW), Jomori (85, MW), Nyera Amari I (125 MW) and Nyera Amari II (137 MW) together are expected to generate over 7,982 MW. When all the hydropower projects are commissioned, Bhutan is expected to generate 13,824.8 MW of energy. Amongst 10 macro-hydropower and 13 mini-hydropower of which Chenary and Khaling mini-hydropower projects are not operational (BEA, 2014). All these mega and mini hydropower plants are owned by Bhutan Power Corporation Limited.

Hydroelectric dam affects aquatic biodiversity at all stages of life cycle, further the reservoir aggravates the affects by permanently replacing the river channel along with terrestrial and aquatic habitats (Gracey & Verones, 2016). Construction of dams, weirs, tunnels, access roads, power stations and reservoirs intricate impoundment of sediment and organic matter thus fragments aquatic species assemblage and dispersal (Gracey & Verones, 2016). The most common impact on hydropower are freshwater habitat alteration, deterioration of water quality and land use changes (Dejalon, Sanchez & Camargo, 1994; Gracey & Verones, 2016). Dams impair river ecosystems by altering their flow regimes both in terms of the hydrology and geomorphology, thus degrading feeding and breeding habitats along the river (Yu and Xu, 2016). The downstream effect of water quality depletion on aquatic biota has been paid little attention effecting the flow fluctuation induced by the hydroelectric power generation. This type of flow regulation are expected to have an adverse effect on the freshwater communities (Dejalon et al. 1994). Hydropower impoundment alters the species composition, decreases the species richness, modification of life cycle and alteration on population. The intervention applied for fish passages have been proven unsuccessful and even harmful (Winemiller et al. 2016). Following the construction of hydropower dams migratory fish are at high risk besides the socioeconomic impacts requiring displacement (Yu & Xu, 2016). Freshwater biodiversity is increasingly on decline than the most effected terrestrial species (Abell, 2002; Cumberlidge et al.

2009). Freshwater ecosystem is disturbed due to flood protection or water storage, water impoundment (Abell, 2002), dam construction for hydropower and industrial estate which are further imperiled by the climate change effects (Dudgeon et al. 2006). In some part of the world, the largest flowing rivers are dried as a result of flow modification and large scale extraction. The alteration of water flow continuum had lead to not only loss of freshwater biodiversity but also drying up of river (Dudgeon et al. 2006).

In Bhutan, hydropower generation has led to impoundment and regulation of a large number of streams and rivers, and its implication are not studied. Recently a number of hydropower projects have emerged in Bhutan's major river systems claiming to generate clean and sustainable energy. Socio-economic status, terrestrial flora, and fauna are being adequately assessed to understand the effects by hydropower establishment, but on the contrary, the aquatic assessment which is critical for river and stream quality measurement are not given adequate importance. The need to understand the status of the aquatic health before and after the hydropower plant establishment is crucial to enable the future managers to take decisive action on hydropower projects.

At present Bhutan operates five hydropower plants, which are major source of income for the country. None of these hydropower projects have included freshwater biodiversity assessments as components in the Environment Impact Assessment Reports. Therefore the impacts of Hydropower projects on total freshwater biodiversity continues to remain vague in the country. The present study examines the diversity of macroinvertebrates in the downstream and upstream of Mangdechhu Hydroelectric project area, aimed to establish the baseline information for future monitoring. The field survey was conducted in winter, 2015 so that sampling sites could be easy accessible. The aquatic biodiversity of our river systems is very important, especially when we have no records of aquatic diversity from our major rivers systems. This study is even more important as most of our river systems are being dammed or planned for hydropower generation. It is likely that without this study we would not know the diversity of life forms in our rivers, and there will be no basis to establish impacts of hydropower aggravated by climate change on those aquatic lives in our river ecosystems.

1.4 Study Objectives

The main purpose of the assessment was to understand the health and diversity of aquatic macroinvertebrates and fish in the Mangdechhu river. This report covers the assessment during ongoing hydropower construction in February, 2015 and establishes the list of macroinvertebrates and fishes which would serve as the baseline repository for future references.

The specific objectives of the study were to:

1. Document the macroinvertebrates and fishes diversity in the upstream and downstream of Mangdechhu
2. Assess the water quality using HKHbios score
3. Assess the physicochemical parameters along the altitudinal gradients of the Mangdechhu river

2. MATERIALS AND METHOD

2.1 Study Area

The study area was along the confluence of Mangdechhu in Trongsa, Bhutan covering entire stretch of Mangdechhu Hydropower Project (Figure 1).

