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DIVERSITY OF FISHES ACROSS HYDROLOGICAL BASINS AND ELEVATIONAL GRADIENTS IN EASTERN BHUTAN: A PRELIMINARY ANALYSIS

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ABSTRACT: Bhutan's water resources span a tremendous elevational gradient and are home to a diverse ichthyofauna. However, much of the aquatic biodiversity remains understudied and little is known about the ecology of native species. In an effort to strengthen Bhutan's existing fishery database, the National Research and Development Centre for Riverine and Lake Fisheries, Haa, conducted an ichthyofauna assessment from 2017 to 2019 at 496 sampling stations spread across three hydrological basins namely Aiechhu, Manas and Nyera-Amachhu in eastern Bhutan. A total of 108 fish species, representing 47 genera, 19 families and seven orders were recorded during the study. The highest number of species and endemic fish were found concentrated along the Aiechhu hydrological basin, particularly the Aiechhu proper (Maochhu) and below <500 meters elevation. Based on these findings, the Aiechhu proper appears to be best choice for retaining a free-flowing river in Bhutan and plans for future hydropower developments in elevation <500 meters above sea level should be reconsidered.

Keywords: Aiechhu; Eastern Bhutan; elevation; fish diversity; hydrological basin.

1. INTRODUCTION

The aquatic biodiversity in Bhutan is inadequately studied and little is known about the ecology of its lotic systems that span an elevational gradient from <100 to > 7500 masl (Tempa et al. 2019; World Bank 2017). The first comprehensive assessment of Bhutan's ichthyofauna established a baseline at 42 fish species from lotic ecosystems in Bhutan (Dubey 1978). Subsequently, Gurung et al. (2013) expanded the list to 82 species excluding exotic species confined to impoundments below 1000 masl in subtropical parts of the country and findings were supplemented with records available from the earlier studies (Dubey 1978; Dhendup and Boyd 1994; Petr 1999; Bhattarai and Thinley 2005). However, Gurung et al. (2013) reported that the fish species diversity in Bhutan was grossly underestimated and underscored; thus, the need for additional comprehensive studies was highlighted. Subsequent surveys specifically focused on the Royal Manas National Park Dorji and Wangchuk (2014), additional survey Gurung and Thoni (2015) and focused on basins in western Bhutan (National Research Centre for Riverine and Lake Fisheries [NRCRLF] 2017). Based on these studies and a series of discoveries of new species (Thoni and Gurung 2014; Thoni et al. 2016), the latest update by National Biodiversity Centre [NBC] (2017) records 116 fish in lotic systems across Bhutan. Most recently, discovery of five new species Thoni and Gurung (2018) extended the number of fish species found in Bhutan to 121 species, with eight species considered endemic (i.e., only known from Bhutan).

The lotic water resources of Bhutan are represented mostly by near-pristine, fast-flowing rivers and streams. As per the Dorji et al. (2020), this network of river systems (≈ 9,900 km) is delineated into five major hydrological basins (Amochhu, Wangchhu, Punatshangchhu, Mangdechhu and Drangmechhu) and five smaller hydrological basins (Jaldakha, Aiechhu, Nyera-Amachhu, Jomochhu and Sektengchhu) for the implementation of the integrated water resources management plan (National Environment Commission [NEC] 2016). Traditionally, water resources in Bhutan were restricted to household consumption, running of prayer wheels and watermills. In recent years, the immense techno-economic feasibility of hydroelectricity (23,760 MW) offers an important avenue for economic development in Bhutan (Norwegian Agency for Development Cooperation [NORAD] 2017). However, the World Bank (2017) identified hydropower as major concern for the inadequately studied aquatic biodiversity of Bhutan, requiring priority attention during hydropower development

In recent years, minimizing impacts of hydropower on aquatic biodiversity has become an integral part of hydropower development and regulation. However, most studies were focused on generating a descriptive list of the species across Bhutan. This information needs to be enhanced by documenting not only species richness, but also exclusive occurrences to appropriately prioritize and implement conservation and management plans (Bhatt et al. 2012). Hydropower projects are mainly concentrated along western Bhutan, particularly in the Punatshangchhu and Wangchhu basins, and are more fragmented as compared with rivers across eastern Bhutan. Therefore, the main objective of this study was to (i) determine the ichthyofauna richness along an elevational gradient, and (ii) compare hydrological basin-specific diversity of the ichthyofauna across basins located in eastern Bhutan, particularly in the Aiechhu, Manas and Nyera-Amachhu hydrological basins.

