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Research Article

Spatiotemporal variability in water quality, ichthyofaunal diversity, and its conservation in the rivers of Nepal: A mini review

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Abstract

Nepal has a diverse geography, ranging from an altitude of 60 m to the world's highest peaks at 8849 m. Fish diversity has been observed to extend up to an elevation of 3600 m. With its intricate topography, fluctuating climatic conditions, and abundant water resources, the region exclusively comprises freshwater habitats spanning 745,000 ha. These habitats include rivers, lakes, ponds, marshes, reservoirs, and irrigated rice fields. There are roughly 6,000 rivers and creeks in the country (194,471 km² drainage area). Four major river systems, namely Koshi, Gandaki, Karnali, and Mahakali, originate from the upper Himalayas at an altitude greater than 5000 m above sea level and drain about 75% of the country. Freshwater fishes are often overlooked in biodiversity conservation efforts, leading to a significant decrease in fish diversity, particularly in densely populated urban areas and wetlands in the southern plains of Nepal. The decrease in fish diversity is likely linked to inadequate prioritization, funding, and human resources allocated to fish conservation. According to the literature and FishBase database records, the freshwater river system in Nepal contains a total of 255 fish species from 12 orders, 41 families, and 124 genera. This includes 15 fish species that are unique to Nepal and 15 that are not native to the region. Additionally, 34 fish species in this system are considered threatened and have been listed under the IUCN Red List. These fish have pronounced vertical dispersion throughout the country and horizontal distribution within the area and continent, displaying diverse adaptations. This research specifically examines the fluctuations in water quality and the range of fish species, together with their conservation status in the rivers of Nepal.

Introduction

Nepal is a land of extreme altitudes, from a mere 60 meters above sea level to the towering heights of the world's highest peaks at 8849 meters. In this diverse terrain, fish thrive even at altitudes reaching 3600 m. Its complex topography, ever-changing climate, and rich water sources create a haven for freshwater habitats sprawling across 745,000 ha. These habitats encompass rivers, lakes, ponds, marshes, reservoirs, and irrigated rice fields. The aquatic environment harbors a wide range of creatures, encompassing plants, insects, fish, invertebrates, and microorganisms, so constituting a significant natural asset. Freshwater fish are considered to be bioindicators due to their ability to strongly respond to alterations in their ecological environment (Labh, 2023). Hence, it is imperative to conduct regular investigations of aquatic ecosystems, particularly rivers, to collect adequate biodiversity data within the complex context of fish variety. Labh (2023) asserts that the Ganga River possesses significant cultural, heritage, and economic significance for the nation of India. In terms of water flow, it is positioned as the fifth largest river on a global scale and holds the distinction of being the longest river within the nation. In addition to its vast 2525 km distance from Gangotri to Gangasagar, which carries profound spiritual and emotional importance, it has historically functioned as a crucial pathway for navigation and communication (Adhikari *et al*., 2021). The primary source of Nepal's water supply is derived from the snow-covered Himalayas located in the northern region, as well as glaciers. Nepal is blessed with a significant number of freshwater resources, which span a wide range of elevations, ranging from 50 m to the highest peaks in the world, which are more than 8849 m in height. Nepal boasts a vast network of over 6000 rivers and rivulets. Four principal river systems traverse around 70% of the nation's total area, all of which originate from the elevated Himalayas at an altitude exceeding 5000 m above sea level (Table 1).

