Diversity, evenness, & richness of wild mammals along the Sutlej River, Punjab, Pakistan

Muhammad Amir Sial*

Department of Wildlife & Ecology, University of Veterinary and Animal Sciences, Lahore, Pakistan

Field surveys were conducted at three different water heads—Sulemanki, Islam, and Panjnad—of the Sutlej River from June 2021 to November 2021. This study aimed to estimate the diversity and assess the current threats to the mammalian fauna of the Sutlej River. During the surveys, a total of 266 individuals belonging to four orders, seven families, and twelve different species were observed. The greatest number of individuals belonged to the Rodentia order and the Muridae family. While the lowest number of individuals belonged to the Lagomorpha order and the Leporidae family, both had the same number of individuals. The Panjnad waterhead had the greatest diversity and evenness. The richness of mammals was the same at all three localities. Several threats, such as pollution, habitat destruction, and human–wildlife conflict, which drastically affect mammalian diversity, were observed throughout the investigation.

Introduction

Pakistan is a country with a diverse range of environmental features, including great Himalayan ranges, northern Hindu Kush and Karakorum mountain ranges, deserts, and plains of the Indus River. This geographical diversity supports a wide variety of wildlife habitats and ecosystems, including numerous wetlands and associated flora and fauna (Akhtar et al., 2018). The country is divided into three biogeographic regions—Palearctic, Oriental, and Ethiopian—encompassing eighteen distinct ecological zones, such as alpine meadows, inundation zones, monsoon-influenced subtropical forests, and dry temperate coniferous forests (Sheikh et al., 2009).

Mammals are essential to ecosystems because they perform crucial functions, such as seed dispersal and pollination, and serve as prey for larger carnivores (Jahangeer et al., 2023). Their existence is essential to many ecosystems and greatly enhances sustainability. Furthermore, a variety of mammalian species are beneficial for nutrition, providing important sources of protein for human diets (Altaf et al., 2023). Currently, there are approximately 4763 known mammal species worldwide (Altaf et al., 2014), with Pakistan hosting approximately 195 species (Roberts, 2005). Among these, five species are commonly found in Pakistan, whereas

others are critically endangered or vulnerable (Kanwal and Ashraf, 2021). The remaining species are categorized as follows: twelve are critically endangered (one is endemic), twelve are endangered (all endemic), twenty are vulnerable, one is near threatened (one is endemic), seventy-one is of least concern, thirty-eight are data deficient, and eight are regionally extinct. Additionally, two species have not been evaluated (Akhtar et al., 2018).

In Pakistan, preferred habitats vary among species. For example, northern palm squirrels (*Funambulus pennantii)* thrive in peri-urban areas (Altaf et al., 2012). The Indian hare (*Lepus nigricollis dayanus*) is found mainly in open grassy areas and cultivated plains (van der Geer, 2008), and small Indian mongooses (*Herpestes javanicus*) prefer agricultural surroundings (Safeer et al., 2018). Indian Grey Mongoose (*Herpestes edwardsii*) inhabit a variety of environments, including open spaces, agricultural areas, scrub jungles, mountain forests, arid deserts, and plains (Rajashekara and Venkatesha, 2015). This highlights the need for effective biodiversity management to combat threats such as habitat loss and fragmentation (Altaf et al., 2014).

The first step in protecting or conserving mammal species is gathering data on the diversity and distribution of mammals (Altaf et al., 2023). Species diversity is primarily composed of richness, the total number of species in a specific area, and evenness, the distribution of relative abundance among species. Diversity indices, which include both of these components, are valid indicators of an ecosystem's overall functioning or health. Diversity monitoring is important because it illustrates how human activity affects the environment (Christie et al., 2019).

The measurement of diversity is fundamental for understanding the relationships between species and their environments. Richness, which counts the number of different species in a habitat, and evenness, which assesses how individuals are distributed among those species, help ecologists identify patterns and processes within ecosystems (Harrison and Sin, 2006). High species richness typically indicates a more diverse and resilient ecosystem, whereas low richness can indicate ecological decline or habitat degradation (Morris et al., 2014). Evenness, on the other hand, assesses the distribution of individuals among different species, providing insights into community structure (Izsák and Papp, 2000). The integration of richness and evenness indices into ecosystem management plans allows for a more informed approach to resource use and conservation (Stirling and Wilsey, 2001). By comparing these indices across different time periods, researchers can identify trends in species populations, including declines or surges that may indicate ecological disturbances (MacDonald et al., 2017). Such monitoring is crucial for evaluating the effectiveness of conservation strategies and adapting them as necessary (Roberts, 2019).