2. MATERIALS AND METHODS

2.1. Study Site and Sampling Design

Fishes were sampled along an elevational gradient ranging from 140-2880 masl from three hydrological basins (HBs): Aiechhu, Manas and Nyera-Amachhu (Figure 1). The Manas hydrological basin includes four subbasins:

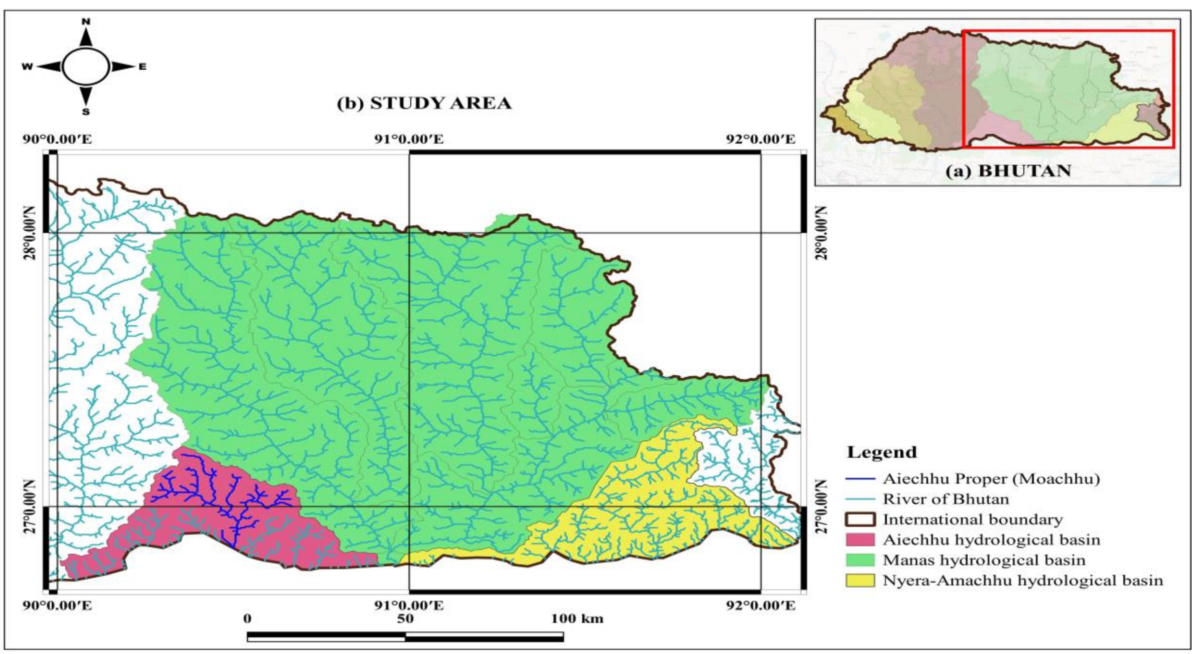

Figure 1: Major hydrological basins in Bhutan. Panel (a) shows all nine river basins in Bhutan (Drangmechhu and Mangdechhu considered as Manas), whereas (b) shows the three basins in eastern Bhutan assessed in this study (2017-2019). The three basins in western Bhutan were previously surveyed (2013-2016) including the partially shown Punatsangchhu hydrological basin and unsurveyed hydrological basin (Jomochhu and Sektengchhu)

Mangdechhu, Chamkharchhu, Kurichhu, and Drangmechhu. The Aiechhu Proper (Maochhu) was considered as a separate subbasin within Aiechhu hydrological basin. Two additional hydrological basins in far eastern Bhutan (Jomochhu and Sektengchhu) were not surveyed in this study.