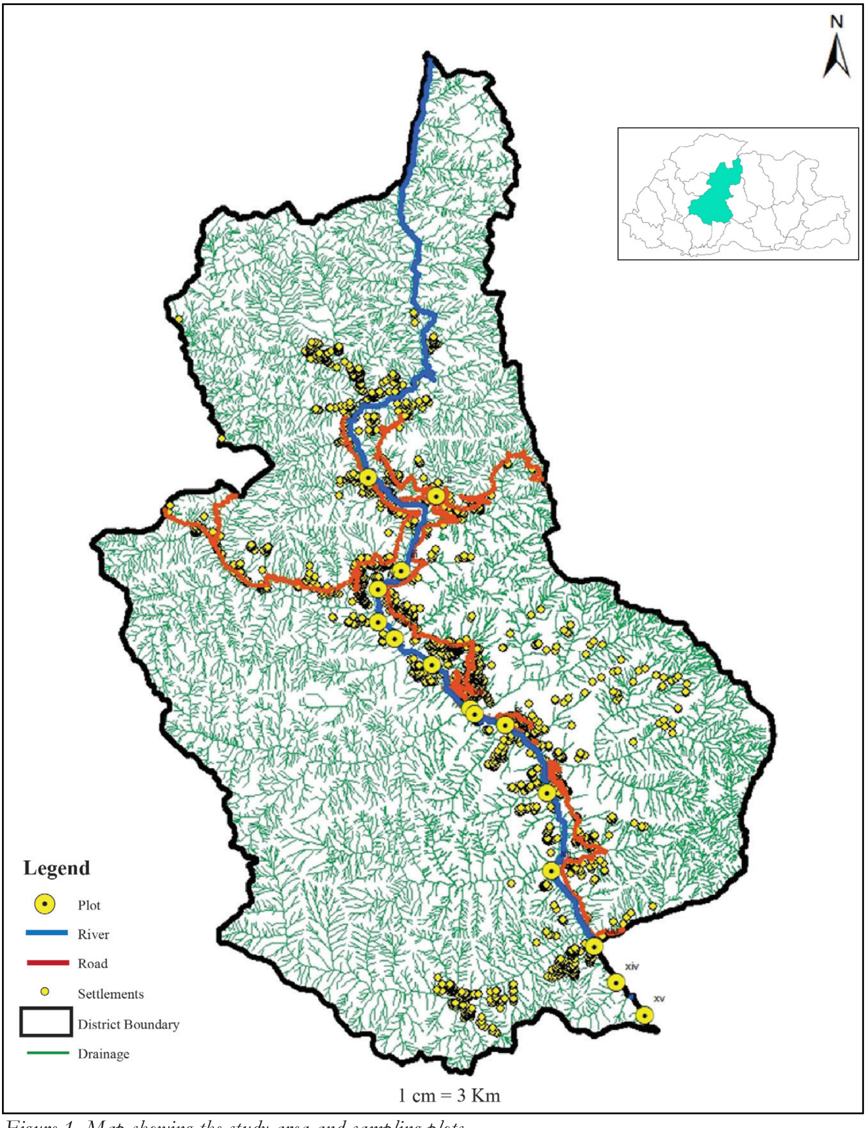

Figure 1. Map showing the study area and sampling plots

This study covers an area from Bjezam in Trongsa to Tingtibe in Zhemgang. Construction of hydropower project started in the year 2012. The dam is being constructed downstream of the place close to Chunjapang, at the mountain base of the Trongsa Dzong and the powerhouse is at Yurmo. Headrace tunnel is about 13.54 km (MHPA, 2016). This project is within 23 km river stretch from dam site to powerhouse and the tail race is located at Langthel.

2.2 Sampling Design

A total of 15 sampling plots were established along the altitudinal range from 583 masl in Tingtibe, Zhemgang to 1822 masl at Bjezam, Trongsa at an interval ~100 meters change in elevation. Each sampling plots were further divided into four subunits (replicate) namely riffles, pools, cascades and rapids. These replicates were used to assess the diversity and habitat preference of macroinvertebrates species. However, it was very difficult to obtain replicates from all sampling plots because of the steep geographic terrain.

2.3 Field Sampling and Analysis

The field survey was conducted during the winter of 2015 to cover all sampling plots as accessibility was much better during winters. The macroinvertebrates were collected using locally made 30 cm x 30 cm kick net (500 µm mesh) within 100 m sampling reach. The kick net was placed against the water current and the substrate was thoroughly disturbed to dislodge samples in the net. The samples were rinsed with water in the bowl or bucket before segregating into different taxa or family in ice cube trays using forceps and pipette. Different taxa were identified and those samples which could not be identified in the field were collected in small vials and examined in the laboratory using a dissecting scope. The samples were then preserved in 70% ethanol.

Fish were sampled using the cast net within 1000 m reach at each sampling plot. After recording the physical parameters, the fishes were immediately released back to the river. Physicochemical parameters (temperature, total dissolved solids, pH, conductivity and salinity) were measured using multi-parameter PCSTestr, model PPTestr 35 (EUTECH instrument, USA and OAKTON, Singapore). Turbidity was measured to assess the cloudiness of the river using Micro TPI turbidometer (HF Scientific, Inc. 3170 Metro Parkway, Fort Myers, Florida 33916-7597). From the entire survey area, 33 replicates were measured from different microhabitats such as riffles (12), pools (13), cascades (4), and rapids (4). Microsoft Excel-2010, SPSS 16.1 and HKHBios biotic score were used for data analysis.

3. RESULTS & DISCUSSIONS

3.1 Macroinvertebrate Diversity

This survey recorded 10 orders and 44 species of macroinvertebrates at the family level, from 14 sampling sites. At the Plot II, dam construction site was not accessible as the river was diverted through the tunnel during the time of survey (Plate 1). The sampling plots which were far away from the project site had the highest species diversity at the family level while the lowest (Figure 2) was from the plot near to the project site (Plot IV).

Plate 1: Dam construction site of Mangdechhu Hydropower plant.

The diversity of the macroinvertebrates increased with the increasing distance from the disturbance site. The most dominating family was Baetidae. The variation in the family among the sampling sites was mainly attributed to number of sampling effort from each plot. The number of replicates were determined based on the availability of different habitat within the 100 meter reach. However, some plots were limited by only one replicate which underestimate diversity. The macroinvertebrates species diversity was lower in the depleted stretch as compared to upstream and towards the extreme downstream. Results are further limited as the taxa were identified up to family level. Diversity would have substantially increased, if the specimens were identified up to genus and species level.

