



Assessing Wildlife and Ecology Amid Infrastructure Development in the Upper Indus Basin, Pakistan

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ABSTRACT

Understanding the baseline ecology of the Upper Indus Basin, Pakistan has become absolutely essential with ongoing infrastructure projects in the region as it would have various consequences on different habitats of the area. This study aims to provide a comprehensive understanding of the ecological dynamics, offering insights into the richness and diversity of fauna species of the area. The study area encompasses Upper Indus Basin, the Karakoram and Himalayan Mountain ranges, and was concentrated on the infrastructure developments in Khyber Pakhtunkhwa and Gilgit-Baltistan along the Indus River. Field surveys were conducted from May 2021 to December 2022 using the point count method for birds, pitfall method for reptiles and tracks and stools were utilized to identify mammals along with the direct observations, focusing on the nine identified habitats. Thorough search method was employed for all the taxa (birds, mammals, reptiles and amphibians). The surveyed species included birds, mammals, reptiles, and amphibians, and data were collected using GPS, binoculars, digital cameras, spotting scopes, and field guides. The study recorded a total of 322 species, including 242 birds, 47 mammals, 21 reptiles, and 12 amphibians. The values of Margalef, Menhinick's, Simpson, Shannon-Weiner and Evenness are as follows: 31.98, 2.13, 0.94, 3.65 and 0.63. Critical information on taxonomy, IUCN status, and trends for each group was analyzed along with hotspots. Overall, this study reveals that the area has high species diversity and provides habitat associations between nine habitats of the area. The infrastructure developments can disrupt these habitats, leading to biodiversity loss and altered species distribution. The findings contribute to a better understanding of the ecological dynamics in this region and can help in devising conservation and management strategies for the diverse habitats present.

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Authors' Contribution

UA, SRA and ZA conceptualized the study. UA, ZA and RA conducted the field visits. UA, ZA and RA assembled and analyzed the dataset. UA and RA drafted the manuscript. SRA and ZA reviewed and improved the manuscript.

Key words

Infrastructure development, Habitat, Ecological baseline, Upper Indus Basin, Biodiversity hotspots, Conservation, Wildlife conservation strategies, Wildlife management strategies

INTRODUCTION

Situated in the mountainous expanse of the Hindu-Kush Karakoram Himalaya (HKH) region, the Upper Indus Basin (UIB) is characterized by a transnational river network that includes both the western rivers (Upper Indus, Kabul, Jhelum, and Chenab) and the eastern rivers (Ravi and Satluj) (Orr *et al.*, 2022). The water resources in the UIB exhibit pronounced seasonality, mainly dependent on the influx of water from snow and glacial melt during the spring and summer months, as well as the summer

monsoonal rainfall (Lutz *et al.*, 2014, 2016). In Pakistan, the majority of agricultural land relies on irrigation, and irrigation-based agriculture contributes approximately 90% of the total annual agriculture production (Hussain *et al.*, 2021), which accounts for about 25% of the country's GDP (Zahra *et al.*, 2023). The river holds immense importance as Afghanistan, Pakistan, India and China rely on river systems that originate from the mountainous region of the Upper Indus Basin (UIB) (Mukherji *et al.*, 2019; Wester *et al.*, 2019). The water resources within the UIB are vital for various purposes, including agriculture, power generation, domestic consumption, industrial processes, tourism, fishing, and religious ceremonies. Furthermore, they support a diverse range of terrestrial and aquatic ecosystems (Xu *et al.*, 2019). These rivers sustain the world's largest continuous irrigation system (Qureshi, 2011) and play a critical role in ensuring a reliable supply of electricity to downstream populations through numerous hydropower projects (Nie *et al.*, 2021; Hennig *et al.*, 2023).

Development of large transportation facilities, economic zones, and infrastructure are among the main measures for the development of the remote and

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disadvantaged areas of any country (Ramachandran and Linde, 2011). A well-built road network helps in accessibility to the basic facilities of life, such as health, education, employment, and economic opportunity (Sackey *et al.*, 2023). UIB is confronted with the challenge of massive and rapid infrastructure development in its entire history (Khan *et al.*, 2020). Mega infrastructure projects like China Pak Economic Corridor, Dams, High Voltage Transmission Lines, etc. are transforming natural landscape. It is expected to result in inducing very negative impacts on the environment, ecology and natural resources of the area (Huo *et al.*, 2021). Extensive anthropogenic stressed land use practices are already triggering climate change impacts (Xiaolong *et al.*, 2021). UIB is of great scientific importance, as it serves as a crucial source of freshwater for agricultural purposes and the generation of hydropower electricity (Yaseen *et al.*, 2020). Additionally, it plays a pivotal role in preserving biodiversity, owing to its high-altitude mountains, extensive glaciers, and unique ecological support systems (Zhang and Wang, 2021). The identification of ecologically vulnerable regions constitutes a fundamental aspect within the realm of ecological conservation and environmental management. This paper attempts to provide biodiversity hotspots and ecological baseline for UIB considering the major infrastructure developments in the area.