Furthermore, China is the source of multiple tributaries of these rivers (Chapagain *et al*., 2021). According to (Khatiwada *et al*., 2021), the rivers and lakes of Nepal provide a habitat for a wide range of aquatic organisms, including fish. The nation has significant freshwater resources for aquaculture, which make up around 5% of its overall land area. It is estimated that around 54% of the total water bodies in the country are comprised of the aggregate water surface area and natural water resources. These water resources include rivers, lakes, and reservoirs. According to (Rajeev and Bhandarkar, 2022), a combined area of 8200 ha, comprising reservoirs and village ponds, exhibits considerable promise for the cultivation of fish. The river sustains a wide variety of fish species that are essential for numerous businesses, serving as the basis for riverine fisheries. Zoologists and fisheries enthusiasts have shown considerable interest in studying the correlation between fish species diversity and water quality, going beyond its practical implications. As a result, the primary purpose of this investigation is to investigate the aquatic status and the variety

of fish that are found inside the river system of Nepal.

Materials and methods

The current study on ichthyofauna is conducted using the obtained literature from the internet, discussions among researchers, and published research articles. There is a belief that the diversity of fish species may have undergone changes both before and after the *April 2015 Nepal Earthquake* (Gorkha Earthquake) and due to climate change. Currently, there is a lack of comprehensive data regarding the rivers in Nepal and the management system for its aquatic resources. There is little interest among scholars in studying a variety of features, as most of them are primarily focused on molecular factors. The information has been initially focused on the freshwater river system in Nepal, followed by studies on the diversity of fish species in these rivers. The inclusion of historical reviews and distribution status, in addition to water quality studies and observations, enhances the overall value. Hence, the authors explained all important aspects of fisheries and aquatic studies in the context of Nepal.

Aquatic ecosystem in Nepal

Freshwater river systems

Nepal possesses rivers and rivulets, which collectively serve as a drainage system for an area of 194,471 km². It is estimated that seven major river systems, namely the Koshi, Gandaki, Karnali, and Mahakali (Table 1), are responsible for draining over 75% of the country. In the Himalayas, which are located at an elevation of at least 5000 m above sea level, all four of these systems may trace their roots back to their origins.

Table 1: Current status of the river system and its tributaries in Nepal.

Name		Area (%)	Major Tributaries	Key point
Large rivers	Koshi	19.0	Seven tributaries (Indravati, Sunkoshi, Tamakoshi, Dudhkoshi, Likhu, Arun and Tamor)	Northern region
	Gandaki	21.7	Seven tributaries (Daraudi, Seti, Madi, Ka li Gandaki, Marshyangdi, Budhi Gandaki, and Trishuli)	Mid-Central region
	Karnali	29.3	Seven tributaries (Sani Bheri, Thuli Bheri, Tila, Mugu Karnali, Humla Karnali, Budhi Ganga and Seti Karnali)	Western region
	Mahakali	3.2	Chamelia drains and all the tributaries in the west connecting Indo-Nepal border	Far-Western region
Medium rivers	Kankai	0.9	Kankai river originates in the Mahabharat range	Eastern
	Bagmati	3.2	Between Koshi and Gandaki	Kathmandu
	Rapti	4.2	Western Hills and joining Jhimruk and Mardi	West Highland
	Babai	2.6	Inner Tarai of Dang Valley	Mid-Western
Siwalik		15.9	Originates Siwalik Hills through Madhesh Province	Indo border

Source: National Biodiversity Strategy and Action Plan, 2014–2020, with slight modification.

Additionally, certain tributaries of these systems also come from Tibet (Khadka *et al*., 2018). The Karnali River has the largest catchment area, covering 29.3% of the country. It is followed by the Gandaki River, which covers 21.7% of the nation, and the Koshi River, which covers 19.0%. It is estimated that around 3.2% of Nepal's total land area is comprised of the catchment region of the Mahakali River, which flows along the western boundary between Nepal and India. According to Sharma *et al*. (2015), Nepal experiences an average annual precipitation surpassing 1500 mm, accompanied by an estimated annual surface water availability of approximately 224.7 billion m^3. Despite the ample availability of water resources in Nepal, there exists a significant dearth of comprehensive and well-structured knowledge regarding fish variety. The predominant focus of scholarly investigations has predominantly revolved on the inventory of distinct sections of rivers and tributaries, with a restricted range of lentic systems encompassing lakes, ponds, pools, and irrigation canals throughout the country. There is a lack of research on fish species that live in marshy terrain (Nelms *et al*., 2021). According to Mishra *et al*. (2021) the estimated total water resources allocated for the development of fisheries and aquaculture in Nepal amount to 828,171 ha (Tabel 2). Moreover, the influence of human activity on land and water resources exacerbates Nepal's inherent susceptibility. Nepal is recognized as one of the most water-rich nations globally because to its varied geography, encompassing elevations ranging from 500 to over 8,000 m.