To identify sampling sites, hydrological maps were developed using Google Earth and rivers were stratified into zones and sampling stations (FAO 1983). Zones were identified at five kilometres intervals along rivers and streams in each hydrological basin. Within each zone, a 300 m stretch of multiple habitats (i.e., pools, riffles, and runs) was designated as sampling site. To be considered for sampling, the site had to be accessible by road or on foot. In total, 124 zones and 496 sampling sites across three HBs were identified. Regardless of hydrological basins, these sites were allocated to six elevational ranges, i.e., <500 m, 500−1000 m, 1000−1500 m, 1500−2000 m, 2000–2500 m, and 2500−3000 m a.s.l. Exclusive species are those with occurrences within a particular hydrological basin or subbasin or elevational range.

2.2. Fish Sampling

Sampling was conducted from 2017-2019 and performed diurnally (07:00-17:00) following protocols adopted from (FAO 2006). To target all potential species, a variety of fishing gear was used (e.g., cast net, seine net, dragnet, hand net, minnow trap, fishing rod and line, and electro-fisher). To account for temporal variability of species assemblages, sampling was conducted during two seasons, pre-monsoon and post-monsoon. The approval for sampling was obtained from Department of Forests and Park Services (DoFPS). Sampling was avoided during auspicious days, corresponding to the Bhutanese calendar.

2.3. Sample processing

The colours and patterns of live specimen are often considered an important characteristic for identifying and distinguishing species (Fischer 2013). However, these characteristics quickly disappear after the death of a fish or are lost during preservation. In order to retain original colour patterns and qualitative data (shape, spots, patterns and other visible characters), photos of live specimens were taken using a photarium and DSLR camera (Nikon D3400). To retain voucher, the specimens were initially fixed with 10 % formalin following Jayaram (1981) and maintained upside down in a container to prevent damage to the caudal fin (Mandal and Jha 2013). For proper preservation of larger specimens (fish >150 mm total length), formalin was injected into the abdominal cavity to ensure proper fixation of the internal organs. Specimens were segregated by sampling site and stored in a designated container labelled with site data recorded for each sampling site (e.g., site name, GPS coordinates, collectors' names, date of collection, gear type, and habitat characteristics). The collected samples were transported to the laboratory at the National Research and Development Centre for Riverine and Lake Fisheries (NRDCRLF) for identification and accession into the Fish Repository in Haa. After fixation, specimens were thoroughly washed in flowing water for 24 hours and stored in 70-75% ethanol for long-term preservation.

2.5. Fish Identification

While tentative identifications were conducted in the field, taxonomic verifications were confirmed at the NRDCRLF laboratory. Fishes were identified on the basis of morphometric and meristic characters. Morphological measurements and counts were made following (Ng and Kottelat 2007). All measurements were taken on the left side of the specimen using digital callipers (to nearest 0.1 mm). Identifications and taxonomic review were performed using available references and published literature (Vishwanath et al. 2007; Talwar and Jhingran, 1991; Gurung and Thoni 2017; Dorji and Wangchuk 2014; NRCRLF 2017). The taxonomic classification and valid names of taxa followed FishBase (http//www.fishbase.org) and were accordingly catalogued into NRDCRLF database.

3. RESULTS AND DISCUSSIONS

3.1. Fish biodiversity in eastern Bhutan

Across the 496 sampling sites in eastern Bhutan, a total of 108 species of fishes were recorded during the present study (Table 1). Species represented 47 genera, 19 families and seven orders. Cypriniformes was represented by the highest number of species (*S* = 59), followed by Siluriformes (*S* = 33), Perciformes (*S* = 10) and Synbranchiformes (*S*=3). Three orders, Salmoniformes, Beloniformes and Anguilliformes were represented by a single species each (Figure 2). Among families, Cyprinidae was represented by the highest number of species (*S*=38), followed by Sisoridae (*S* = 18) and Nemachillidae (*S* = 13; Figure 3). In comparison to fish species documented from eastern Bhutan by previous studies Thoni & Gurung (2014), Dorji and Wangchuk (2014), Gurung and Thoni (2015), Thoni et al. (2016), Thoni and Gurung (2018), an additional 37 species were recorded during our study, whereas 31 species previously documented were not detected during our survey. Of 108 species recorded from rivers of eastern Bhutan, only one, *Salmo trutta* was detected in surveyed rivers. In addition, six exotic species appear to be restricted to aquaculture facilities. They are *Cirrhinus cirrhosis*, *Ctenopharyngodon idella*, *Cyprinus carpio*, *Gibelion catla*, *Hypophthalmichthys molitrix* and *Labeo rohita*.