This study was the first effort to investigate the natural mammalian diversity of the Sutlej River and assess the current threats to the wild mammalian fauna of different localities of the Sutlej River.
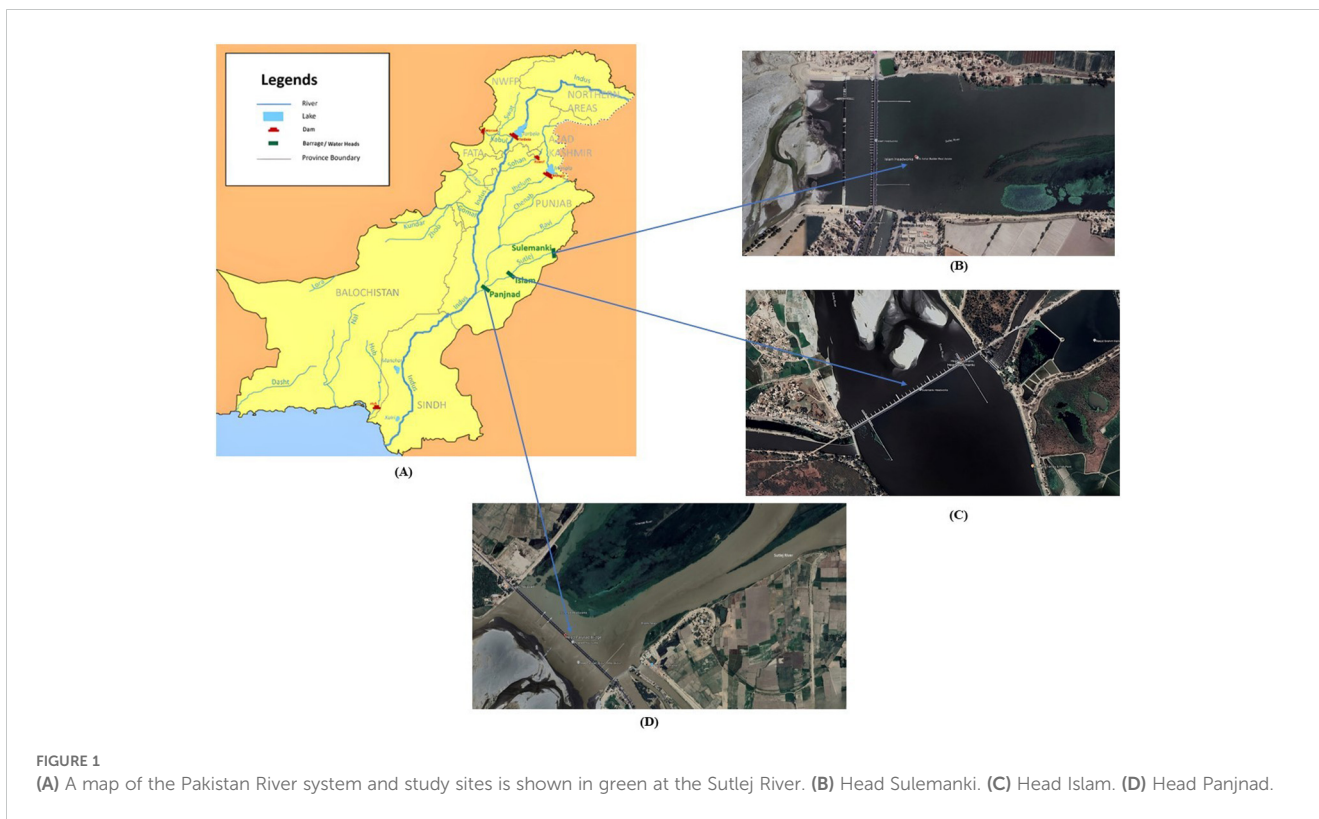
Materials and methods

Study area

The research was conducted from June 2021 to November 2021 at three water heads along the Sutlej River: Sulemanki, Islam, and Panjnad (Table 1) (Figures 1A–D). Water arrives from India via the Sulemanki waterhead, travels to Islam, and then moves to the Panjnad water head, which resides close to the Pakistan–India border. There are four distinct seasons in the area's micro- and mesothermal climates: the hot season, the season of blooming, the cold season, and the fall season. The annual average temperature ranges from 4°C in the winter to 50°C in the summer. River water has an average pH of 7.8, which is alkaline (Anjum et al., 2023). All three river head works fall under the plain area of Punjab, and most of the area around all the headworks has been turned into cultivated land, some of which are present in basins of rivers and dry regions such as islands. In the research region, reeds (*Phragmites karka*), water lilies (*Nymphaea lotus*) and lesser Indian reed mace (*Typha angustata*) are prominent aquatic plant groups. (*Zzyphus mauritiana*) Indian plum, goosegrass (*Eleusine compressa*) and Athel (*Tamarix aphylla*) are among the significant native plants found in nearby plains.

