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Impact of Irrigation Dams on Fish Diversity of Budhikhola in Bardiya, Lumbini Province of Nepal

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Abstract

This extensive study describes the current status of freshwater fish diversity in the Budhikhola which is an important branch of the Karnali River that runs through the western region of the Bardiya district covering about 30 km distance in the north-south direction. To examine the effects of irrigation dams on habitat modification and fish variety, fish were collected from the entire Budhikhola stretch, with four sampling stations established depending on habitat structure. The freshwater system of the Budhikhola harbors a diverse and ecologically complex fish community comprising 41 species from 6 orders and 13 families. The dominance of the Cyprinidae family, represented by *Barilius barna, Chanda nama, Chagunius chagunio,* etc., highlights its ecological significance. On the other hand, the loss of important fish species is proof that the building of irrigation dams has had significant ecological effects. Human-induced hazards such as damming and overexploitation, have adversely impacted the river environment, resulting in reduced water depth, habitat structure changes, and restricted nutrient flow. The majority of the riverbed had been observed to be silt-covered. Significant fish species loss indicates ecological instability brought on by human activity. Changes in the distribution of fish sizes and spatial differences between upstream and downstream areas highlight the complex link between habitat modifications and community functioning. The catch-per-hour seasonal tendency, which peaks in September and falls in March, is correlated with fishing patterns, environmental factors, or breeding seasons. The evenness value (0.96) and high Shannon-Weiner Diversity Index (H'= 3.57) show a diverse and harmonious fish community. The relevance of family-level distinctions in implementing effective conservation and management measures is highlighted by major differences among family groups ($p<0.001$). As the findings make clear, the long-term survival of the diversified fish ecosystem of the Budhikhola depends on addressing and reducing anthropogenic stressors. This study provides valuable insights for informed conservation efforts in the aquatic ecosystems of Nepal.

Keywords: Bardiya, Budhikhola, fish diversity, impacts, irrigation dam, siltation

Introduction

The southeast Asian landlocked nation, Nepal is situated in the Himalayan region. Its varied geography, which stretches from the high Himalayas to the plain Terai, has produced a variety of aquatic environments (Labh et al., 2017). Many freshwater organisms, particularly fish species, use these water resources as their habitats (Gurung, 2003). With an estimated 34,300

species, fish is one of the most significant and diverse groups of vertebrates (Froese & Pauly, 2020). There are over 230 native fish species from various regions of Nepal, representing 104 genera, 32 families, and 11 orders (Rajbanshi, 2012). 50 fish species belonging to 8 orders, 17 families, and 32 genera were reported from the lower Karnali River by Karki (2000). Thapa (2005) has identified 36 species representing 5 orders, 11 families, and 26 genera from the Karnali River.

The Budhikhola is one of the important downstream branches of the Karnali River. It runs in the western part of Bardiya district of Lumbini province of Nepal from Okhariya of Janaknagar (North) to Durganagar (South) covering about 30 km distance reaching up to the Indian border and again meets the Karnali river and is named Ghaghra in India. The Karnali River is the main water resource of Budhikhola and almost all the fish species of downstream Karnali River are represented in Budhikhola. Chaudhari (1999) has documented 67 fish species from 9 orders, 22 families, and 47 genera from the Budhikhola including 5 vulnerable and 1 endangered species. The degree of effects on aquatic flora and fauna is directly correlated with the rate and size of dam construction and other types of river modification. Since 1970, human activity-related biodiversity loss has accelerated at the fastest rate in recorded human history (Millennium ecosystem assessment, 2005). It is experienced that the natural habitat of the Budhikhola is deteriorating and the fish population in the river is declining due to several factors such as construction, fishing pressure, siltation, and erosion. Rivers are becoming more and more affected by damming, channelization, pollution, and water abstraction. The Government of Nepal constructed an intake dam in the mouth of the Budhikhola and 6 feeder dams for irrigation purposes in 2001 in collaboration with ADB which is identified as one of the important factors for deteriorating the habitat of the Budhikhola. Data from Nepal and other worldwide river systems show that certain dams have negative consequences (Agostinho et al., 2008; Gubhaju, 2012; Mandal & Jha, 2013; Rai, 2008; Sankar et al., 2012; Yoshida et al., 2020). Fish vulnerability in Nepal has increased due to the construction of fish ladders, and the construction of waterways and dams without completing an environmental impact assessment (EIA) (Hang Limbu et al., 2021). Nepal's National Biodiversity Conservation Strategy includes fish fauna (HMG/MFSC, 2002). The government enacted the Aquatic Animal Conservation Act 2005 with a revision in 2001 to conserve aquatic species, particularly fish. To maintain fish diversity, the damming techniques must require harmonizing technologies (Ranjan[1] et al., 2007). It would be difficult to develop the necessary technology for the conservation of native fish, raise public awareness, and incorporate academic courses into the curriculum (Gurung, 2012). It will be difficult to preserve fish and fisheries due to poisoning, non-sustainable fishing, irrigation dams, and hydropower. Sustainable management of water resources and the preservation of significant habitats and species are the goals of contemporary water legislation. Therefore, the purpose of this study was to evaluate the present status of the fish diversity, distribution pattern, fish catch, and frequency of occurrence of fish species after the construction of irrigation dams in Budhikhola, which is an important branch of the Karnali River in the Bardiya district of Nepal.