Table 1: List of fish species recorded from three HBs in eastern Bhutan during the 2017-2019 survey. Hydrological basins are shown in Figure 1; HB stands for Hydrological Basin and acronyms are: APHB = Aiechhu Proper, AHB = Aiechhu, MHB = Manas, NAHB = Nyera-Amachhu; ✓ = Present, X = Absent.

Order	Family	Genus	Species	Elevation	PHB	AHB	MHB	NAHB
Anguiliformes	Angulidae	*Anguilla*	*Angulla bengalensis*	289	✓	✓	X	X
Beloniformes	Belonidae	*Xenentodon*	*Xenentodon cancila*	209–325	✓	✓	X	✓
Cypriniformes	Balitoridae	*Balitora*	*Balitora brucei*	224–1073	✓	✓	X	X
	Botiidae	*Botia*	*Botia almorhae*	320–451	X	✓	✓	✓
			Botia Dario	153–513	✓	✓	X	✓
	Cobitidae	*Lepidocephalichthys*	*Lepidocephalichthys guntea*	284–303	✓	✓	X	X
		Pangio	*Pangio apodo*	325	X	X	X	✓
	Cyprinidae	*Bangana*	*Bangana dero*	195–380	✓	✓	✓	✓
		Barilius	*Barilius bendelisis*	195–599	✓	✓	✓	✓
			Barilius vagra	303–718	✓	✓	X	✓
		Chagunius	*Chagunius chagunio*	224–320	✓	✓	X	X
		Crossocheilus	*Crossocheilus latius*	195–450	✓	✓	✓	✓
		Cyprinion	*Cyprinion semiplotus*	195–513	✓	✓	✓	✓
		Danio	*Danio assamila*	224–338	✓	✓	✓	✓
			Danio dangila	195	✓	✓	X	X
			Danio rerio	195–303	✓	✓	X	X
		Devario	*Devario aequipinnatus*	195–542	✓	✓	✓	✓
			Devario assamensis	224	✓	✓	X	X
		Esomus	*Esomus danrica*	195–384	✓	✓	X	✓
		Garra	*Garra annandalei*	195–578	✓	✓	✓	✓
			Garra arupi	495	X	X	✓	X
			Garra bimaculacauda	579	X	X	✓	X
			Garra birostris	313–912	✓	✓	X	X
			Garra gotyla	195–800	✓	✓	✓	X
			Garra lamta	495	X	X	✓	X
			Garra lissorhynchus	224–1073	✓	✓	✓	✓
			Garra quadratirostris	495–579	X	X	✓	X
			Garra sp 4.	313	✓	✓	X	X
		Labeo	*Labeo pangusia*	224	✓	✓	X	X
		Neolissochilus	*Neolissochilus hexagonolepsis*	195–1073	✓	✓	✓	✓
			Neolissochilus	1073	✓	✓	X	X
		Opsarius	*Opsarius barna*	224–599	X	X	X	✓
		Oreichthys	*Oreichthys cosuatis*	224	✓	✓	X	X
			Oreichthys	224	✓	✓	X	X
		Pethia	*Pethia onchonius*	224	✓	✓	X	X
			Pethia ticto	224	✓	✓	X	X
		Ptychobarbus	*Ptychobarbus* sp.	303–1073	✓	✓	X	X
		Puntius	*Puntius sophore*	224	✓	✓	X	X