Methodology

The diversity of the mammalian fauna in the study area was estimated via a linear count survey approach with a combination of direct (e.g., physical counting) and indirect (e.g., voices, nests, feces pellets, tree markings, collective question sheet surveys, and footprints) approaches to determine the diversity of mammals in the research area (Altaf et al., 2023). To estimate the number of individuals in each study area, vocalizations were analyzed, active nests were counted, and fecal matter and footprints were assessed. Vocalizations were mapped to distinguish individual calls, whereas nest counts were supplemented with species-specific family size data. The density of feces and tracks was used alongside known territory sizes to derive accurate population estimates. Specimen observations were conducted via field Landscout (10 × 50 mm) Porro binoculer, and the species was accurately identified by consulting field guides (Roberts, 2005).

TABLE 1 Research sites along the Sutlej River.

Sr No.	Water Head	Coordinates	Elevation	Wetland Area
1	Sulemanki	30°22'55"N, 73°51'43"E	199 m	250 ha
2	Islam	29°49'35"N, 72°32'55"E	145 m	150 ha
3	Panjnad	29°21'07"N, 71°01'34"E	100 m	1926.8 ha

FIGURE 1
(A) A map of the Pakistan River system and study sites is shown in green at the Sutlej River. **(B)** Head Sulemanki. **(C)** Head Islam. **(D)** Head Panjnad.

Analysis of data

To perform the data analysis, various diversity indices were used to determine the various levels of diversity. The different levels of diversity in a specific research area were determined via the Margalef Richness, Shannon–Wiener, and species evenness indices.

Index of diversity

The Shannon–Wiener diversity index was used to determine the diversity of the present research site. The main objective of this index is to ascertain the dispersal of mammal species among reported varieties (Sial, 2024b).

$$H' = -\sum [pi \times \ln(pi)]$$

where H' is the index of diversity and $\ln(pi)$ represents the natural logarithm of the proportion (pi) of individuals of species i. pi is the proportion of individuals of species i to the total number of individuals, calculated as pi=ni/N, and ni is the total number of individuals of each species variety i and N is the total number of identified individuals of all species in the community. The requirements of the diversity index values are provided in Table 2.

Richness index

The richness of species can be determined by using the Margalef index (R). The total number of individuals in a population is called its richness, and the number of individuals depends on the size of the sample region and the time required to reach it (Sial, 2024b).

$$R = (S - 1)(1)/\ln N$$

where S is the number of detected species, ln is the value of the natural logarithm, N is the number of reported individuals of all species, and R is the Margalef index of species richness. The requirements of the richness index values are provided in Table 3.

Index of evenness

The evenness index can be determined via the Magurran equation (Sial, 2024a).

$$E = \frac{H'}{\ln(S)}$$

where S is the overall number of species, ln is the natural logarithm, H' is the estimated Shannon–Wiener diversity index,

TABLE 2 Requirements of index (diversity) values.

Index standards	Categorizations
If H' is< than one	Indicates the level of diversity is lower
H' > one but< three	Indicates diversity is medium
H' > three	Shows diversity is greater

TABLE 3 Requirements of index (richness) values.

Index standards	Categorizations
R value is< than 2.5	Shows low richness of species
R value is > than 2.5 but< than 4	Indicates richness is medium
R is > than 4	Shows high richness of species

and E is the evenness index. The requirements of the richness index values are provided in Table 4.

Threat identification

Threats to mammal diversity, including habitat destruction, human–wildlife conflict and pollution, were identified through a combination of direct field observations and community surveys. Habitat destruction and human–wildlife conflict were measured via surveys and questionnaires in the local community at the research sites, and the questionnaires included specific questions such as their education level and source of living. The threats were categorized into high, medium, and low levels on the basis of their reported frequency of answers. The habitat destruction threat is measured via field surveys and real-time observations, and this threat is categorize on the basis of diversity index values. The pollution threat is measured by assessing the pH of river water and the presence of heavy metals and toxic chemicals, and this threat is characterized as high, medium or low on the basis of the amount of chemicals and pH.