Materials and Methods

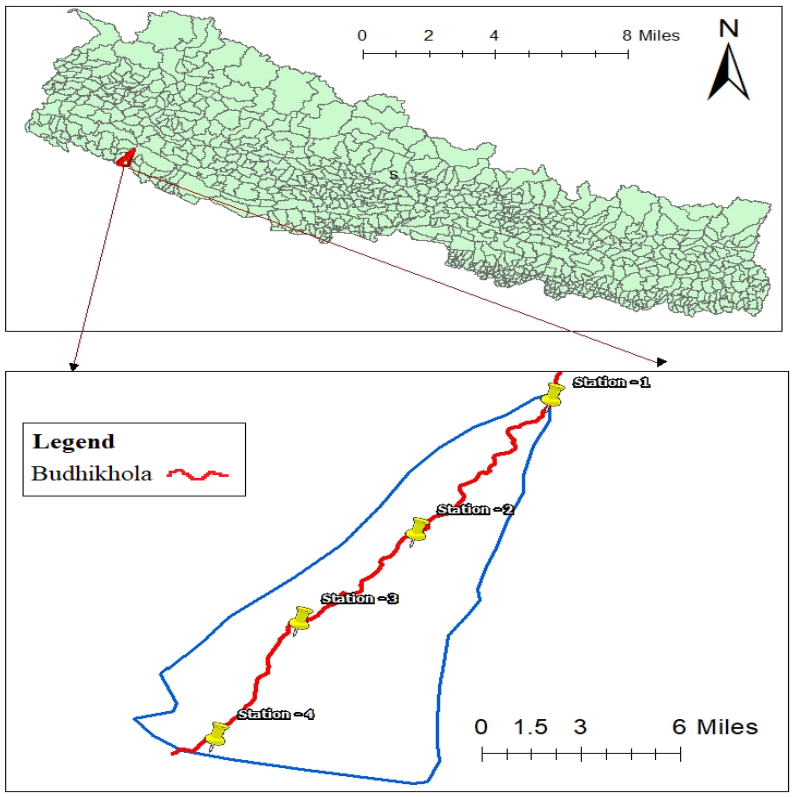
Study area

The study was carried out in the Budhikhola which is used as the main water resource for agricultural irrigation of the fields in Geruwa rural municipality and Rajapur municipality. The field study was carried out for nine months from January 2023 to September 2023. Toposheets of

LRMP (Land Resource Master Plan) were used to select the sampling stations for data collection. The selection of sampling stations was based on habitat and the presence of feeder irrigation dams. A total of 4 sampling stations were selected i.e., Janaknagar village (station-1) located at 28˚34′27.76″ N and 81˚14′42.87″ E, Shantibajar (station-2) located at 28˚30′9.24″ N and 81˚11′9.69″ E, Sendura village (station-3) located at 28˚27′17.41″ N and 81˚8′7.68″ E, and Bhimmapur village (station-4) located at 28˚23′34.89″ N and 81˚5′54.92″ E for sample collection (Fig 1). A map of the study area was prepared by QGIS 3.34.