		Raiamas	*Raimas bola*	191	X	X	X	✓
		Schizothorax	*Schizothorax molesworthi*	303–1073	✓	✓	X	X
			Schizothorax progastus	250–578	X	X	✓	X
			Schizothorax richardsonii	288-2800	X	X	✓	X
			Schizothorax sp 2	288–2,800	X	X	✓	X
			Schizothorax sp 3	495–578	X	X	✓	X
		Tor	*Tor putitora*	195–325	✓	✓	✓	✓
	Nemacheilidae	*Aborichthys*	*Aborichthys elongatus*	195–1008	✓	✓	✓	✓
			Aborichthys kempi	1008	X	X	✓	X
			Aborichthys pangensis	1008	X	X	✓	X
			Aborichthys sp 5.	224	✓	✓	X	X
			Aborichthys sp 7.	195	X	X	X	✓
			Aborichthys tikaderi	1008	X	X	✓	X
		Paracanthocobitis	*Paracanthocobitis abutwebi*	200–284	✓	✓	X	✓
			Paracanthocobitis botia	224–303	✓	✓	X	X
			Paracanthocobitis sp.	224–303	✓	✓	X	X
		Schistura	*Schistura beavani*	284–533	X	✓	✓	X
			Schistura chindwinica	578	X	X	✓	X
			Schistura savona	578–1073	✓	✓	✓	X
			Schistura tirapensis	790–842	X	X	✓	X
	Psilorhynchidae	*Psilorhychus*	*Psilorhychus arunachalensis*	303–1073	✓	✓	X	X
			Psilorhychus balitora	101–1073	✓	✓	X	X
			Psilorhychus	303–1073	✓	✓	X	X
Perciformes	Badidae	*Badis*	*Badis assamensis*	224	✓	✓	X	X
			Badis badis	224–284	✓	✓	X	X
			Badis dibruensis	224	✓	✓	X	X
			Badis singenensis	195–224	✓	✓	X	X
			Badis sp 1.	195–224	✓	✓	X	X
	Channidae	*Channa*	*Channa gachua*	195–300	✓	✓	✓	✓
			Channa hartcourtbutlerai	224	✓	✓	X	X
			Channa punctata	577	X	X	✓	X
			Channa quinquefasciata	224	✓	✓	X	X
			Channa stewartii	224–325	✓	✓	X	✓
Salmoniformes	Salmonidae	*Salmo*	*Salmo trutta**	950–2800	X	X	✓	X
Siluriformes	Amblycipitidae	*Amblyceps*	*Amblyceps apangi*	224	✓	✓	X	X
			Amblyceps arunachalensis	206–224	✓	✓	X	✓
			Amblyceps cerenum	211–224	✓	✓	✓	X
	Bagridae	*Batasio*	*Batasio fasciolatus*	220	✓	✓	X	X
			Batasio merianeinsis	195–229	✓	✓	X	X
		Mystus	*Mystus dibrugarensis*	224–284	✓	✓	X	X
			Mystus prabini	224	✓	✓	X	X
			Mystus vittatis	224–284	✓	✓	X	X
	Erethistidae	*Pseudolaguvia*	*Pseudolaguvia shawi*	284–839	X	✓	✓	X
	Olyridae	*Olyra*	*Olyra praestigiosa*	303	✓	✓	X	✓
	Siluridae	*Ompok*	*Ompok pabda*	224–284	✓	✓	X	X
		Pterocryptis	*Pterocryptis barakensis*	224	✓	✓	✓	✓
			Pterocryptis gangelica	150	✓	✓	X	X
		Creteuchiloglanis	*Creteuchiloglanis bumdelingensis*	790–842	X	X	✓	X
			Creteuchiloglanis sp 1.	2417	X	X	✓	X

		Exostoma	*Exostoma labiatum*	247–535	X	X	✓	X
			Exostoma	1083	X	X	✓	X
		Glyptothorax	*Glyptothorax botius*	224–350	✓	✓	X	X
			Glyptothorax cavia	313–1073	✓	✓	X	X
			Glyptothorax panda	224–325	✓	✓	X	✓
			Glyptothorax sp 1.	180	✓	✓	X	X
			Glyptothorax sp 2.	313–1073	✓	✓	X	X
			Glyptothorax sp 3.	303	✓	✓	X	X
			Glyptothorax sp 5.	325	X	X	X	✓
			Glyptothorax striatus	284–303	✓	✓	X	X
			Glyptothorax telchitta	284–303	✓	✓	X	X
		Parachiloglanis	*Parachiloglanis benji*	265–1083	X	X	✓	X
			Parachiloglanis bhutanensis	790–2033	X	X	✓	X
			Parachiloglanis dangmechhuensis	533	X	X	✓	X
			Parachiloglanis drukyelnensis	284–513	X	X	✓	X
			Parachiloglanis	284–513	X	✓	✓	✓
		Pseudecheneis	*Pseudecheneis serenica*	533	X	X	✓	X
			Pseudecheneis sulcata	284–839	X	✓	✓	X
Synbranchiformes	Mastacembelidae	*Macrognathus*	*Macrognathus*	209–224	✓	✓	X	X
			Mastacembelus armatus	140	✓	✓	X	✓
	Synbranchidae	*Monopterus*	*Monopterus albus*	191	X	X	X	✓