Results

The study sites included wetland ecosystems, natural plantations, terrestrial ecosystems, and irrigation canals. These environments provide food and habitat, sustaining diverse mammalian populations. In this study, 266 individuals belonging to 12 different species, 7 families, and 4 orders were recorded (Table 5). The Rodentia order had the most individuals (n=144), whereas Lagomorpha had the fewest number of individuals (n=9) (Figure 2). The Muridae family had the maximum number of individuals (n=107), and Leporidae had the minimum number of individuals (n=9). The Herpestidae family was reported only from Head Islam and Panjnad (Figure 3). In terms of their feeding habits, omnivorous mammal species individuals (n=212) were the most common, and carnivorous mammal species individuals (n=13) were the least common and were observed only at Head Islam and Panjnad (Figure 4). The wild boar species had the greatest number of individuals, and the small Indian mango species had the lowest number of individuals recorded from different research sites (Figure 5). According to the IUCN Red List, all the species observed during the study are classified as least concerning (Table 5). The Shannon–Wiener indices for Sulmanki, Islam, and Panjnad were 2.20, 2.13, and 2.45, respectively. The species richness index was 1.61 at all three sites. The species evenness values at

TABLE 4 Requirements of index (evenness) values.

Index standards	Categorizations
When E get closer to zero	Individuals of a species do not show an equal distribution.
When E get closer to one	Individuals of a species show an equal distribution.

Sulmanki, Islam, and Panjnad were 0.95, 0.92, and 1.00, respectively. Most of the area at the research site was agricultural land, which fragmented the land and contributed to greater evenness in the mammal community. Despite some species having more individuals, the overall distribution was balanced across species. No single species dominated, as most had similar proportions of the total individuals. According to the results of this research, the Sutlej River has a moderately stable and relatively balanced ecosystem, which is attributed to high evenness and medium species diversity. However, its low species richness indicates a simplified ecosystem with less complexity.

Threats

During research, habitat degradation, pollution, and conflicts between humans and wildlife are common threats. These factors disturb species richness and diversity as well as degrade the riverine habitat areas at the study sites, and in the future, species richness and diversity will both be disrupted if appropriate action is not taken promptly (Table 6).

Habitat destruction

This threat is assessed on the basis of mammal diversity, population level and real-time observations at survey sites, which help to classify this threat. Due to the medium level of mammal diversity and the low population at the survey sites, this threat was classified as high. The human population, which leads to more infrastructure, such as traffic roads or highways, the construction of public parks and buildings and railway lines near the study areas, eventually causes habitat loss and reduces the available space and resources for mammalian species. If timely measures are not taken, populations of certain mammal species, such as the Indian hare (*Lepus nigricollis dayanus*), small Indian mongoose (*Herpestes auropunctatus*) and Indian gray mongoose (*Herpestes edwardsii*), may decline or become locally vulnerable in the future.