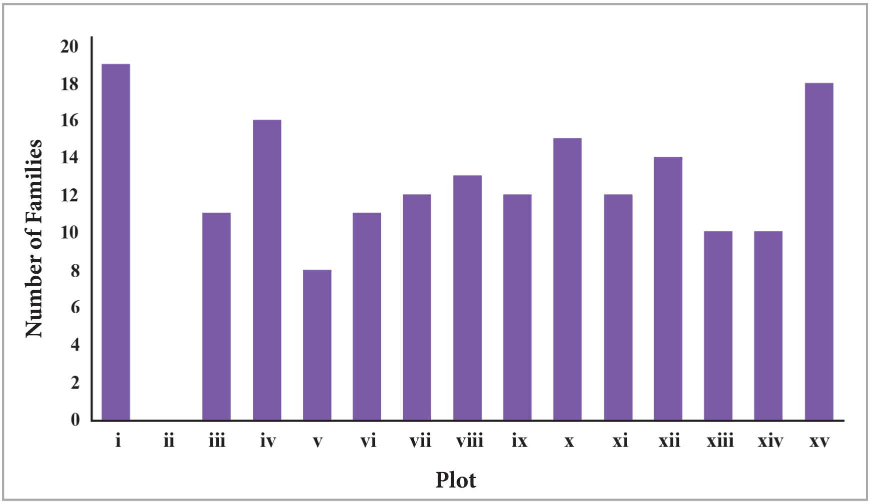

Figure 2: Number of family level diversity in different sampling plots

3.1.1 Habitat Types and Diversity

The samples were collected from a total of 33 replicates (13 pools, 12 riffles, 4 cascades, and 4 rapids). The highest numbers of individuals were recorded from riffles and the lowest were from rapids. The higher individuals in the pool, rapid and cascade were dominated by Diptera indicating presence of pollution in the river and also attributed to more sampling effort compared to cascades and rapids.

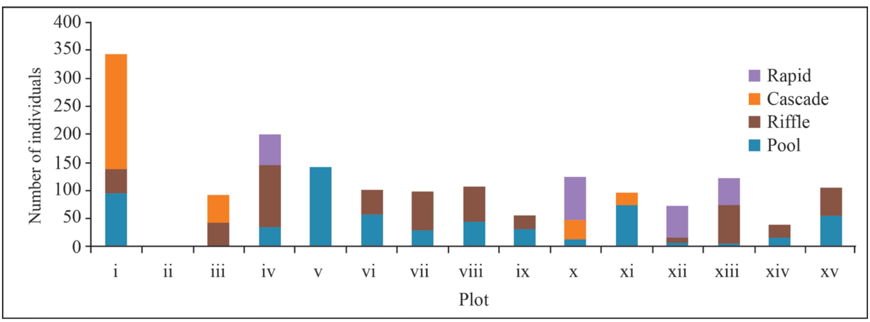

Figure 3: Number of individuals in different sampling plots and habitats

3.1.2 Disturbance and Macroinvertebrate Diversity

The highest Shanon Diversity Index (H') was recorded at plot-XV and the lowest was at plot-V (Table 1). Data suggested that macroinvertebrates diversity was lower in the depleted sampling reach compared to the upstream and downstream. A similar finding was revealed from the study at Bonfield Ghyll in North Yorkshire (Uttley, 2012). Macroinvertebrates responds to the ecological health as the construction may have disturbed their survival and reproduction (Lisa and Lowee, 2010). The upstream and downstream end plots represent the higher diversity, mainly attributed to the presence of lower sediments and disturbances when compared with the construction site. The last plot (XV) in downstream possess sediments but supports higher diversity, as the river flows downstream the sediment decreases compared to the disturbed site. The higher diversity at the plot-I has been backed by less sediment and healthy energy flow compared to downstream areas.

Table 1: Diversity Index (Shannon diversity, richness and evenness for each plot).

PLOT	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
Altitude	1822	1684	1585	1464	1402	1288	1171	1078	993	887	832	787	690	598	583
Count	341*	-	90	198	139	99	96	106	53	123	94	71	121	36'	102
H'	2.57	-	1.9	2.35	1.17'	1.81	1.68	2.09	2.23	2.19	1.65	2.05	1.88	2.44	2.63*
Richness	1.35	-	1.26	1.42	0.68	1.11'	1.52	1.46	1.65	1.71	1.24	2.14	1.09'	2.47	2.28*
Evenness	0.65	-	0.77	0.79	0.56'	0.75	0.62	0.77	0.90*	0.74	0.66	0.71	0.76	0.9	0.84

**Highest 'Lowest*

The sampling stretch from plot III to plot VIII falls within the heavily disturbed while plots IX to XV were away from construction of hydropower infrastructures. The diversity indexes were compared between the two stretches. An independent sample t-test showed that the difference in Shannon diversity index between the groups near (n = 7, M = 1.89, SD = .36) and far (n = 7, M = 2.4, SD = .32) were not significant t (11) = -1.184, p = .261, 95% CI [.214, -.714]. Similar results were indicated with other biodiversity indices richness and evenness (Table 2). The plots at construction site, both near and away from the downstream were equally affected with no differences in the diversity of macroinvertebrates. Construction activities causes an adverse impact on hydrology of river with reduced discharge, unusual fluctuation, affecting the riverine ecosystem, fish, macroinvertebrates, plants and livelihoods along the downstream (Department of Water Resources, 2004).