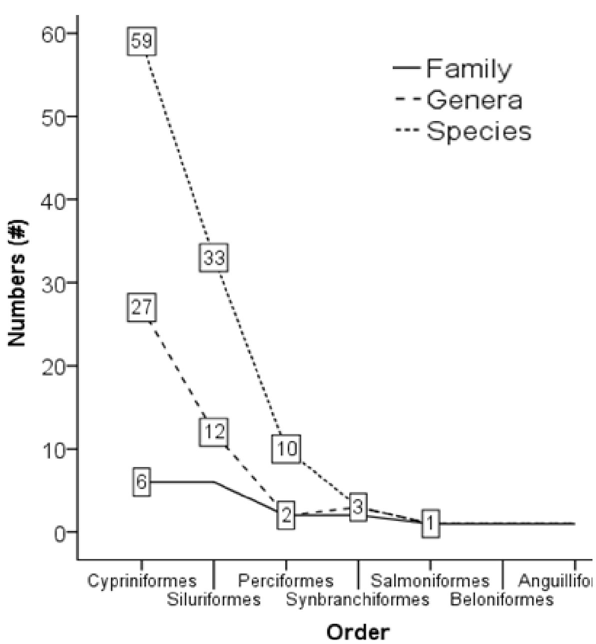

Figure 2: Numbers of families, genera and species within each of the seven orders recorded in eastern Bhutan during this study.

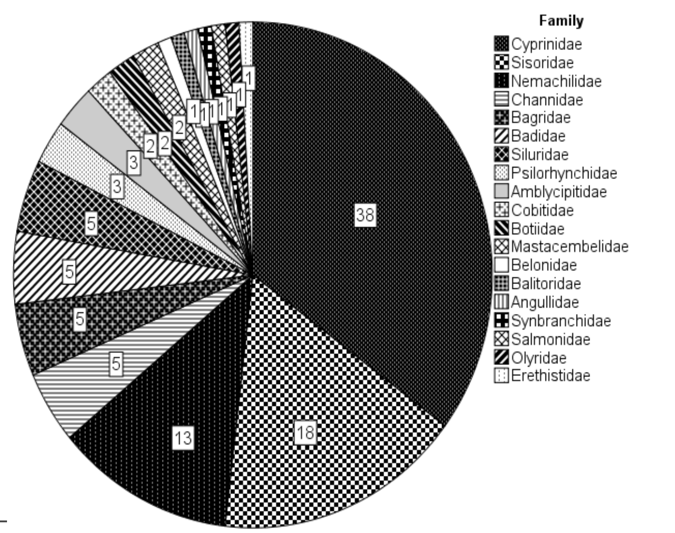

Figure 3: Distribution of the 108 fish species across the 19 families recorded in this study (2017-2019). Data are based on a survey of 496 sampling sites within three HBs in eastern Bhutan. Species are listed by family in Table 1.