Human–wildlife conflict

This factor was measured via surveys and questionnaires in the local community at the research sites, and the questionnaires included specific questions such as their education and source of living or economic situation. According to the surveys, only 14% of the residents at all three waterhead sites had an initial level of education, although the majority of the residents (86%) were uneducated. Owing to a low level of literacy, the locals were unaware of the importance of wild mammalian species and were ignorant about sustainable management techniques. Moreover, species such as the Indian wild boar and Bengal fox can conflict with humans over resources such as crops or livestock. This can lead to revengeful killings and habitat disturbances, which impact the populations of these species. The poor economic situation of the local households at all the study sites is due to
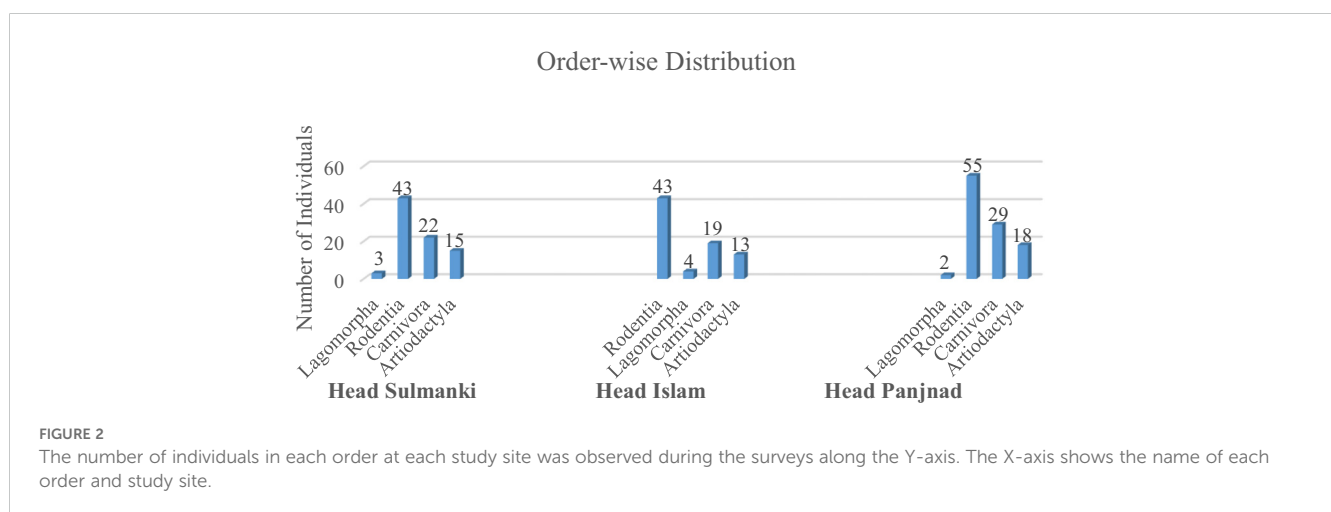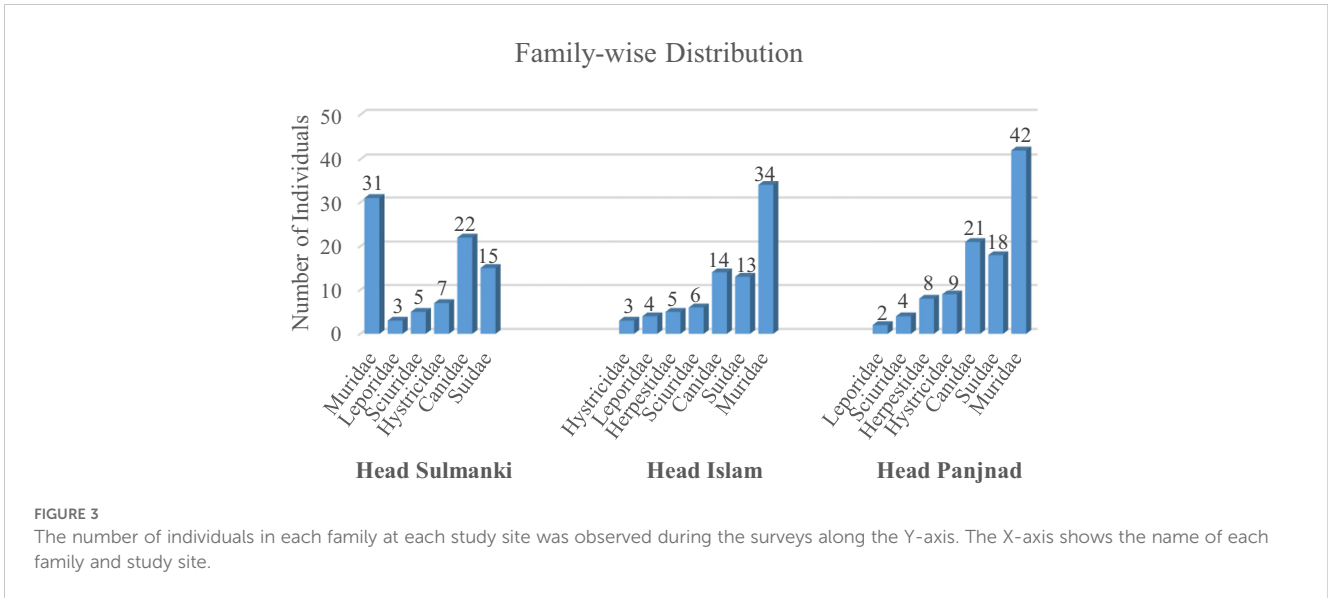
TABLE 5 Recorded data of the mammalian species observed during Sutlej River surveys.

Serial numbers	Common Names	Scientific Name	Order	Family	IUCN Status	Feeding Habit	Locations	Numbers of individuals
1	Indian hare	*Lepus nigricollis dayanus*	Lagomorpha	Leporidae	Least Concern	Herbivorous	Sulmanki, Islam, Panjnad	3, 4, 2
2	Short tailed bandicoot rate	*Nesokia indica*	Rodentia	Muridae	Least Concern	Herbivorous	Sulmanki, Islam,	4, 9
3	Five-striped Palm Squirrel	*Funnambulus pennantii*	Rodentia	Sciuridae	Least Concern	Omnivorous	Sulmanki, Islam, Panjnad	5, 6, 4
4	Indian crested porcupine	*Hystrix indica*	Rodentia	Hystricidae	Least Concern	Herbivorous	Sulmanki, Islam, Panjnad	7, 3, 9
5	House rat	*Rattus rattus*	Rodentia	Muridae	Least Concern	Omnivorous	Sulmanki, Islam, Panjnad	8, 10, 14
6	Golden/ Asiatic jackal	*Canis aureus*	Carnivora	Canidae	Least Concern	Omnivorous	Sulmanki, Islam, Panjnad	8, 8, 10
7	House mouse	*Mus musculus*	Rodentia	Muridae	Least Concern	Omnivorous	Sulmanki, Islam, Panjnad	9, 15, 16
8	Indian gerbil	*Tatera indica*	Rodentia	Muridae	Least Concern	Omnivorous	Sulmanki, Panjnad	10, 12
9	Indian/Bengal fox	*Vulpes bengalensis*	Carnivora	Canidae	Least Concern	Omnivorous	Sulmanki, Islam, Panjnad	14, 6, 11
10	Indian wild boar	*Sus scrofa*	Artiodactyla	Suidae	Least Concern	Omnivorous	Sulmanki, Islam, Panjnad	15, 13, 18
11	Indian grey mongoose	*Herpestes edwardsii*	Carnivora	Herpestidae	Least Concern	Carnivorous	Panjnad	8
12	Small Indian mongoose	*Herpestes auropunctatus*	Carnivora	Herpestidae	Least Concern	Carnivorous	Islam	5
								Σ=266