Earthquake-2015 and aquatic environment

Nepal is located between China to the north and India in all other directions. The northern region is home to towering snow-covered mountains, including Mount Everest. Conversely, the southern part of the country comprises the Terai belt, characterized by a tropical/subtropical climate, accounting for 17% of the nation's territory. This diverse geographical layout results in a wide range of climatic conditions across the country (Rimal *et al*., 2019). The Nepal earthquake of April 2015, registering a magnitude of 7.8 Mw at 11:56 Nepal Standard Time on Saturday, had widespread effects across various regions. A significant portion of the Ganges River plain in northern India, as well as Tibet and the western Bhutan Plateau, were all affected by the earthquake. It stands as one of the most devastating natural disasters in recent memory, particularly impacting central and eastern Nepal, where it claimed the lives of 9,000 individuals. Additionally, over 600,000 structures were either damaged or destroyed (Dangal *et al*., 2021). The quake severely disrupted water systems in and around the Kathmandu valley, leading to the drying up of numerous water sources across the 14 districts that bore the brunt of the disaster. According to evaluations conducted by the authority of Nepal with district-level offices, out of a total of 11,288 water supply systems in the districts that were most severely impacted, 1,570 were found to have sustained considerable damage. Similarly, in the 17 moderately affected districts, 747 systems were substantially damaged, with 1,761 experiencing partial damage (Pokhrel and Giri, 2018). A

considerable amount of food and livestock was also lost as a result of the earthquake. According to (Acharya *et al*., 2019), roughly 135,200 tons of food, 16,399 large cattle, 36,819 small livestock, and 60,762 poultry animals were destroyed. Furthermore, the event triggered a staggering 2,782 landslides covering an area of 38.2 km^2 in the 14 affected districts, resulting in an estimated 19,118,538 m^3 of sediment being generated. This surge in sediment loads significantly affected downstream water courses (Goda *et al*., 2015), with the majority (75%) of landslides occurring in the Indrawati, Sunkoshi, Tamakoshi, Dudhkoshi, and Koshi river basins, thereby impacting fish diversity.

Water quality in the river of Nepal

Examining water quality in rivers, regardless of their unique characteristics, involves analyzing various biological and biogeochemical processes. According to Wolfram *et al*. (2021), effective management of surface water quality demands regulating pollution levels below specific thresholds and ensuring minimal dissolved oxygen concentrations crucial for aquatic life. Table 2 outlines water quality parameters, encompassing chemical, physical, and biological aspects, relevant to applications like drinking, swimming, and aquaculture (Tyagi *et al*., 2013). Rivers and streams, invaluable assets, face contamination risks from urban and agricultural sources, distinct from those affecting lakes. Lake water quality primarily suffers from reduced clarity due to excessive suspended algae, elevated pH from algae abundance, or high indicator bacteria levels at beaches (Alm *et al*., 2003).

Table 2: Freshwater surface area and percentage coverage in Nepal.

S.N.	Water Resources	Area(ha)	%Coverage
1	Rivers and Streams	395000	47.77
2	Lakes	5000	0.60
3	Reservoirs	1500	0.18
4	Ponds	12749	1.38
5	Marginal swamps	12500	1.51
6	Irrigated paddy fields	398000	48.14
7	Irrigation canals	3160	0.38
8	Highway side ditches	262	0.04
Total		**828171**	**100**

Source: Annual Report of DLFD, Govt. of Nepal (2078/79 B. S.).