Table 2: Independent sample test on biodiversity indices between near and far from construction site (Significance level was set at $p < 0.05$).

	Near		Far				
VARIABLE	M	SD	M	SD	t (11)	p	95% CI
H'	1.89	0.365	2.14	0.32	-1.84	.26	[-.71, .21]
Richness	1.3	0.3	1.82	0.51	-2.07	.06	[-.10, .03]
Evenness	0.73	0.104	0.76	0.08	-.54	.95	[-.15, .09]

3.1.3 Elevation and Diversity

Plot I represents the highest elevation plot, while plot XV represents the lowest (Table 1). Although fewer individuals in the Plot XII and XIV, these plots supports species richness equally to that of Shannon Diversity Index, indicating higher diversity. This also indicated the sampling effort was not taken uniformly and inadequately represented. The diversity increases with increasing sampling efforts downstream and upstream (Figure 4).

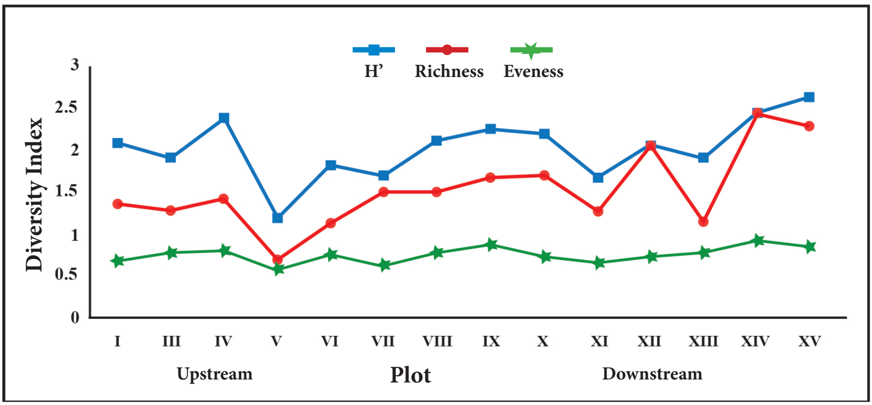

Figure 4: Diversity variation along sampling reach.

3.2 Physicochemical Parameters

All life forms prefers in water having favorable physicochemical properties. Water in the pure state has specific heat and neutral pH. The natural state supports a high diversity of macroinvertebrates than the disturbed habitats. The physicochemical properties of Mangdechhu had been altered. The pH at the study site was 7.90 ± 2.25 (slightly alkaline); salinity 42.55 ± 13.50 (ppm); temperature 9.25 ± 7.74 (°C); turbidity 13.76 ± 7.74 (NTU); conductivity 87.14 ± 29.82 (µs/cm) and TDS 62.17 ± 20.52 (mg/l) (Table 3). The pH of river was within the normal range from neutral to slightly alkaline. Electrical conductivity ranged much below the permissible limit (up to 500 µs/cm for drinking water) indicating less acid, base and salt in the river. Turbidity exceeded the permissible limit (5 NTU) in the entire sampling plots except in plot I (3.58 NTU). The total dissolved solid (TDS) determines the taste of the water. TDS exceeding the permissible limit (500 mg/l) may cause gastro intestinal irritation. In the present study TDS value was within the permissible limit.

Table 3: Mean± SD of various physicochemical properties for each plot.

Plot	pH	Salinity	Temperature	Turbidity	Conductivity	TDS
I	7.81	42.73	*7.30*	*3.58*	93.90	65.43
III	*7.20*	40.10	7.65	9.29	90.60	64.20
IV	8.48	41.40	7.37	13.95	92.73	65.67
V	8.65	40.60	7.50	4.20	90.70	64.50
VI	8.51	40.60	8.40	14.73	89.40	63.00
VII	8.55	40.50	9.50	22.69	63.40	67.10
VIII	8.60	**58.50**	9.80	24.11	87.70	65.50
IX	8.79	46.75	11.65	14.68	97.55	69.80
X	8.83	45.07	9.43	**25.43**	97.57	69.07
XI	8.79	*34.50*	10.35	13.46	*54.90*	*30.90*
XII	8.73	47.85	9.84	15.59	101.80	75.50
XIII	8.68	55.70	12.28	21.09	**128.65**	78.60
XIV	7.56	50.80	12.55	7.06	105.50	74.20
XV	**9.39**	53.10	**13.70**	16.50	112.65	**79.10**
Mean	7.90	42.55	9.15	13.76	87.14	62.17
SD	2.25	13.50	3.24	7.74	29.82	20.52

Italic indicates the lowest value while **bold red** indicates the highest.

3.2.1 Physicochemical parameters in plots near and away from MHPA construction site

Dam construction not only incurs heavy destruction at the construction site but also affects downstream river continuum. Physicochemical processes has direct impact on the aquatic ecosystem and livelihood of people. An independent sample t-test on physicochemical parameters showed the results similar to biodiversity indices. No significant differences was observed in physicochemical parameters between the plots near and far from the construction site (Table 4) except the temperature.

Table 4: Independent sample test on physicochemical parameters near and far from MHPA construction site.