MATERIALS AND METHODS

Study area

The present study was conducted in the Upper Indus

Basin (72.20°–77.69° E; 32.92°–37.09° N), define as the Tarbela dam catchment area in Pakistan. The area lies at higher elevation ranging from 1000 to more than 5000 meters. It comprises of about 147,000 km², focused on the Karakorum and Himalaya Mountain ranges. Study includes primarily the areas of Haripur, Abbottabad, Mansehra, Battagram, Shangla and Kohistan districts of Khyber Pakhtunkhwa; and Diamer, Astore, Skardu and Ghanche districts of Gilgit-Baltistan, along river Indus.

The area was stratified into nine potential habitats: agriculture land, alpine grassland, bare rock/gravel, snow/glacier, sub-tropical broad leaf, sub-tropical chir pine, temperate forest, urban area/ settlements and waterbodies/swamp (Table I, Fig. 1).

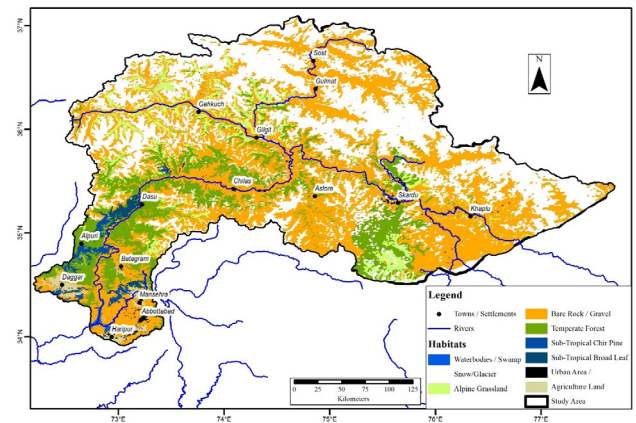


Fig. 1. Map highlighting nine potential habitats in the Upper Indus Basin area studied for ecological assessment.

Table I. Brief description of habitats.

S.	Habitat	Description
1	Agriculture land	Cultivated land used for growing crops, fertile soil, hot and dry climate in the plains, cooler climate in the hilly areas, mix of natural vegetation and cultivated crops.
2	Alpine grassland	Cold temperatures, low growing vegetation, grasses and herbs adapted to harsh environmental conditions.
3	Bare rock/ gravel	Rocky and gravelly terrain with little or no vegetation, thin and nutrient-poor soils, extreme temperatures
4	Snow/Glacier	Snow-capped peaks and glaciers, harsh environmental conditions, limited vegetation, wildlife adapted to cold conditions
5	Sub-tropical broad leaf	Dense forests with broadleaf trees adapted to warm, humid areas, diverse plant and animal life, mangrove forests in the Indus Delta region
6	Sub-tropical chir pine	Forests dominated by Chir Pine trees, wildlife includes the Himalayan black bear, leopard and several bird species
7	Temperate forest	Trees that shed leaves during winter months, diverse vegetation and wildlife, moderate temperatures
8	Urban area/ Settlements	Concentrated areas of buildings and infrastructure, high population density, limited natural vegetation
9	Waterbodies/ Swamp	Wetland areas with diverse plant and animal life, important breeding grounds for fish and bird species, provide important ecological services

Field surveys

The monthly surveys were conducted between May 2021 and December 2022. Fifteen points were selected in each habitat for primary observations. In addition to spending 15 min at each point for direct observations of birds, other methods were employed for different habitats and species. In grassland and agricultural areas, the flushing method was used, while the sky view method was utilized for observing raptors. Points were also strategically selected to set up pitfalls for reptiles. For mammals, direct observations were complemented by identifying tracks and stool. Thorough search method was employed for all the taxa (birds, mammals, reptiles and amphibians). The equipment used for this study included GPS, binoculars (Bushnell power view, 60X 90 m), digital camera (Nikon p-900), spotting scope (Harrier 65mm ED Spotting Scope) and field guides Birds of Pakistan (Roberts, 1991, 1992; Mirza and Wasiq, 2007; Grimmitt *et al.*, 2008), Mammals of Pakistan (Roberts, 1997) and Amphibians and Reptiles of Pakistan (Khan, 2006). These guides were used for species identification.