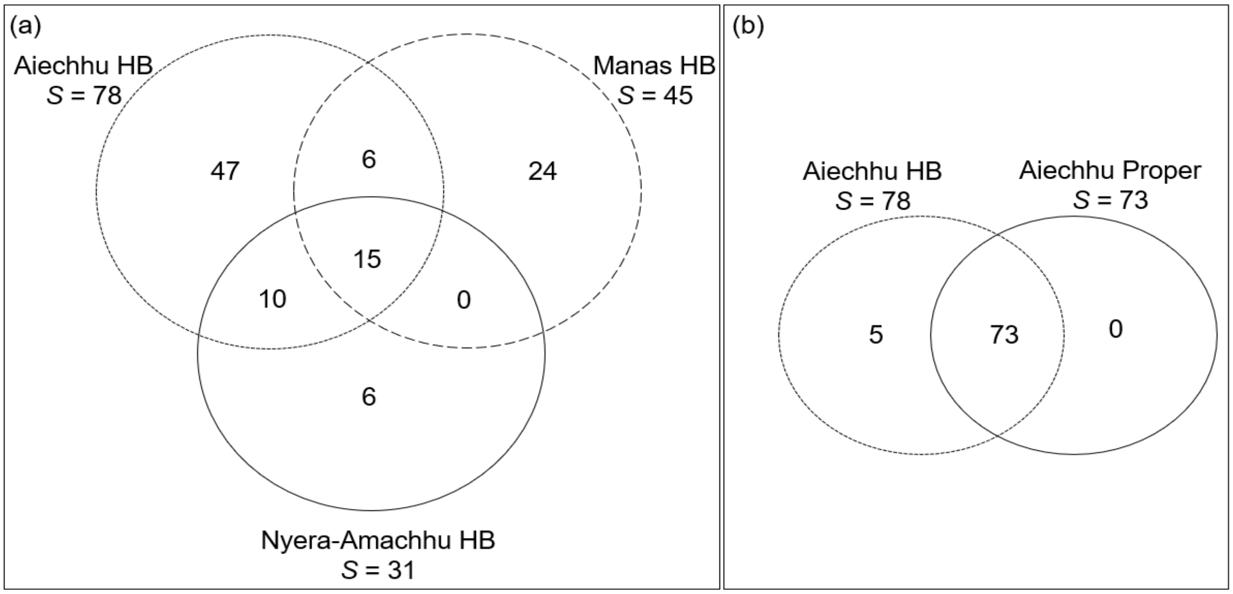

Figure 4: Comparison of fish richness and exclusive species among (a) the three hydrological basins (HB) in eastern Bhutan, and (b) the Aiechhu HB and Aiechhu Proper (Maochhu). Location of HBs are shown in Figure 1 and details on species are listed in Table 1

3.2. Fish biodiversity across hydrological basins and elevational gradients

Of the 108 species enumerated from rivers across Eastern Bhutan, the highest number of species was detected in the Aiechhu HB (*S* = 78), followed by Manas HB (*S* = 45) and Nyera-Amachhu HB (*S* = 31; Figure 4a). Only 15 species were detected across all three hydrological basins. In addition, 10 species were detected both in the Aiechhu HB and Nyera-Amachhu HB, but not the Manas HB, whereas only six species were recorded from the Aiechhu HB and Manas HB, but not the Nyera-Amacchu HB. Within the Aiechhu HB, the majority of species (*S* = 73) was detected in the Aiechhu Proper (Maochhu subbasin), whereas five species were exclusive to other specific rivers across the Aiechhu HB, such as Sarpangchhu, Bhurchhu, Sistychhu and Taklaichhu (Figure 4b).

The comparison among the three hydrological basins indicated Aiechhu HB to contain the highest taxonomic diversity in terms of orders, families, genera and species, followed by Aiechhu Proper, which also exhibited a higher species richness than much larger Manas HB and Nyera-Amari HB (Figure 5). There was sharp decline in species richness and exclusive species

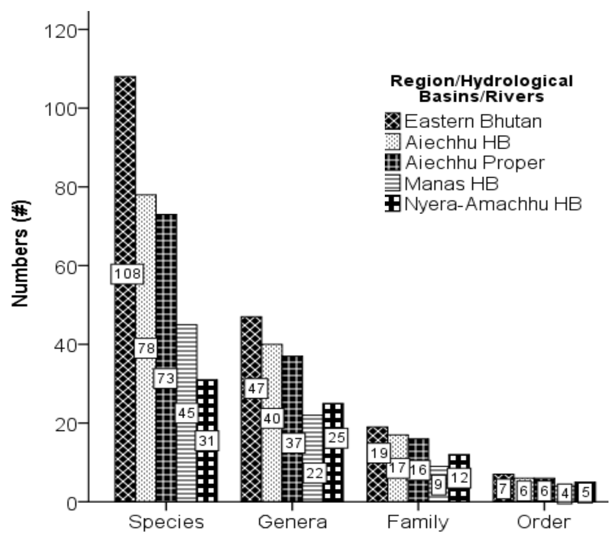

Figure 5: Comparison of fish taxon diversity across hydrological basins and the Aiechhu Proper subbasin in eastern Bhutan with respect to total number recorded for each category. Taxa are listed in Table 1 and location of basins are depicted in Figure 1. The data were recorded across 496 sites sampled from 2017-2019