Understanding water quality's significance and monitoring changes over time are vital for effective water resource management. In surface water quality management, key pollution factors like phosphorus, nitrogen compounds, biochemical and chemical oxygen demand are crucial. Dissolved oxygen (DO), pivotal for stream ecology, is vital for aquatic organisms' well-being (Chang, 2005). Surface water quality management aims to maintain minimal DO levels for aquatic life and keep pollution parameters below predetermined thresholds (Labh, 2024). Research on water pollution in Nepal is limited (Mainali and Chang, 2021). Chakraborty *et al*. (2021) compared pollution levels and trends in rivers in Bangladesh, India, and the Kathmandu

Valley, but no spatial-temporal changes or main river versus tributary comparisons in Nepal have been studied. Vaidya and Labh (2017) identified pollution sites and prioritized mitigation zones based on limited river sections' water quality analysis.

Fish diversity in Nepal

Historical review of fish diversity

Fish studies in Nepal boast a rich historical legacy dating back to the 1800s, with scholars making significant contributions to the field of Ichthyology (Johal *et al*., 2002). Hamilton (1822) seminal work stands out as the first comprehensive documentation of Nepalese fishes, wherein he meticulously described 269 species in his publication "An account of the fishes found in the river Ganges and its branches." Following Hamilton, Day's 1888 publication (Day, 1888), "Fishes of India, Burma, and Ceylon," further enriched our understanding by documenting numerous freshwater fish species from Nepal (Table 3).

Table 3: List of commercially important fishes of Nepal.

S.N.	Local Name	Scientific Name	Introduced	Water
1	Rohu	*Labeo rohita*	1947	Warm
2	Naini	*Cirrhinus mrigala*	1947	Warm
3	Bhakur	*Catla catla*	1947	Warm
4	Common Carp	*Cyprinus carpio*	1956	Warm
5	Silver Carp	*Hypophthalmichthys molitrix*	1967	Warm
6	Bighead Carp	*Aristichthys nobilis*	1972	Warm
7	Grass Carp	*Ctenopharyngodon idella*	1968	Warm
8	Rainbow Trout	*Oncorhynchus mykiss*	1969	Cold
9	Pangasius	*Pangasianodon hypophthalmus*	2012	Warm
10	Tilapia	*Oreochromis niloticus*	1985	Warm

Source: Annual progress report, DoFD 2077/78.

Subsequent scholars like (Hora, 1937) reported on 22 species from Nepal, including notable mentions like *Neolissochilus hexagonolepis* and *Tor putitora*, elucidating the distribution of the latter across the Himalayas. (Menon, 1950) provided a distribution list of 69 known fish species within the Himalayan drainage system. (Taft, 1955) survey contributed significantly, compiling a checklist of 94 species from various locations such as Kathmandu, Trisuli, Simara, and Biratnagar. Majupuria and Shrestha (1968) delved deeper into "Freshwater fishes and Fisheries of Nepal," adding another layer of understanding to the field. Recent contributions by Ng and Edds (2005), Shrestha (2002), and Sharma (2008) have reported varying numbers of fish species from diverse water bodies in Nepal. Notably, Shrestha *et al*. (2009) published "Fishes of Nepal," a pivotal work detailing 120 freshwater fish species across 10 orders, 26 families, and 63 genera. Overall, Nepal's freshwater ecosystem is estimated to harbor a diverse array of fish species, totaling 255 across 12 orders, 41 families, and 124 genera. This includes a noteworthy presence of 15 endemic and 15 exotic species, highlighting the ecological significance and biodiversity of Nepal's aquatic environments.