Data analysis

The data were analyzed by using formulae of Simpsons index, Shannon-Wiener diversity index species evenness, Margalefs index, Menhinicks index, Relative abundance, Sorensons similarity index, and Jaccard similarity index, Simpson's index ($D = 1 - \sum n(n-1) / N(N-1)$)

Where, n is total number of individuals of a particular species, and N is total number of individuals of all species (Ahmad *et al.*, 2022).

Shannon-Wiener diversity index ($H' = -\sum_{i=1}^S P_i \ln P_i$)

Where, H' Shannon-wiener diversity index, S is No. of Species, P_i is Proportion of a species relative to the total number of individuals (Ahmad *et al.*, 2022).

Species evenness: ($J' = H' / \ln(S)$)

Where, J' is Pielou Index, H' is Shannon-Wiener Index, and S is No. of species (Kazam *et al.*, 2022)

Margalef's diversity index ($D_{Mg} = S - 1 / \ln N$)

Where, S is No. of species, and N is total no. of individuals in the sample (Gamito, 2010).

Menhinick's diversity index ($D_{Mn} = S / \sqrt{N}$)

Where, S is No. of species, and N is total no. of individuals in the sample (Mulya *et al.*, 2021).

Relative abundance (RA) = $n/N \times 100$

Where, n is number of individuals of the specie i in the specific area, N is total number of individuals of all species in a specific area (Kazam *et al.*, 2022).

Sorenson's similarity index (SSI) = $(2C/(a+b)) \times 100$

Where, C is number of species in both habitats a and b , a is number of species in habitat a , b is number of species in habitat b . The similarity index was used to determine the

interspecific linkages between species in different habitats (Sørensen, 1948). SSI between two was calculated using the following formula (Nath *et al.*, 2005).

Jaccard similarity index (C_j) = $a / (a + b + c)$

Where, a is the number of common species in both habitats, b is the number of species in habitat a , not in habitat b while c is the number of species in habitat b , not present in habitat a . It determines and compares the similarities between various habitats.

It is important to note that neither coefficient (Sorenson's and Jaccard) takes into account the number of individuals present in each area (Barbour *et al.*, 1980; Magurran, 2004).

Identification of hotspots

Hotspots were identified based on the density and the highest number of infrastructure projects in an area. This method highlights regions with the most significant concentration of development activity.

RESULTS

The major infrastructure developments in the area include Dam/Hydropower, dry Ports/SEZ, roads, settlements and transmission lines as highlighted in Figure 2. A total of 322 species were recorded in different habitats of Upper Indus Basin. It included 242 birds, 47 mammals, 21 reptiles and 12 amphibians. Further details about order, family, IUCN status and trend are given in Supplementary Table I and a summary is given in Table II.

Table II. Taxonomic details and IUCN status.

	Birds	Mam- mals	Rep- tiles	Amphib- ians
Order	22	9	2	1
Family	63	23	9	2
IUCN status				
Least concern (LC)	219	29	4	10
Near threatened (NT)	10	6		
Vulnerable (VU)	8	6		
Endangered (EN)	3	3	1	
Critically endangered (CR)	2			
Data deficient (DD)			1	
Not available (NA)		3	15	2
Trend				
Increasing	40	3		1
Decreasing	77	18	2	1
Stable	100	9	1	7
Unknown	25	14	1	1
Not available		3	17	2