multiple factors, such as political unrest and the lack of earning sources in all the research areas. Therefore, they strongly rely on biodiversity for survival and well-being; they engage in the illegal hunting or poaching of mammals, such as Indian crested porcupine, Indian wild boar, and Asiatic jackal, which are targeted by poachers or hunters either for their meat or fur or as pests. Unsustainable hunting practices can lead to a decline in the population, species richness, and diversity of wild mammals.

FIGURE 2
The number of individuals in each order at each study site was observed during the surveys along the Y-axis. The X-axis shows the name of each order and study site.

FIGURE 3
The number of individuals in each family at each study site was observed during the surveys along the Y-axis. The X-axis shows the name of each family and study site.

Pollution

The Environmental Protection Agency (EPA) and World Health Organization (WHO) guidelines define the level of pollution. Owing to the slightly alkaline pH of river water and the presence of heavy metals in river soil and water, low pollution levels are classified according to guidelines. Owing to the lack of sustainable management and the lack of an agricultural waste management system, all the waste released in rivers increases the toxic chemical level, heavy metal level, and pH (alkalinity) level due to agricultural fertilizers and artificial pesticides, which directly or indirectly affects mammal species through their aquatic food sources. Chemical pollutants and heavy metals bioaccumulate in mammalian species through the environment, causing health diseases and decreasing species richness.

Discussion

This study, the first to estimate mammalian diversity and assess threats along the Sutlej River, indicates a moderately stable ecosystem with high evenness and moderate species diversity but low species richness, suggesting a simplified ecosystem. The dominance of Rodentia and the scarcity of Lagomorpha are associated with global patterns, reflecting a uniform distribution crucial for ecosystem health. However, threats such as habitat degradation, pollution, and human−wildlife conflict disturb the ecological balance. Habitat degradation from agricultural expansion and infrastructure development results in the significant loss of natural habitats. Pollution from agricultural runoff and industrial activities contaminates water and degrades habitat quality. Human−wildlife conflicts, especially near