	NEAR		FAR				
VARIABLES	M	SD	M	SD	T	P	95% CI
pH	8.33	0.56	8.68	0.55	-1.13	0.28	[-1.02, .32]
Salinity	43.62	7.30	47.68	6.89	-1.03	0.32	[-12.73, 4.60]
Temperature	8.37	1.06	11.40	1.57	-3.99	0.00	[-4.70, -1.35]
Turbidity	14.83	7.65	16.26	5.82	-0.38	0.70	[-9.64, 6.68]
Conductivity	85.76	11.08	99.80	22.58	-1.38	0.19	[-36.42, 8.32]
TDS	65.00	1.41	68.17	16.89	-0.45	0.65	[-18.48, 12.14]

Differences within the plots were tested by an independent sample T- test. Significance level was set at $P < 0.05$.

3.3 Water Quality Assessment

The HKHbios score was used to assess the water quality in our sampling sites. The score-based system for bioindication using indicator taxa score were determined based on their response to sensitivity to a stressor (Thomas et al. 2010). It was developed for HKH regions to facilitate biological monitoring of rivers. The HKHbios provides a cost effective, scientifically valid method for biological surveys that can be applied to all stream types covered by the ASSESS-HKH project (Thomas Ofenböck et al. 2010). The score-based assessment methods are mostly based on higher taxonomic bioindication units (genus, family and order). Overall 168 samples were used from five HKH countries (Bangladesh, Bhutan, Nepal, India and Pakistan) which were taken in two different seasons, pre and post monsoon (Thomas Ofenböck et al. 2010). In Bhutan 34 samples were taken from 17 site in ecoregion (Himalayan Subtropical Pine Forests: IM0120) and 17 sites in Eastern Himalayan Broadleaf Forest (IM0401) (Ofenböck, Moog & Sharma, 2005; Thomas Ofenböck et al. 2010). The present study area falls in the ecoregion IM0401 and the inferences were drawn using the biotic score of different taxa.

Amongst the five class scheme (Table 5) for delineation of water quality class in HKHbios, ecoregion IM0401- Eastern Himalayan Broadleaf forest (Ofenböck et al. 2005) was used to draw the inferences as the area falls within this region. The scoring list comprised of 44 taxa at family level. The result showed the water quality in the study area was much lower than the class boundary categories of 'poor/bad" except in the plot I**,** in which water quality was much better than other plots. This was obvious as the plot was located upstream of the construction site of the power plant.

Table 5: HKHbios water quality class boundaries and water quality for each sampling plot.

Class boundaries	IM0120	IM0166	IM01301	IM0401	IM0403
References/Good	≥5.5	≥7.5	≥6.8	≥7.7	≥7.5
Good/Moderate	≥4.1	≥6.5	≥5.7	≥6.3	≥6
Moderate/Poor	≥4.3	≥5.3	≥4.7	≥4.6	≥4.3
Poor/bad	≥3.3	≥4	≥3.4	≥2.3	≥2.6

Source: Ofenböck, Moog & Sharma, 2008

Plot	I	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV
HKHbios	2.12	0.92	0.77	0.29	1.04	0.83	0.71	1.17	0.80	0.80	1.01	0.50	1.19	0.96

3.4 Fish Diversity

A total of 13 individuals were caught in sampling plot X and XIII. The sampling effort covered about one kilometer reach in all the plots. *Schizothorax rechardsonii, Neolissochilus hexagonolipsis, Salmo truta,* and *Garra sp.* were recorded during the survey. In the past surveys, *Parachiloganis hodgarti, Tor putitora, Schizothorax progastrus, Barilius barna* and *Garra gotyla* were reported (Gurung et al. 2013; Gurung & Thoni, 2015; Tenzin, 2006). However, the reason for not being able to encounter expected representative sample of fish throughout the reach, was possibly due to 1) heavy disturbance by the construction which further accrued the sedimentation, 2) limited sampling seasons and equipment, 3) fragmentation of food trophic levels. River fluctuations inevitably results in decline of fish population (Department of Water Resources, 2004) which also suggest higher anthropological pressure in the present study reach.

The effects of high head dams are known. Fish are not only affected by post construction of hydropower plants but also during the construction period. Their habitats are fragmented and passage of migratory fish, breeding and feeding habitats are cut off (Gracey & Verones, 2016; Uttley, 2012; Winemiller et al. 2016). The damming of Mekong River in China is typical example of impacts accentuated across the international transboundary including Cambodia, Laos and Thailand (Department of Water Resources, 2004; Winemiller et al. 2016). Amongst all, migratory fish, including spawning habitats and trophic energy along the river ecosystem have been disturbed the most.

4. RECOMMENDATIONS

This study was the first of its kind to determine the baseline information of aquatic biodiversity in rivers where mega hydropower projects has been approved. However, the field survey for the assessment was carried out after the commencement of the Mangdechhu hydropower plant construction that limited the data for pre-construction period. Thus we could not draw a comparison between pre and post construction period to clearly understand the impact of the hydropower project on the Mangdechhu river ecosystem. A baseline study during pre-construction of hydropower on macro-invertebrates and fish are crucial to understand the changes and alteration caused by the construction of the hydropower plants. Another limitation of our study was that we could survey only during one season which greatly underestimated the species diversity.