Figure 1

Study Area



Data collection and analysis

The fish were captured for 4 hours in January, March, May, July, and September from each sampling site and a total of 20 samples were made from 4 stations of Budhikhola. Substratum compositions were noted within the sampling area of 400 m^2. The fishes were collected by the cast net and dragnet at each station and preserved in 10% formaldehyde solution for further study. Samples were collected from different habitats separately at each station and weighed by beam balance in the field itself nearest to the gram and results were noted as average catch. An attempt was also made to estimate the catch per hour at each sampling station of the Budhikhola. Some fish species were also collected from local fishermen who frequently catch fish from the Budhikhola. Species were identified using standard taxonomic references (Talwar & Jhingran, 1991; Jayaram, 2010).

Shannon-Weiner Diversity index was calculated on MS Office (Excel) 2010 using the equation-1

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \quad 1$$

Here,
H – Diversity index
s – Total number of species
pi – Proportion of individuals of each species belonging to the *i*th species of the total number of individuals.
ANOVA was applied to determine whether there were statistically significant differences among the means of the family groups in the Budhikhola or not.

Result

The present paper is an attempt to give the current status of fish species diversity and the impact of irrigation dams in the Budhikhola which is an important branch of Karnali River. 41 species under 25 genera belonging to 6 orders and 13 families were recorded in this study from the different sampling stations of the Budhikhola (Table 1). The maximum frequency of occurrence was of *Barilius barna* (7.04%) and the minimum was of *Wallago attu* (0.44%). The Cyprinidae was found to be the most dominating family with the greatest number of species (46.34%). Cobitidae (9.75%), Channidae, Bagridae, Mastacembelidae (7.31%) each, and Chandidae (4.87%) were the next highest numbers of species. Similarly, the family Gobidae, Belonidae, Claridae, Sisoridae, Saccobranchidae, and Siluridae each contributed by (2.43%). The status of the abundance of fish species and the frequency of occurrence of each species in different localities of Budhikhola are given in Table 2 and Fig 2. The dominant riverbed substratum was recorded as silt (Table 4). Over the period of nine months, a maximum of 3550 gm and a minimum of 880 gm of fish were caught at station-1, and station-4 respectively.

Similarly, only 2275gm and 1990 gm of fish were caught from station-2, and station-3 respectively (Table 3). The maximum catch per hour was calculated during September and the minimum during March in each sampling station (Table 3). However dominant family was cyprinidae, out of 13 families, fishes of 11 families were identified from station-3 and station-4. Fish of only 3 families were identified from station-1 and fish of 7 families were from station-2 (Table 5). The Shannon-Weiner Diversity Index (H') value was calculated as 3.57 suggesting a relatively high diversity indicating a community with a large number of the fish species in the Budhikhola. The evenness value was 0.96, which proves distribution of the species is relatively balanced. Since the $p<0.001$, there is a highly significant difference among the means of different family groups (Table 6)

Table 1

Fish species of Budhikhola with their Local Name (Based on the Classification of Jayaram (2010)