Current conservation status of ichthyofaunal diversity in Nepal

Fish, comprising an estimated 34,300 species (Mishra *et al*., 2021), are a vital and diverse group of vertebrates, with around 3,000 species found in Asia alone (Levêque *et al*., 2008). Nepal is globally renowned for its remarkable fish biodiversity, contributing nearly one-fourth of all vertebrate species in freshwater habitats (Hishamunda *et al*., 2009). Unfortunately, freshwater biodiversity is declining at a rate twice that of oceans and forests, with nearly one-third of freshwater fish species facing extinction, including sixteen declared extinct in 2020 (Nguyen and De Silva, 2006). Nepal's Ichthyofaunal diversity exhibits a remarkable transition from alpine to tropical ecosystems over short distances, hosting numerous fish species, including endemics, and displaying significant species turnover within close proximity. Regular assessment of fish diversity in aquatic habitats is crucial for effective management and conservation. Despite its global and local significance, freshwater biodiversity in Nepal has received less attention compared to terrestrial biodiversity (Subba *et al*., 2020). Research on hill stream fish diversity is still in its early stages, with limited studies focusing on mountainous streams (Chapagain *et al*., 2021). On the other hand, having an awareness of the interaction between fish assemblage and environmental variables within stream habitats can be of considerable assistance in the conservation of fish biodiversity and the rehabilitation of rivers (Huang *et al*., 2019). Although there have been occasional survey efforts, the knowledge of fish faunal variety in Nepal is still in its infancy (Labh *et al*., 2017). There are a great number of species that have not yet been discovered or described. Unfortunately, fish often receive less equitable protection compared to terrestrial megafauna, making them more susceptible and endangered (Ghimire and Koju, 2021). Shrestha (2002) recognized as a pioneering indigenous Ichthyologist who authored "Fishes of Nepal" in 1981, describing 120 freshwater fish species across 10 Orders, 26 Families, and 63 genera. However, there is a lack of emphasis on fish taxonomy and conservation research by government organizations, universities, and institutions in Nepal. Nepal's freshwater system is home to 255 different fish species of which 15 are indigenous and 15 are exotic (Khatri *et al*., 2020).

Status of endemic fishes in Nepal

The quantitative representation of indigenous fish species in Nepal exhibits variability between different writers. In 1995, Shrestha documented the presence of 8 endemic species (Shrestha, 1999), however Gurung (2012) documented the existence of just 6 endemic fish in the same year. According to Rajbanshi (2002), there were 7 fish species that were found exclusively in the frigid alpine waters of Nepal. As per Froese (2005), Nepal's freshwater system supports a grand total of 255 fish species, which are distributed among 12 Orders, 41 Families, and 124 Genera. Among these, there are 15 species (Table 4) that are exclusive to Nepal, as indicated in. To enhance the protection of native fish, it may be advantageous to raise general awareness and incorporate academic courses into the school system.

Status of exotic fishes in Nepal

The initial introduction of exotic fish species into Nepal began with *Cyprinus carpio*, as documented by (Labh and Shakya, 2016). Subsequent reports from Rajbanshi (2002) indicated the introduction of 7 exotic fish species for commercial purposes. Additionally, Shrestha and Pant (2012) reported the presence of 10 exotic fish species in the region. However, a study by Labh *et al.* (2017) documented the presence of 8 exotic fish species. When all these different sources of information are compiled and analyzed, it is possible to get the conclusion that there are currently 15 species of foreign fish that have been recorded in Nepal. This information is presented in Table 4. The introduction of exotic fish species into the country may have implications for native biodiversity and ecosystem dynamics, warranting careful management and monitoring strategies.

Table 4: List of endemic and exotic fish recorded in Nepal.