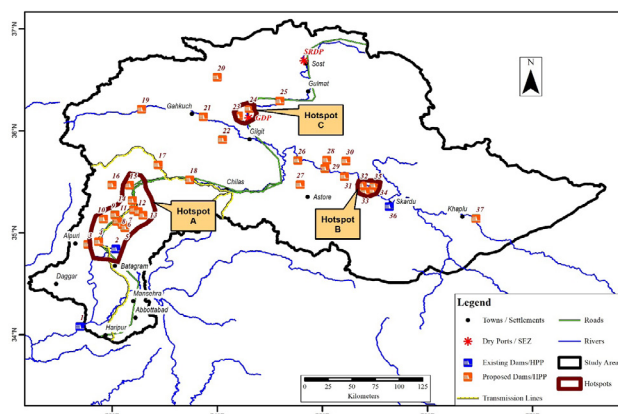


Fig. 2. Hotspots identified by the density and number of infrastructure projects, indicating regions with high hydropower activity in Upper Indus Basin. (1) Tarbela Dam, (2) Allai Khwar, (3) Khan Khwar, (4) Thakot Dam, (5) Palas valley upper, (6) Palas valley lower, (7) Palas valley middle, (8) Pattan Dam site, (9) Keyal Khwar, (10) Dubair Khwar, (11). Spat Gah Lower, (12) Spat Gah Middle, (13) Spat Gah Upper, (14) Dasu Dam, (15) Karang, (16) Kaigah, (17) Tangir, (18) Basha Dam, (19) Phander, (20) Baru, (21) Kanch, (22) Sher Qila, (23) Naltar– 1, (24) Nasirabad, (25) Altit, (26) Bunji Dam Site, (27) Doyian, (28) Talu, (29) Yulbo Dam Site, (30) Tormic, (31) Harpo, (32) Tungas Dam Site, (33). Kachura, (34) Skardu, (35) Basha, (36) Satpara, (37) Shyok (Yugo) HPP.

Among birds, order Passeriformes was most abundant with 119 species followed by Charadriiformes, Accipitriformes with 25 and 17 species, respectively. The most abundant bird species were great cormorant (*Phalacrocorax carbo*), black-headed gull (*Larus ridibundus*), carrion crow (*Corvus corone*), large-billed crow (*Corvus macrorhynchos*) and house crow (*Corvus splendens*) with relative abundance 14.56, 10.48, 9.56, 7.46 and 5.00, respectively. Only two critically endangered species were recorded during surveys, sociable lapwing (*Vanellus gregarius*) and white-rumped vulture (*Gyps bengalensis*). Among mammals, order Carnivora exhibited the highest species richness with 15 species followed by Rodentia (14 species). Three endangered species were recorded *viz.*, Indian pangolin (*Manis crassicaudata*), Indian wild dog (*Cuon alpinus*) and Himalayan musk deer (*Moschus moschiferus*). In reptiles twenty species belonged to order Squamata and only one species belonged to order Testudines. All species belonged to order Anura in amphibians.

Three hotspots were identified based on the infrastructure developments in the study area. Hotspot A stretches from upstream of Battagram city of District Battagram up to District Kohistan in the North, all along the River Indus. The area inhabits 201 species (169 birds, 18

mammals, six reptiles and eight amphibians). Hotspot B spreads around Kachura town just downstream of Skardu, all along the River Indus. The area inhabits 79 species (62 birds, 11 mammals, five reptiles and one amphibian). Hotspot C lies upstream of Gilgit covering areas of Jutial and Naltar Valleys, along the Gilgit River. The area inhabits species (90 birds, 12 mammals and two reptiles). Forty-six species are common in these hotspots and can be considered as species of concern as their population may decline due to physical and environmental changes during construction and operation phases of the infrastructure developments (Supplementary Table II).

Table III. Species richness, abundance and diversity indices.

	Rich- ness	Abun- dance	Indices				
			Mar- galef	Men- hinick	Simp- son	Shan- non	Even- ness
Overall	322	22850	31.98	2.13	0.94	3.65	0.63
Birds	242	22487	24.05	1.61	0.96	3.57	0.65
Mammals	47	148	9.21	3.86	0.96	3.49	0.9
Reptiles	21	194	3.80	1.51	0.89	2.43	0.79
Amphibians	12	21	3.61	2.62	0.94	2.37	0.95

Different indices were employed to understand the diversity and habitat associations of the area. The value of Margalef's index for birds was 31.98 referring to high richness while Menhinick's index value was 2.13. The minimum value for this index is one (01) and as the value increases, it corresponds to higher diversity. The indices details are given in Table III. The richness indices, such as Margalef and Menhinick's, offer insights into the diversity of each taxonomic group, indicating higher diversity among birds and mammals. The diversity indices, including the Simpson and Shannon-Weiner indices, suggest that overall species composition is relatively diverse and evenly distributed, with birds exhibiting slightly higher diversity compared to other groups. The Shannon-Weiner index value of 3.65 indicates a high level of diversity in the area.