S.N.	Scientific Name	Local Name	Order	Family
1	*Barilius barna* (Hamilton)	Namsehara	Cypriniformes	Cyprinidae
2	*Barilius bendelisis* (Hamilton)	Namsehara	Cypriniformes	Cyprinidae
3	*Barilius shacra* (Hamilton)	Namsehara	Cypriniformes	Cyprinidae
4	*Barilius vagra* (Hamilton)	Namsehara	Cypriniformes	Cyprinidae
5	*Botia almorhae* (Day)	Gherra	Cypriniformes	Cobitidae
6	*Chagunius chagunio* (Hamilton)	Golawa	Cypriniformes	Cyprinidae
7	*Chela labuca* (Hamilton)	Sedhari	Cypriniformes	Cyprinidae
8	*Cirrhinus reba* (Hamilton)	Rawa	Cypriniformes	Cyprinidae
9	*Clarias batrachus* (Linnaeaus)	Mangur	Siluriformes	Claridae
10	*Channa gachua* (Hamilton)	Charanga	Channiformes	Channidae
11	*Channa marulius* (Hamilton)	Chitain	Channiformes	Channidae
12	*Channa punctatus* (Bloch)	Charanga	Channiformes	Channidae
13	*Chanda nama* (Hamilton)	Chandarbijwa	Perciformes	Chandidae
14	*Chanda ranga* (Hamilton)	Chandarbijwa	Perciformes	Chandidae
15	*Colisa fasciatus* (Bloch and Schneider)	Kheski	Perciformes	Belontidae
16	*Danio devario* (Hamilton)	Sedhari	Cypriniformes	Cyprinidae
17	*Danio dangila* (Hamilton)	Sedhari	Cypriniformes	Cyprinidae
18	*Esomus dandricus* (Hamilton)	Dedwa	Cypriniformes	Cyprinidae
19	*Glyptothorax telchitta* (Hamilton)	Murala	Siluriformes	Sisoridae
20	*Glossogobius guris* (Hamilton)	Bolna	Perciformes	Gobidae
21	*Heteropneustes fossisis* (Bloch)	Singi	Siluriformes	Saccobranchidae
22	*Labeo calbasu* (Hamilton)	Kathlaggi	Cypriniformes	Cyprinidae
23	*Labeo dero* (Hamilton)	Gardi	Cypriniformes	Cyprinidae
24	*Labeo gonius* (Hamilton)	Gardi	Cypriniformes	Cyprinidae
25	*Labeo pungusia* (Hamilton)	Karahwa	Cypriniformes	Cyprinidae
26	*Lepidocephalichthys guntea* (Hamilton)	Guita	Cypriniformes	Cobitidae
27	*Mystus tengra* (Hamilton)	Tengna	Siluriformes	Bagridae
28	*Mystus vittatus* (Bloch)	Tengna	Siluriformes	Bagridae
29	*Mystus seenghala* (Sykes)	Sujaha	Siluriformes	Bagridae
30	*Macrognathus acculeatus* (Bloch)	Bam	Matacembelifromes	Mastacembelidae
31	*Mastacembalus armatus* (Lacepedo)	Bam	Matacembelifromes	Mastacembelidae

32	*Mastacembalus puncalus* (Hamilton)	Bam	Matacembelifromes	Mastacembelidae
33	*Noemacheilus beavni* (Gunther)	Gherra	Cypriniformes	Cobitidae
34	*Noemacheilus botia* (Hamilton)	Gherra	Cypriniformes	Cobitidae
35	*Puntius chola* (Hamilton)	Sedhari	Cypriniformes	Cyprinidae
36	*Puntius sophore* (Hamilton)	Sedhari	Cypriniformes	Cyprinidae
37	*Puntius ticto* (Hamilton)	Sedhari	Cypriniformes	Cyprinidae
38	*Rosbora daniconius* (Hamilton)	Dedwa	Cypriniformes	Cyprinidae
39	*Tot tor* (Hamilton)	Chanwar	Cypriniformes	Cyprinidae
40	*Wallago attu* (Schneider)	Padhni	Siluriformes	Siluridae
41	*Xenentodon cancila* (Hamilton)	Dhongwa	Beloniformes	Belonidae

Table 2

Status of Species Distribution and Frequency Occurrence of Each Species at Four Stations of Budhikhola