along an elevational gradient up to 1500 m a.s.l. (Figure 6). However, highest diversity of the ichthyofauna was restricted to elevations <500 m asl, with 92 fish species recorded, of which 60 were not detected at higher elevations (Figure 6). In an assessment of the ichthyofauna across Himalayan rivers Bhatt et al. (2013) found a steady decline in species richness with increasing elevation and decreasing discharge. Although our findings mirror those of Bhatt *et al*. (2013), some species recorded by previous studies (Thoni and Gurung 2014; Dorji and Wangchuk 2014; Gurung and Thoni 2015; Thoni et al. 2016; Thoni and Gurung 2018) were not detected in our study and need to be accounted for; however, this was not possible in our analysis due to lack of published information with regards to elevational ranges.

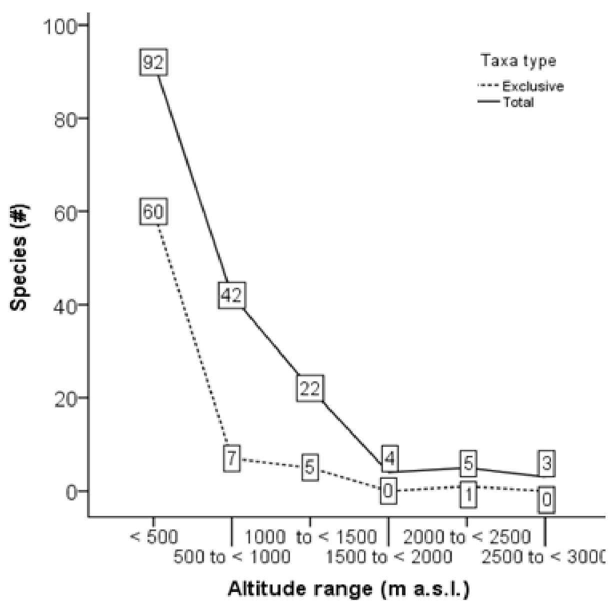

Figure 6: Comparison of fish species richness along elevation in eastern Bhutan. Samples were categorized according to six elevational ranges. Listed are both total number of species detected within a particular elevational category, as well as species that were exclusively found within one elevational category

4. CONCLUSION

Globally, rivers are increasingly exploited for hydropower production, which are predominant in Asia and Africa. As a consequence, only 78 % of Asia's medium-sized rivers remain free flowing (Grill et al. 2019). Bhutan is one of few countries in the world with relatively unmodified and near-pristine water resources; however, over the past few years, hydropower development has steadily increased. To date, seven rivers and their tributaries are fragmented by hydropower constructions. To address the potential impact on aquatic diversity, designation of at least one river as a free-flowing river (FRR) is gaining attention among environmental agencies and the conservationists. Future decisions about hydropower development need to be based on adequate scientific information about aquatic biodiversity to ensure appropriate conservation plans. The present study serves as a preliminary initial baseline for the ichthyofauna in Eastern Bhutan and was motived as an attempt to strengthen conservation efforts of aquatic biodiversity. In view of preliminary findings from this study, Bhutan should consider designating the Aiechhu Proper (Maochhu) as Bhutan's free flowing hydrological basin and minimize new hydropower developments <00 masl. The Aiechhu serves as an ideal choice for a free-flowing river as it is subjected to relatively few anthropogenic impacts, its water source originates within Bhutan, and the basin has minimal potential for hydropower development of 54 MW (NORAD 2017) compared to other hydrological basins. However, an extensive review of existing information and further studies are needed to strengthen the current knowledge of the ichthyofauna diversity in Bhutan so appropriate conservation plans can be adopted that are based on sound science.

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