Based on the current study, we recommend the following:

1. Baseline aquatic biodiversity assessments should be conducted before the pre-construction of the proposed hydropower plants.
2. Future field surveys should cover all seasons to get a representative estimates of aquatic diversity.
3. Carryout further in-depth assessment with increased upstream and downstream sampling reach and tributaries to estimate the gross biodiversity.
4. Comprehensive aquatic biodiversity assessment should be part of the EIA requirements for all the Hydropower projects.
5. Long term aquatic biodiversity studies should be initiated in-order to study the species change and adaptation to altered changes in the riverine ecosystems.

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ANNEXURE I

FISH

Schizothorax rechardsonii

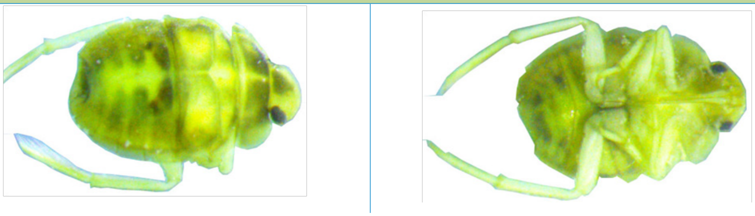
Neolissochilus haxagonolepsis

Salmo truta

Garra sp.

MACROINVERTEBRATES

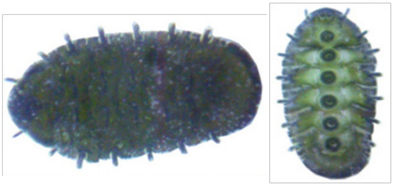
HEMIPTERA



Aphelocheridae (*Aphelocherius sp.*)

DIPTERA

Athericidae (*Atherix sp.*)



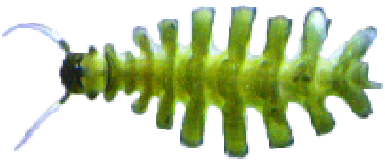
Blephariceridae

Limoniidae

Simuliidae

Tabanidae

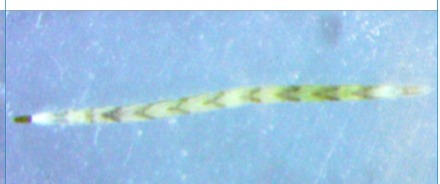
Tipulidae



Deuterophlebiidae

Syrphidae

Chironomidae (*Chironomus sp.*)

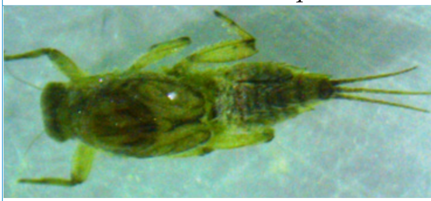


Ceratopogonidae

EPHEMEROPTERA

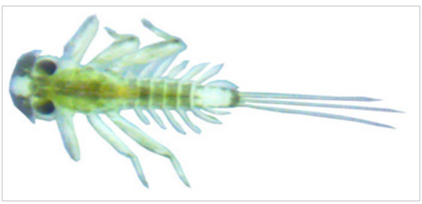
Baetidae (*Baetis sp.*)

Baetidae

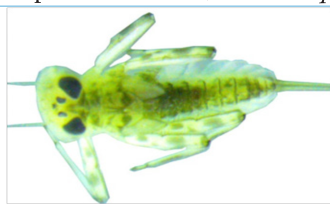


Ephemereliidae (*Attenella sp.*)

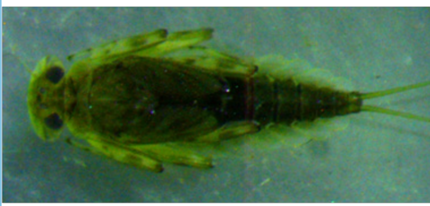
Ephemerellidae (*Drunella sp.*)



Heptageniidae (*Cynigmula sp.*)

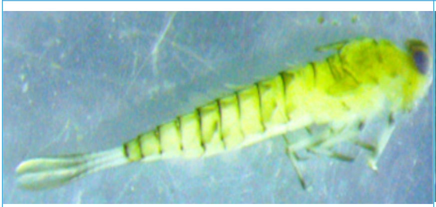


Heptageniidae (*Iron sp.*)



Heptageniidae (*Epeorus sp.)*

Caenidae



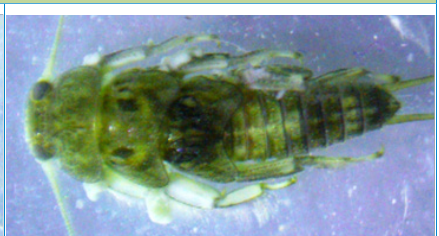
Siphlonuridae

Ephemeridae (*Ephemera sp.*)