S.N.	Species Name	Sampling Stations				Total	Frequency %
		1	2	3	4		
1	*Barilius barna* (Hamilton)	10	20	9	8	47	7.04647676
2	*Barilius bendelisis* (Hamilton)	6	6	4	3	19	2.84857571
3	*Barilius shacra* (Hamilton)	6	4	5	1	16	2.3988006
4	*Barilius vagra* (Hamilton)	7	6	8	6	27	4.04797601
5	*Botia almorhae* (Day)	0	8	4	0	12	1.79910045
6	*Chagunius chagunio* (Hamilton)	22	14	0	0	36	5.39730135
7	*Chela labuca* (Hamilton)	0	0	9	13	22	3.29835082
8	*Cirrhinus reba* (Hamilton)	18	9	0	0	27	4.04797601
9	*Clarias batrachus* (Linnaeaus)	0	0	4	7	11	1.64917541
10	*Channa gachua* (Hamilton)	0	0	7	9	16	2.3988006
11	*Channa marulius* (Hamilton)	0	0	0	11	11	1.64917541
12	*Channa punctatus* (Bloch)	0	5	9	13	27	4.04797601
13	*Chanda nama* (Hamilton)	0	4	11	22	37	5.54722639
14	*Chanda ranga* (Hamilton)	0	3	8	12	23	3.44827586
15	*Colisa fasciatus* (Bloch and Schneider)	0	0	2	4	6	0.89955022
16	*Danio devario* (Hamilton)	0	0	5	8	13	1.94902549
17	*Danio dangila* (Hamilton)	0	0	4	7	11	1.64917541
18	*Esomus dandricus* (Hamilton)	0	2	3	8	13	1.94902549
19	*Glyptothorax telchitta* (Hamilton)	9	4	0	0	13	1.94902549
20	*Glossogobius guris* (Hamilton)	0	0	0	10	10	1.49925037
21	*Heteropneustes fossisis* (Bloch)	0	0	4	7	11	1.64917541
22	*Labeo calbasu* (Hamilton)	9	6	3	0	18	2.69865067
23	*Labeo dero* (Hamilton)	11	5	3	0	19	2.84857571
24	*Labeo gonius* (Hamilton)	4	3	2	1	10	1.49925037
25	*Labeo pungusia* (Hamilton)	12	4	0	0	16	2.3988006

26	*Lepidocephalichthys guntea* (Hamilton)	4	5	3	0	12	1.79910045
27	*Mystus tengra* (Hamilton)	0	0	8	7	15	2.24887556
28	*Mystus vittatus* (Bloch)	0	0	6	8	14	2.09895052
29	*Mystus seenghala* (Sykes)	0	3	4	5	12	1.79910045
30	*Macrognathus acculeatus* (Bloch)	0	3	7	9	19	2.84857571
31	*Mastacembalus armatus* (Lacepedo)	0	2	3	7	12	1.79910045
32	*Mastacembalus puncalus* (Hamilton)	0	2	1	3	6	0.89955022
33	*Noemacheilus beavni* (Gunther)	6	5	3	0	14	2.09895052
34	*Noemacheilus botia* (Hamilton)	5	6	2	0	13	1.94902549
35	*Puntius chola* (Hamilton)	0	3	4	4	11	1.64917541
36	*Puntius sophore* (Hamilton)	0	3	8	9	20	2.99850075
37	*Puntius ticto* (Hamilton)	0	4	6	15	25	3.74812594
38	*Rosbora daniconius* (Hamilton)	0	2	3	5	10	1.49925037
39	*Tot tor* (Hamilton)	4	2	0	0	6	0.89955022
40	*Wallago attu* (Schneider)	0	0	1	2	3	0.44977511
41	*Xenentodon cancila* (Hamilton)	0	0	1	3	4	0.59970015
	41	133	143	164	227	667	

Table 3

Status of Total Catch and Catch per Hour Effort in the Budhikhola

Sampling Station	Sampling Date	Sampling Period (hour)	No. of collected fish	Total Catch (gm)	Catch/hour effort (gm)
1	8-Jan	4	20	300	75
	14-Mar	4	12	250	62.5
	18-May	4	25	800	200
	10-Jul	4	33	1000	250
	5-Sep	4	43	1200	300
2	10-Jan	4	26	250	62.5
	16-Mar	4	20	200	50
	20-May	4	23	225	56.25
	13-Jul	4	32	600	150
	9-Sep	4	42	1000	250
3	12-Jan	4	30	160	40
	18-Mar	4	27	100	25
	22-May	4	32	330	82.5
	16-Jul	4	35	500	125
	12-Sep	4	40	900	225
4	18-Jan	4	53	150	37.5
	22-Mar	4	38	100	25
	25-May	4	23	130	32.5
	20-Jul	4	58	200	50
	15-Sep	4	55	300	75

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Table 4

Substratum Composition (%) of Sampling Stations

Sampling stations	Stones	Pebbles	Silt	Mud
Station 1	20	10	70	0
Station 2	10	15	75	0
Station 3	5	5	85	5
Station 4	0	0	95	5