FIGURE 4
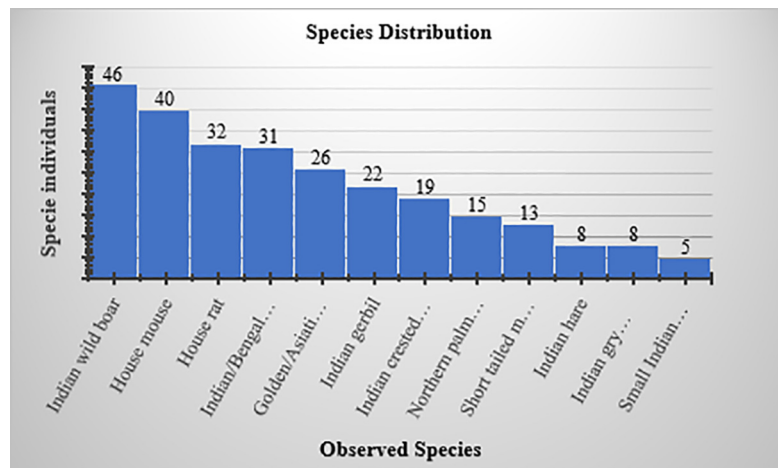Mammalian individuals classified according to their feeding habits.
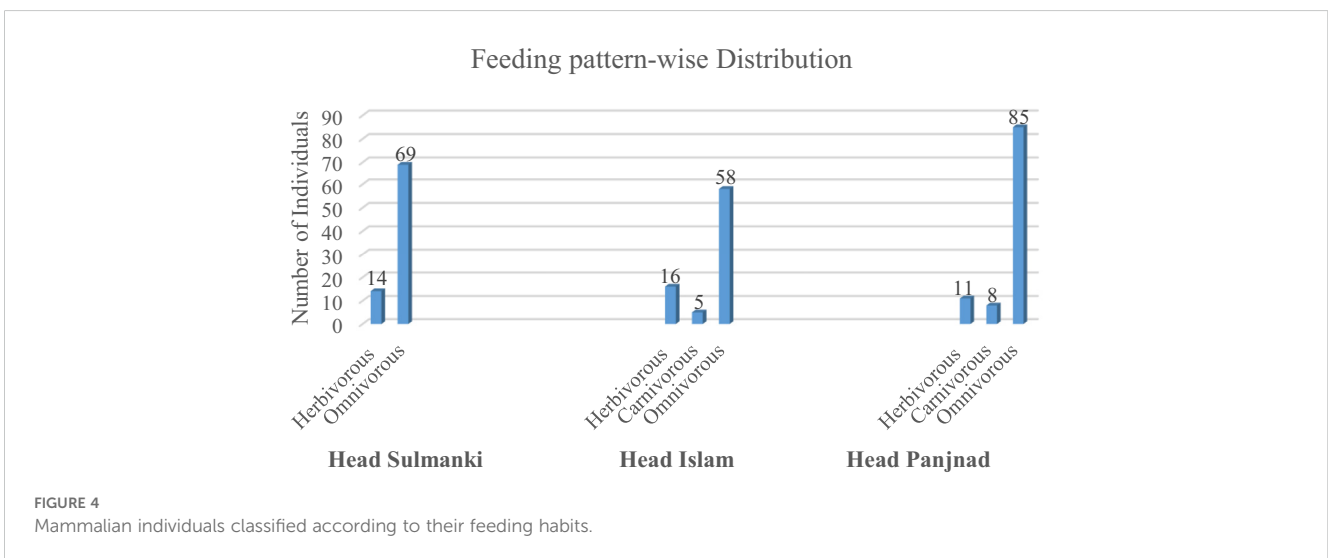
FIGURE 5
Overall abundance of recorded mammal species.

settlements, threaten both wildlife and local communities, often leading to wildlife persecution and species decline. To mitigate these threats, effective management strategies are essential. Establishing protected areas and community-based conservation programs can help. Ongoing monitoring and further studies are recommended to track changes in mammalian diversity and assess conservation efforts. Public awareness and education programs are crucial for emphasizing the importance of biodiversity and the need for conservation. Overall, this study highlights the need to preserve mammalian diversity along the Sutlej River. In the future, addressing identified threats and implementing conservation measures are vital for maintaining resilient ecosystems that support diverse mammalian species.

The species diversity of mammals of the Mahaban and Malka valleys in the Buner district, Khaber Pakhtunkhwa, was investigated from October 2015 to October 2016. Shalhodabuna, Muhammad Baig, Sharra, Hanjar, Shahkot and Hkar gata were the six localities that collectively made up the study area. Ten distinct species of mammals from five orders, nine families, and ten genera were identified during this investigation. *Nemorhedus goral*, *Myotis*, *Macaca mulatta*, *Vulpes vulpes*, *Panthera pardus*, *Herpestes edwardsii*, *Lepus nigricollis*, and *Sus scrofa* and *Hystrix indica* are the species that have been identified (Akhtar et al., 2018). *Hystrix indica*, *Sus scrofa* and *Herpestes edwardsii* are common species that were also found in the present study because their ecological generalists and Habitats similarities, such as their vegetation and water sources. Wild boars are highly adaptable pest species that often propagate in almost all types of habitats, including plains, swamps, mountains, coastal areas, and almost all kinds of forests (Khattak et al., 2021).

To identify mammalian species, research was conducted in the Khirthar Protected Area Complex between 2010 and 2011. There were 33 different species of mammals identified. The most reported Muridae family included the (*Lepus nigricollis dayanus*) Indian hare, (*Vulpes bengalensis*) Indian fox, (*Mus musculus*) house mouse, (*Tatera indica*) Indian gerbil, (*Rattus rattus*) house rat, (*Hystrix indica*) Indian crested porcupine, (*Canis aureus*) Asiatic jackal and (*Funnambulus pennantii*) soft-furred field rat. Overall, thirty-three mammalian species have been documented (Khan et al., 2013). These common species are also native to the Sutlej River. The most reported orders are Rodentia and Carnivora, which are also the same as those in the current study. These mammals occur in different habitats because of their wide geographical range across the Indian subcontinent and their adaptability to various habitats (Singh, 2013).