S.N.	Endemic Fishes	Exotic Fishes
1	*Balitora eddsi*	*Barbonymus gonionotus*
2	*Batasio macronotus*	*Carassius carassius*
3	*Erethistoides ascita*	*Catla catla*
4	*Erethistoides cavatura.*	*Cirrhinus mrigala*
5	*Myersglanis blythii*	*Clarias gariepinus*
6	*Pseudecheneis crassicaudata*	*Ctenopharyngodon idella*
7	*Pseudecheneis eddsi*	*Cyprinus carpio*
8	*Pseudecheneis serracula*	*Hypophthalmichthys molitrix*
9	*Psilorhynchus nepalensis*	*Hypophthalmichthys nobilis*
10	*Psilorhynchus pseudechenies*	*Labeo rohita*
11	*Schizothorax macrophthalmus*	*Oncorhynchus mykiss*
12	*Schizothorax nepalensis*	*Oreochromis mossambicus*
13	*Schizothorax raraensis*	*Oreochromis niloticus*
14	*Neoanguilla nepalensis*	*Pangasianodon hypophthalmus*
15	*Turcinoemacheilius himalaya*	*Salmo trutta*

Source: Nepal Journal of Environmental Science 8, 39-52 (Khatri *et al*., 2020).

IUCN red list categories of fish species in Nepal

Nepal places a large amount of importance on the conservation and sustainable usage of natural resources across a wide variety of ecosystems. These ecosystems include forests, grasslands, wetlands, high mountains, the Himalayas, and lowland plains. According to the report that was published in 2018, the International Union for the Conservation of Nature (List and Red, 2018) plays a significant part in the provision of services to local communities and the nation as a whole in the process of developing and conserving the diversity of flora and fauna. The IUCN Red List, widely regarded as the foremost authority on the status of biological diversity, serves as a valuable tool for conservation efforts, benefiting from a robust scientific foundation. In addition to the global Red List, a series of Regional Red Lists are compiled by countries or organizations, evaluating the risk of species extinction within specific political management units. Notably, the assessment of fish species for

the Red List has seen an increase in recent years. Out of the 252 fish species documented in Nepal, the IUCN has identified 34 fish species in the red list (Table 5). This recognition underscores the urgent need for conservation measures to protect vulnerable fish populations and preserve Nepal's aquatic biodiversity.

Status of fisheries promotion in Nepal

Nepal, classified as one of the world's poorest and least developed nations, grapples with significant poverty, with approximately one-third of its population living below the poverty line.

Table 5: IUCN red list categories of fish species in Nepal.

S. N.	Fish Species	Common/Local Name	IUCN Red List
1	*Anguilla bengalensis*	Indian mottled eel	Near Threatened
2	*Balitora brucei*	Gray's stone loach	Near Threatened
3	*Garra rupecula*	Suker	Near Threatened
4	*Hypophthalamichthys molitrix*	Silver carp	Near Threatened
5	*Labeo pangusia*	Pangusi labeo	Near Threatened
6	*Neolissochilus hexagonolepis*	Copper mahseer	Near Threatened
7	*Schistura devdevi*	Loach	Near Threatened
8	*Systomus clavatus*	Stedman barb	Near Threatened
9	*Chitala chitala*	Clown knife fish	Near Threatened
10	*Ctenops nobilis*	Frail gourami	Near Threatened
11	*Oreochromis mossambicus*	Mozambique tilapia	Near Threatened
12	*Parambassis lala*	Highfin glassy perchlet	Near Threatened
13	*Ailia coila*	Gangetic ailia	Near Threatened
14	*Bagarius bagarius*	Goonch	Near Threatened
15	*Bagarius yarrelli*	Goonch	Near Threatened
16	*Ompok bimaculatus*	Butter catfish	Near Threatened
17	*Ompok pabda*	Pabdah catfish	Near Threatened
18	*Ompok pabo*	Pabo catfish	Near Threatened
19	*Wallago attu*	Wallago	Near Threatened
20	*Cirrhinus cirrhosis*	Mrigal carp	Vulnerable
21	*Cyprinion semiplotum*	Assamese kingfish	Vulnerable
22	*Nemacheilus inglisi*	Loach	Vulnerable
23	*Physoschistura elongate*	Dwarf loach	Vulnerable
24	*Schistura prashadi*	Creek loach	Vulnerable
25	*Schizothorax richardsonii*	Snow trout	Vulnerable
26	*Tor chelynoides*	Dark mahseer	Vulnerable
27	*Hypselobarbus micropogon*	Korhi barb	Endangered
28	*Schismatorhynchos nukta*	Nukta	Endangered
29	*Tor putitora*	Golden mahseer	Endangered
30	*Pangasianodon hypophthalmus*	Striped catfish	Endangered
31	*Cyprinus carpio*	Common carp	Critically Endangered
32	*Schizothorax nepalensis*	Snow trout	Critically Endangered
33	*Schizothorax raraensis*	Rara snow trout	Critically Endangered
34	*Glyptothorax kashmirensis*	Catfish	Critically Endangered