Fig 2

Frequency occurrence (%) of Fish in Budhikhola

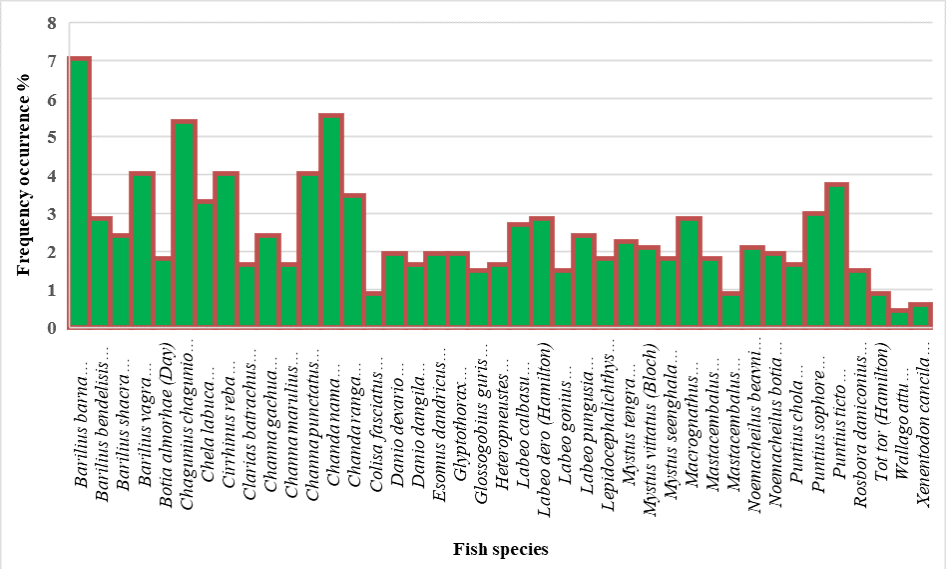

Table 5

Familywise Distribution of Fish in the Budhikhola

Family	**Station-1**	**Station-2**	**Station-3**	**Station-4**
Cyprinidae	109	93	76	88
Cobitidae	15	24	12	0
Bagridae	0	3	18	20
Channidae	0	5	16	33
Mastecembalidae	0	7	11	19
Chandidae	0	7	19	34
Siluridae	0	0	1	2
Sisoridae	9	4	0	0
Saccobranchidae	0	0	4	7
Claridae	0	0	4	7
Bolonidae	0	0	1	3
Gobidae	0	0	0	10
Belontidae	0	0	2	4

Table 6

Test of Significance of Familywise Diversity of Fish at 4 Stations

Anova: Single Factor

SUMMARY

Family	*Sampling Stations*	*Sum*	*Average*	*Variance*
Cyprinidae	4	366	91.5	187
Cobitidae	4	51	12.75	98.25
Bagridae	4	41	10.25	104.25
Channidae	4	54	13.5	213.6667
Mastecembalidae	4	37	9.25	62.91667
Chandidae	4	60	15	222
Siluridae	4	3	0.75	0.916667
Sisoridae	4	13	3.25	18.25
Saccobranchidae	4	11	2.75	11.58333
Claridae	4	11	2.75	11.58333
Belonidae	4	4	1	2
Gobidae	4	10	2.5	25
Belontidae	4	6	1.5	3.666667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28118.19	12	2343.183	31.69483	2.3E-16	2.010183
Within Groups	2883.25	39	73.92949			
Total	31001.44	51				

Discussion

A total of 255 fish species have been identified in the freshwater system of Nepal, which belong to 12 Orders, 41 Families, and 124 Genera including 15 endemic and 15 exotic fish species (Khatri et al., 2020). 121 fish species were reported from Solta to Kothiyaghat of Karnali River (Shrestha, 1990). In the present study, a total of 41 species of fish were recorded which belong to 6 orders, and 13 families. With over half of the total species, Cyprinidae is the most dominant family, indicating that this family is significant in the aquatic ecology of the Budhikhola. Its ecological significance is further highlighted because *Barilius barna* is the most common species. Chaudhari (1999) reported 67 fish species from the Budhikhola before the construction of the concrete irrigation dams in Budhikhola. Fish movement along river courses is a major concern throughout Asia due to the possibility of dams blocking. Dewatering of stream and river channels downstream from dams can also be a significant issue (Jackson & Marmulla,