Leptophelibiidae *(Paraleptophelibia sp.)*

PLECOPTERA

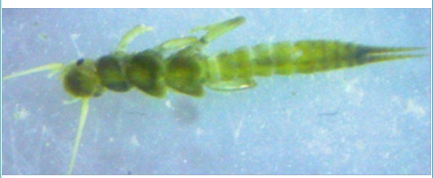
Nemouridae



Peltoperlidae (*Peltoperlopsis sp.)*

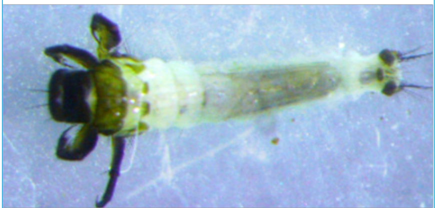
Perlodidae

Perlidae

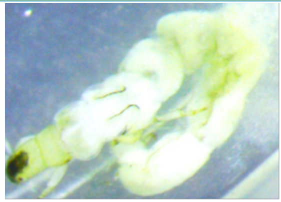


Chloroperlidae

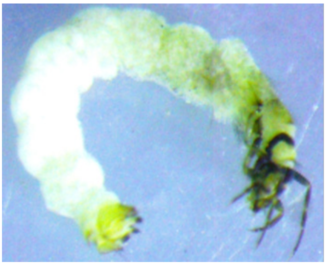
TRICHOPTERA



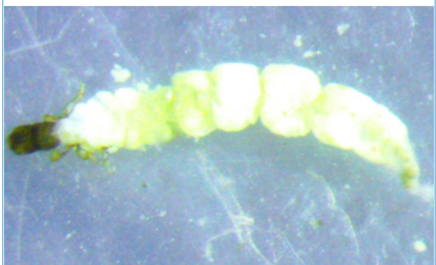
Brachycentridae (*Brachycentrus sp.*)



Polycentropodidae (*Pseudoneureclipsis sp.*)

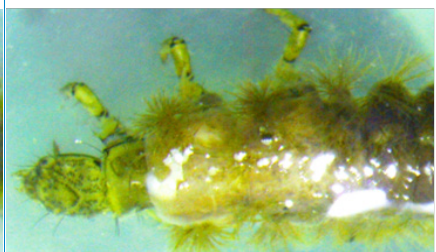


Leptoceridae (*Mystacides sp.*)



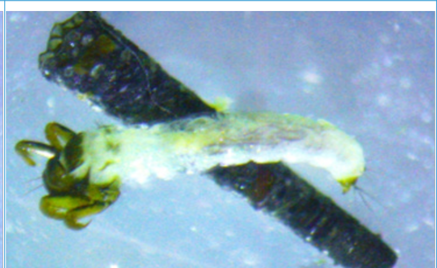
Rhyacophilidae (*Rhayacophila sp.*)

Phryganeidae



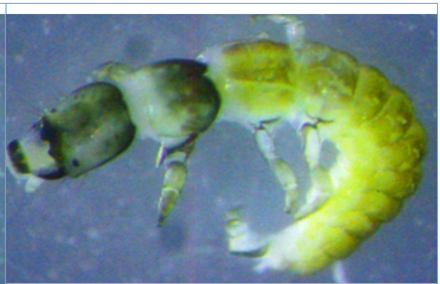
Rhyacophilidae (*Himalopsyche sp.*)

Hydropsychidae

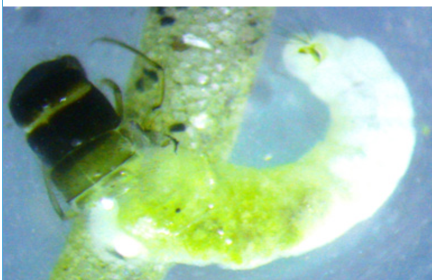


Brachycentridae

Limnephiliidae



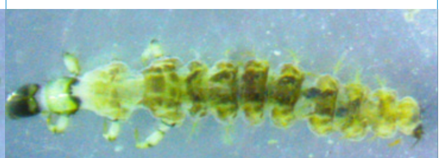
Philopotamidae



Odontoceridae

Lepidostomatidae

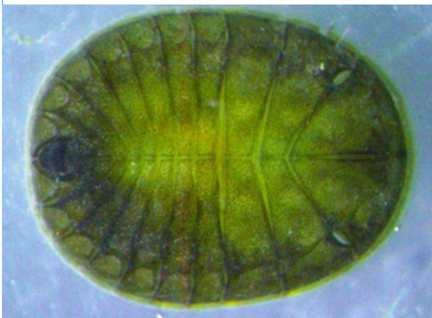
Sericosomatidae



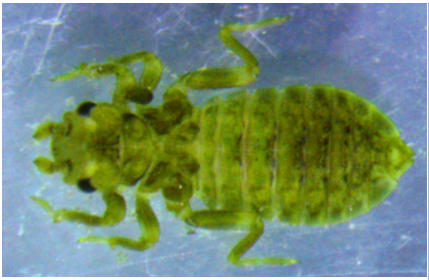
Rhyacophilidae

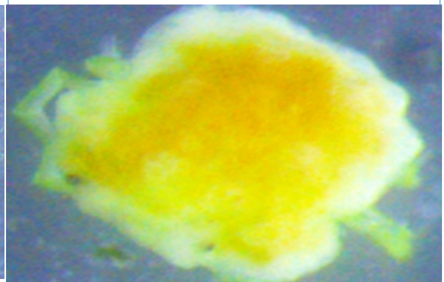
Stenopsychidae (*Stenopsyche sp.)*

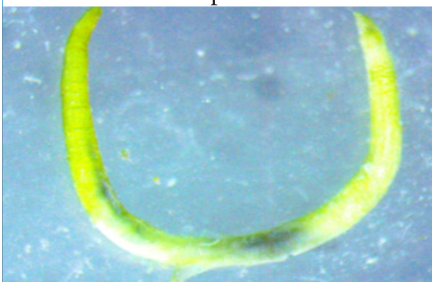
Glossosomatidae

COLEOPTERA	
	
Psephenidae	Elmidae
	
Grynidae	Scirtidae (*Cyphon sp.*)