Sørensen's and Jaccard's similarity coefficients are valuable tools for comparing species associations across different areas/habitats. Given that both Sørensen and Jaccard exhibited similar trends in the raw data (Fig. 2), the discussion will focus solely on Sørensen's coefficient. The habitat associations revealed that based on species composition, agriculture land has a close relationship with bare rock/gravel followed by urban area/settlements (Table IV). Moreover, Alpine grassland was closely related to snow/glaciers and Waterbodies/swamp. The urban area/settlements habitat, having a relatively lower similarity coefficient with other habitats, appears to be

distinct from natural ecosystems. Overall, these similarity coefficients offer insights into the ecological relationships

and associations among different habitats.

Table IV. Habitat associations based on sorenson index.

	Alpine grassland	Bare rock/ Gravel	Snow/ Glacier	Sub-tropical broad leaf	Sub-tropical chir pine	Temperate forest	Urban area/ Settlements	Waterbodies/ swamp
Agriculture land	0.898	0.983	0.883	0.877	0.920	0.974	0.979	0.955
Alpine grassland		0.895	0.984	0.817	0.875	0.915	0.884	0.929
Bare rock / Gravel			0.884	0.860	0.906	0.973	0.968	0.944
Snow/Glacier				0.803	0.858	0.900	0.869	0.917
Sub-tropical broad leaf					0.902	0.883	0.891	0.851
Sub-tropical chir pine						0.926	0.931	0.915
Temperate forest							0.969	0.941
Urban area/ Settlements								0.939

DISCUSSION

Recent studies have improved our understanding of the global impacts of dams and hydropower, aided by emerging databases and maps. However, data limitations, particularly in rapidly developing regions like South Asia's Third Pole, hinder the quality of these analyses. Assessing biodiversity and ecology amid infrastructure development in the Upper Indus Basin (part of South Asia's Third Pole), Pakistan, holds paramount significance due to the region's unique ecological characteristics and the potential environmental impacts associated with large-scale development projects. A comprehensive assessment of biodiversity and ecology was essential to understand the baseline conditions and identify the key habitats. In the Upper Indus Basin. There are a total of around 567 species that can be found, comprising 400 birds, 103 mammals, 48 reptiles, and 16 amphibians according to the guides, Birds of Pakistan (Roberts, 1991, 1992; Mirza and Wasiq, 2007; Grimmett *et al.*, 2008), Mammals of Pakistan (Roberts, 1997) and Amphibians and Reptiles of Pakistan (Khan, 2006). In the course of the surveys conducted, a total of 322 species were observed, encompassing 242 birds, 47 mammals, 21 reptiles, and 12 amphibians. The most abundant bird species included great cormorant (14.56), black-headed gull (10.48), carrion crow (9.56), large-billed crow (7.46) and house crow (5.00) and Ahmad *et al.* (2022) also reported carrion crow (7.48) and larger-billed crow (6.24) as most abundant species of the area between Raikot and Thakot. While Ammanat *et al.* (2022) reported great cormorant (9.36) and carrion crow (5.73) as most abundant species in the area of Dasu Transmission Line (Raikot to Tarbela including the area of Islamabad West Grid Station). We identified three hotspots with 46 common species (forty birds and six mammals) based

on the infrastructure developments in the area. The birds mainly included waterbirds, raptors, pheasants and wheatears. May *et al.* (2021) also suggested that raptors followed by waterfowls were the most affected species specially in terms of collision and barrier during infrastructure developments in Norway. The mammals included common otter (*Lutra lutra*), Himalayan musk deer (*Moschus cupreus*), Himalayan pika (*Ochotona roylei*), Himalayan wood mouse (*Apodemus rusiges*), Turkestan rat (*Rattus turkestanicus*) and house mouse (*Mus musculus*). Common otter and Himalayan musk deer are endangered species and the infrastructure developments can cause further decline in their population. According to Khan *et al.* (2014), musk deer is at the brink of extinction due to exclusion from trophy hunting programs. The decline in musk deer population is not solely attributed to hunting but also to the destruction of their habitat, exacerbated by the growing human and livestock populations in mountainous regions (Nandy *et al.*, 2011, 2015; Navalgund *et al.*, 2019).