Agriculture, particularly primitive farming practices, serves as the country's economic backbone, providing sustenance for three-quarters of the population and contributing to around 40% of the gross national output. In addition to these challenges, Nepal boasts abundant water resources, ranking as the second richest country in terms of water availability, with over 400,000 ha of water suitable for aquaculture development (Khanal *et al*., 2020). Through the utilization of ideal climatic conditions that

are conducive to the cultivation of both warm-water and cold-water species, aquaculture has emerged as one of the agricultural subsectors in Nepal that is seeing the most rapid growth. Carp, both native and exotic, Pangas catfish, and Rainbow trout are among of the species that are cultivated the most frequently. Aquaculture development activities are currently being led by the Ministry of Agriculture, and fisheries research is carried out by the Fisheries Research Division, which is a division of the Nepal Agricultural Research Council (NARC). Additionally, educational institutions such as the Agriculture and Forestry University, Tribhuvan University and Kathmandu University provide academic programs (Bishwakarma, 2022). The practice of fishing from natural sources extends back to ancient times, despite the fact that the history of aquaculture in Nepal is relatively short.

Risks factors in fish diversity

There are several anthropogenic risks that are making things worse for aquatic ecosystems, which are already vulnerable to threats from both nature and humans. Activities such as damming, overharvesting, illicit fishing, waste disposal, and pollution contribute to these threats (Kelkar, 2023). River damming, in particular, poses a significant threat to many fish species, especially considering the proliferation of dams on various rivers and the extensive plans for future hydroelectric projects (Ghimire and Koju, 2021). Numerous studies have highlighted the adverse impacts of damming on fish populations. Loss of hydrological connectivity and alterations in flow regimes can lead to a decline in species diversity and even result in the extinction of migratory species (Amezcua *et al*., 2019). Factors that lead to a decrease in fish diversity and abundance include the loss of migratory pathways, which disrupts fish reproductive cycles. Additionally, turbine blades cause mortality and injury, and fish are more susceptible to parasite infections (Huang *et al*., 2019). The effects of climate change could exacerbate these issues, particularly for cold-water species, which constitute a significant portion of the freshwater fish found in Nepal (Mishra *et al*., 2020). Native fish species are vulnerable to the effects of climate change, including shifts in altitude (Gurung, 2012). As temperatures change and habitats shift, these species may face increased risks of extinction. It is imperative to address these threats through comprehensive conservation strategies to safeguard the rich biodiversity of Nepal's freshwater ecosystems.

The development of aquaculture has significantly bolstered Nepal's rural economy, with a notable increase in employment opportunities and income generation. In the 1980s, approximately 142,000 men and 223,000 women were engaged in fisheries, with about 80,000 individuals reliant on fishing activities. By 2018, the total fisheries production in Nepal reached 81,070 tons (Fig. 1), providing direct or indirect employment to approximately 122,772 individuals, with men constituting 67% of the workforce. Although the aquaculture business in Nepal is flourishing, the freshwater fish variety in the country encounters various obstacles. One such problem is the variability in the

reported total number of fish species, which varies between 220 and 258 according to different writers. However, recent literature indicates a total of 255 species. The Cyprinidae family dominates in terms of both abundance and prominence, particularly in the Gandaki basin, which harbors a diverse array of fish species. According to the Red List maintained by the IUCN, all 34 species of fish that have been identified in Nepal are classified as endangered. However, many fish studies focus solely on specific sections of rivers, failing to capture the true diversity of fish species.