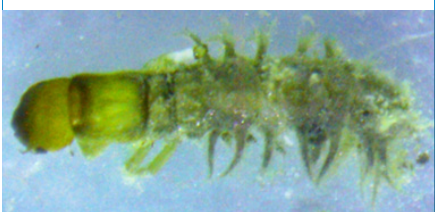
OTHER ORDERS


Gomphidae


Hydracarina


Nematoda (Round worm)


Nematoda *(Gordius sp.)*


Megaloptera (Corydalidae)


Megaloptera

ANNEXURE II

Sl. no	Family	Pool	Riffle	Cascade	Rapid	Total
1	Aphelocheridae[4]	1	3	0	2	6
2	Athericidae[2]	4	7	8	5	24
3	Baetidae[3]	61	182	61	60	364
4	Blephariceridae[2]	0	0	1	0	1
5	Brachycentridae[10]	60	31	3	4	98
6	Caenidae[3]	5	0	0	0	5
7	Ceratopogonidae[2]	0	0	0	1	1
8	Chironomidae[2]	111	55	52	38	256
9	Chloroperlidae[9]	2	2	0	0	4
10	Corydalidae[6]	5	2	0	1	8
11	Deuterophlebiidae[2]	0	0	1	0	1
12	Elmidae[1]	0	2	0	0	2
13	Ephemerellidae[3]	11	70	13	19	113
14	Ephemeridae[3]	3	2	0	0	5
15	Glossosomatidae[10]	24	16	128	59	227
16	Gomphidae[8]	22	8	0	0	30
17	Gordiidae[7]	0	1	0	0	1
18	Gyrinidae[1]	0	1	0	0	1
19	Heptageniidae[3]	78	63	21	2	164
20	Hydropsychidae[10]	4	14	5	7	30
21	Lepidostomatidae[10]	1	0	0	0	1
22	Leptoceridae[10]	76	1	0	4	81
23	Leptophlebiidae[3]	12	21	3	0	36
24	Limnephiliidae[10]	2	0	0	0	2
25	Limoniidae[2]	13	11	0	12	36
26	Nemouridae[9]	0	3	2	2	7
27	Odontoceridae[10]	1	0	0	0	1
28	Peltoperlidae[9]	2	2	3	0	7
29	Perlidae[9]	2	14	2	10	28
30	Perlodidae[9]	0	2	1	8	11
31	Philopotamidae[10]	1	2	0	0	3

32	Phryganeidae[10]	0	1	0	0	1
33	Polycentropodidae[10]	1	0	0	1	2
34	Psephenidae[1]	3	6	0	1	10
35	Rhyacophilidae[10]	1	13	8	1	23
36	Scirtidae[1]	0	1	0	0	1
37	Sericosomatidae[10]	0	0	1	0	0
38	Simuliidae[2]	1	1	26	0	28
39	Siphlonuridae[3]	8	3	1	2	14
40	Stenopsychidae[10]	0	8	0	1	9
41	Syrphidae[2]	1	0	0	0	1
42	Tabanidae[2]	2	1	0	0	3
43	Tipulidae[2]	1	0	0	0	1
44	Hydracarina[5]	0	1	0	0	0

Orders							
1	Coleoptera	4	Hemiptera	7	Nematoda	10	Trichoptera
2	Diptera	5	Hydracarina	8	Odonata		
3	Ephemeroptera	6	Megaloptera	9	Plecoptera		

Fish species recorded in Mangdechhu		
Order	Scientific Name	Common Name
Cypriniformes	***Schizothorax rechardsonii*** (Gray, 1832)	Snow trout
Cypriniformes	*Schizothorax progastrus* (McClelland, 1839)	Snow trout
Cypriniformes	***Neolissocheilus hexagonolepsis*** (McClelland, 1839)	Copper mahseer
Cypriniformes	***Garra sp.***	Sucker head
Cypriniformes	*Garra gotyla* (Gray, 1830)	Sucker head
Cypriniformes	*Tor putitora* (Hamilton, 1822)	Golden mahseer
Cypriniformes	*Barilius barna* (Hamilton, 1822)	Barna baril
Salmoniformes	***Salmo truta*** (Linnaeus, 1758)	Brown trout
Suluriformes	*Parachiloganis hodgarti* (Hora, 1923)	Torrent catfish

***Bold** indicates the species caught during the current survey while others were reported in the past surveys.*

The Ugyen Wangchuck Institute for Conservation and Environmental Research is a government based research and training institute. We strive to foster better stewardship of our natural heritage – land, water, air and species therein – through rigorous science based research and transmission of cutting-edge science results to field practitioners, environmental leaders and policy makers.

Our current focus areas are defined by needs and challenges within Bhutan and outside. We recognize interlinkages between the way forestry is practiced to the dynamics of species conservation and persistence. We understand the implications of land use practices and global climate change on water resources and energy requirements. Above all, we appreciate and seek to understand human impacts and impacts on humans by studying social patterns and economic implications of management and policy interventions.

In addition to conducting research, we provide a two-year certificate course in environment, forestry and conservation. We also offer tailor made course within the field of conservation biology, sustainable forestry and water resources for professionals working in these field. We also offer opportunities for undergraduate students to conduct research projects as part of their Honours program.

As part of our initiative to encourage discourses and dialogue within the environmental community, we regularly organize seminars and host conferences at both national and international level.

Administratively, we are currently housed under the Department of Forests and Park Services in the Ministry of Agriculture and Forests.

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