2001). The flow of water was restricted resulting in siltation and a decrease in the depth of the Budhikhola. It was noticed that the flow of water was restricted altering the habitat of the river, siltation of the river bed, and decrease of depth of the river due to the uplifting of the river bed. According to local fishermen and villagers, the most important deep water-loving fish Thendh (*Bagarius bagarius*), Baikha (*Clupisoma garua),* and current loving fish Chanwar (*Tor putitora*) are not seen in the Budhikhola after the construction of irrigation dams. ADB (2018) and HMGN/MFSC (2002) have identified damming and river pollution are the two principal human-caused threats in Nepalese rivers (Khatri et al., 2020). Due to the decrease in water flow during the winter, a dam greatly restricts the movement of nutrients throughout the ecosystem, which has an impact on downstream fisheries output. As a result, fries, fingerlings, and adult migratory and resident fish will be impacted (Welcomme, 1985). Species diversity increased from the upstream to the downstream area of the Budhikhola. There were fewer larger fish in the deeper habitats of the river in the downstream section, but more small fish were caught in shallow, unstable habitats due to the siltation-induced drop in depth. The depth of water directly or indirectly affects the fish species diversity. Gradual changes in the availability of resources, vegetation, water volume, and channel form are correlated with consistent shifts in community organization. The range of frequency of occurrence (from 0.44% to 7.04%) highlights the varying prevalence of different species. The variation in fish catch among different stations and months provides insights into the spatial and temporal dynamics of fish populations in Budhikhola. Understanding these variations is essential for sustainable fisheries management. The data on catch per hour across months indicates a seasonal pattern, with the maximum catch occurring in September and the minimum in March which is associated with breeding seasons, environmental factors, or fishing patterns. The high Shannon-Weiner Diversity Index (H') of 3.57 signifies a rich and diverse fish community in Budhikhola. This could be attributed to the presence of various habitats and ecological niches supporting different species. The evenness value of 0.96 indicates that the distribution of species abundance is generally balanced. This indicates that the environment is healthy. The highly significant difference among the means of different family groups ($p<0.001$) underscores the importance of considering family-level differences in fish populations. This could have implications for conservation and management strategies.

Conclusion

In conclusion, the comprehensive study of the freshwater system in Nepal, particularly the Budhikhola, highlights the remarkable diversity and ecological complexity of its fish community with a total of 41 species belonging to 6 orders and 13 families. The dominance of the Cyprinidae family, particularly exemplified by the prevalence of *Barilius barna*, underscores its significance in the aquatic ecology of the region. However, the construction of irrigation dams in Budhikhola has had notable ecological consequences, as evidenced by the disappearance of key deep-water and current-loving fish species such as Thendh (*Bagarius bagarius*), Baikha (*Clupisoma garua*) and Chanwar (*Tor putitora*).

The river environment has been negatively impacted by human-induced hazards, such as damming and river pollution, which have been identified by sources including HMGN/MFSC (2002) and ADB (2018). These effects include reduced water depth, changes in habitat structure, and restricted nutrient flow. Notably, the loss of significant fish species is an indication of the ecological instability imposed on by human activity.

The observed increase in species diversity from upstream to downstream areas of the Budhikhola, coupled with changes in fish size distribution, underscores the intricate relationship between habitat alterations and community organization. The varying prevalence of different species, as indicated by the range of frequency of occurrence, provides insights into the spatial and temporal dynamics of fish populations.

The seasonal pattern observed in catch per hour, with peak catches in September and a decline in March, proves potential associations with breeding seasons, environmental factors, or fishing patterns. The high Shannon-Weiner Diversity Index (H') of 3.57 and evenness value of 0.96 reflects a rich and balanced fish community in Budhikhola, indicating a healthy environment.

Furthermore, the highly significant differences among family groups underscore the importance of considering family-level distinctions in fish populations for effective conservation and management strategies. In light of these findings, it is imperative to address and mitigate the anthropogenic threats posed to the aquatic ecosystem of Budhikhola to ensure the long-term sustainability of its diverse fish community.

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