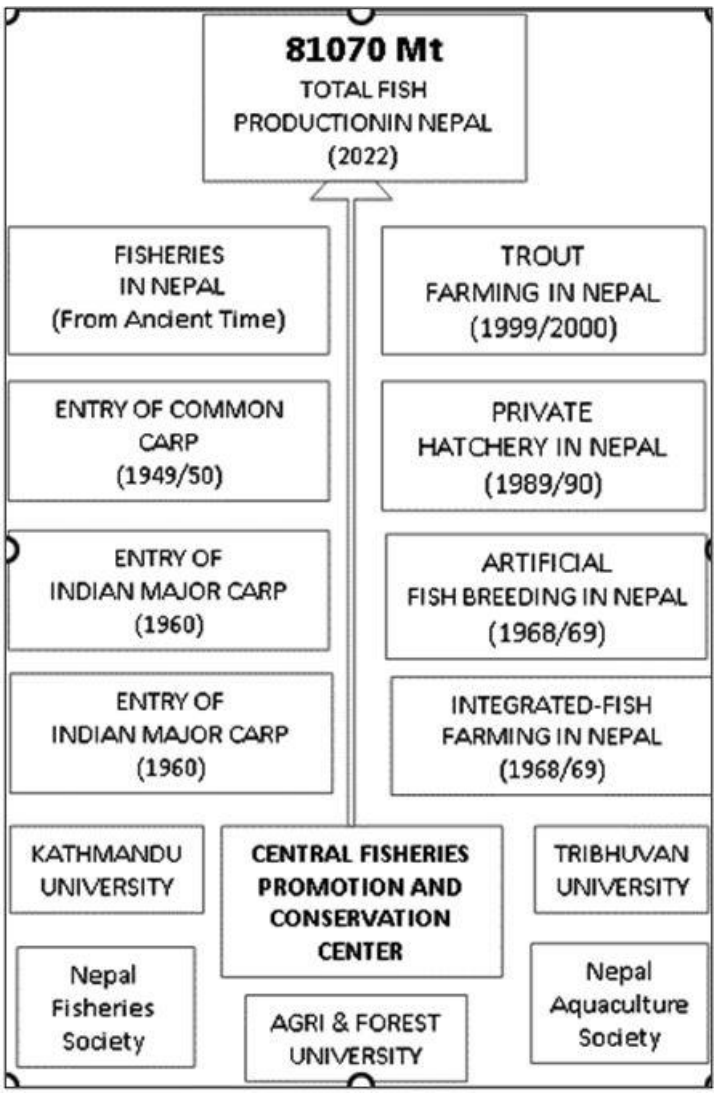

Figure 1: Schematic presentation of fisheries development and conservation in Nepal.

To address this limitation, future research should adopt longitudinal approaches spanning multiple seasons to account for spatio-temporal fluctuations in fish diversity and abundance. Furthermore, there is a pressing need for enhanced taxonomic research to support the deposit of specimens in museums and voucher collections. While morphology-based taxonomy has been prevalent in the

Nepalese context, genetic and molecular investigations offer promising avenues for resolving taxonomic uncertainties and evaluating genetic diversity among species. In conclusion, this study's findings are pertinent not only to ichthyologists and aquatic biologists but also to managers and planners engaged in fish biodiversity conservation, freshwater conservation, and management efforts in Nepal. By addressing the challenges and implementing comprehensive conservation strategies, Nepal can better preserve its rich freshwater fish diversity for future generations.

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Conflicts of interest

The authors declare no conflicts of interest.

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