These species can be impacted by infrastructure developments either during construction or implementation phase. Ammanat *et al.* (2022) conducted a study on species vulnerable to collisions with the 765 kV Dasu Transmission Line, identifying 27 such species in the area. Of these, 23 species were also observed in the present study. Hydropower projects specially run off river, cause major variations in hydrological as well as ecological conditions (Ullah *et al.*, 2023). The Himalayan-Karakoram-Hindukush region harbors exceptionally diverse and globally significant biodiversity, but the implementation of large-scale hydropower development projects poses a significant threat to the habitats of numerous terrestrial plant and animal species (Sharma and Thakur, 2017). While hydropower has the potential to help address the challenges of climate change and enhance energy security

(Berga, 2016), it must not come at the cost of biodiversity loss (Carolli *et al.*, 2023). Research conducted in the HKH region has indicated that such projects can lead to deforestation, resulting not only in the loss of biodiversity within forest ecosystems but also adversely affecting communities reliant on forests for their livelihoods (Pandit and Grumbine, 2012; Batool and Abbas, 2017). Pandit and Grumbine (2012) predicted that the construction of dams in the Indian Himalayas could lead to the extinction of seven vertebrate taxa. These projects also have the potential to disrupt the habitats of aquatic species, further exacerbating the environmental consequences (Kumar and Katoch, 2014).

Jameel *et al.* (2022) also reported threats to the avian species because of illegal hunting, deforestation and major infrastructure development projects. Moreover, major infrastructure development projects pose multiple threats, encompassing issues such as sound and air pollution, resettlement and relocation of local communities residing near riverbeds (dam reservoirs), and the subsequent encroachment upon the pheasants habitats with higher conservation potential (Awan *et al.*, 2021; Bagaria *et al.*, 2021). The Western Tragopan and Koklass Pheasant, observed in the current study, may face similar risks due to ongoing infrastructure developments in the area. These projects also inflict severe damage upon both the avian population and their respective habitats (Hussain *et al.*, 2019). Moreover, hydropower plants have the adverse effect of interrupting and fragmenting the vast expanse of forest cover, which serves as a crucial predictor for species richness and functional biodiversity (Alho *et al.*, 2019). The construction activities associated with hydroelectric plants, regardless of their size, exert multifaceted impacts on both biodiversity and habitat (Alho, 2020). Habitat destruction and fragmentation can result in a loss of biodiversity as species struggle to find suitable places to live and reproduce, reducing the genetic variability (Valenzuela-Aguayo *et al.*, 2020). This can lead to declines in population sizes, and in some cases, even extinction of certain species (Palmeirim and Gibson, 2021). The forthcoming development of hydropower projects has the potential to impede the achievement of sustainable development goal 6 (clean water and sanitation) and sustainable development goal 15 (life on land) (Opoku, 2019) as it may engender local extinctions of various species, including fish, macroinvertebrates, as well as terrestrial flora and fauna (Hermoso *et al.*, 2019). Given that human well-being is intricately linked to biodiversity and the ecosystem services it provides, the preservation of biodiversity has emerged as a critical factor in attaining sustainable development objectives (Gillespie *et al.*, 2015).

Hydropower projects implemented within the Upper

Indus Basin of Pakistan have far-reaching implications for biodiversity. The construction of dams and reservoirs can alter and diminishes natural habitats, leading to the displacement or loss of local species. This disruption of habitats can disrupt migratory patterns and gene flow, ultimately affecting population dynamics (Alho, 2020). Furthermore, the regulation of water flow for hydropower purposes modifies the natural flow regimes of rivers, potentially causing significant impacts on aquatic ecosystems. Altered water flow patterns, including reduced downstream flow, can have detrimental effects on the availability of suitable habitats for various species (Bagaria *et al.*, 2021). Additionally, hydropower projects influence water quality through processes such as sedimentation, changes in temperature regimes, and alterations in nutrient levels. These combined factors contribute to the overall ecological impact of hydropower projects on the biodiversity of the region. This comprehensive understanding of the ecological dynamics in the region serves as a valuable resource for formulating conservation and management strategies tailored to the diverse habitats present. The research thus contributes significantly to the knowledge base necessary for effective conservation and sustainable development in this ecologically crucial area.

CONCLUSION

In conclusion, the research in the Upper Indus Basin has revealed rich biodiversity and highlighted the importance of balancing development with conservation efforts. By identifying key species and hotspots, the study offers valuable insights for informed decision-making. Prioritizing conservation measures alongside infrastructure development is crucial for maintaining ecosystem integrity and promoting sustainable growth in the region.

DECLARATIONS

Funding

The study did not receive any funding.

Ethical statement

The Advanced Study & Research Board at University of the Punjab, Lahore approved the study (Letter number: 6813/Acad, Dated: 12/07/2021).

Supplementary material

There is supplementary material associated with this article. Access the material online at: <https://dx.doi.org/10.17582/journal.pjz/20240223121505>

Statement of conflict of interest

The authors have declared no conflict of interest.

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