The study was carried out in the environment of Chinji National Park in Chakwal, Punjab, Pakistan, from October 2017 to July 2018. Twenty-two species from 15 families and 6 orders were found in the research region. The Muridae family is one of the prominent families, while the Carnivora and Rodentia orders are the most dominant. The Shannon–Weiner diversity index of 0.91, evenness of 0.77, and Margalef index of 5.31 indicated that the main species in the research region were Asiatic jackal (*Canis aureus*) and the dessert hare (*Lepus nigricollis*). This study focused on protected areas with established conservation frameworks. They present relatively high evenness and richness but low species diversity due to relatively high anthropogenic effects, such as illegal hunting, agriculture and industrial development, which are also assessed in current studies investigating unprotected riverine ecosystems (Kanwal and Ashraf, 2021).

To determine the variety of mammalian fauna, research was performed at the head of Qadirabad (SA3), the Khanki waterhead (SA2), and the Marala water head (SA1), which are significant wetland locations on the Chenab River. In the study region, 15 species from 6 orders, 10 families, and 14 genera were identified

TABLE 6 Threats identified at the Sutlej River research sites were categorized as high, medium, or low on the basis of their impact on mammalian species diversity.

Threats	High	Medium	Low
Habitat destruction	●		
Human–Wildlife conflict	●		
Pollution			●

between May 2009 and April 2010. The richness was 0.86 at Marala head, 0.97 at Khanki head, and 6.61 at Qadirabad head; the evenness values were 0.20 (SA1), 0.39 (SA2), and 0.38 (SA2), respectively. The diversity indices for Marala head, Khanki head, and Qadirabad head were 0.86, 0.97, and 0.97, respectively. *Sus scrofa* (Indian wild boars) and *Herpestes javanicus* (Littel Indian mongooses) were the most common species at the research sites. It is a river ecosystem study and has almost the same ecological conditions as the Sutlej River; therefore, this research shows many similar species and reports almost the same threats, but the rates of these threats are higher than those of the Sutlej River threats. Therefore, this study depicts different index values than the current study does (Altaf et al., 2014).

The field surveys were carried out in October and December 2015 to investigate the diversity of mammals in Lal Suhanra National Park (LSNP) in Bahawalpur. Seventeen different species of mammals were identified in this study, including the (*Vulpes bengalensis*) Jungle Fox, (*Herpestes edwardsii*) Indian Gray Mongoose, (*Lepus tibetanus*) Desert Hare, (*Antilope cervicapra*) Black Buck, (*Canis aureus*) Golden Jackal, (*Sus scrofa*) Wild Boar, (*Hystrix indica*) Indian Crested Porcupine, (*Hemiechinus auritus*) Long-Eared Hedgehog, and (*Nesokia indica*) Sand-Tailed Mole Rat. This is a study of protected areas in which most mammal species are the same as those in the present study because of their geographical range (Khan et al., 2018).

According to the global results, carnivores are proportionally more threatened and declining than are all mammals in general (26.9% of threatened species and 48.3% of declining species). In the last update of the Red List Index, carnivores are more threatened (i.e., have lower index values) than mammals in general. However, 31.4% of herpestidae family members show an overall decline in their populations (Fernandez-Sepulveda and Martín, 2022). These results align with the findings of the current study of mammal diversity in the Sutlej River because, in the present study, carnivorous species such as *Herpestes edwardsii* and *Herpestes auropunctatus* were recorded in relatively low numbers, and both belong to the Herpestidae family. Information on the risk of extinction and population trends of species are two key factors in the conservation of global biodiversity (Ceballos et al., 2017). The global loss of carnivores is alarming for several reasons. Carnivores play a crucial role in ecosystems by regulating species populations, and their decline can disrupt ecosystem integrity (Ripple et al., 2014). Additionally, their loss can negatively impact human well-being by reducing ecosystem services such as waste disposal, zoonotic disease control, herbivore control, and increased crop production (O'Bryan et al., 2018).

Conclusion

In the various localities along the Sutlej River, 12 distinct mammal species have been identified. These areas primarily consist of wetlands and thin vegetation in the surrounding areas. Moreover, the Sutlej River features several different barrages and water headworks, with additional canals branching off to irrigate surrounding agricultural land (thin vegitation) with water from these headworks. Hence, the study location is deemed to offer a favorable habitat for mammals. With more time and effort devoted to data collection, more species are expected to be discovered. The recorded mammalian species were observed across three different areas, suggesting a moderate level of species diversity and a moderately stable ecosystem within the research site. This conclusion is supported by the overall results of the different diversity indices, which indicate medium diversity, low species richness and high evenness. Regular monitoring through ongoing studies will help assess any changes in mammalian species diversity, evenness, and richness along the Sutlej River, providing valuable insights into the stability of these ecosystems.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because my research is not based on any trial based and no animal is directly or indirectly used. it is a survey-based study.

Author contributions

MS: Conceptualization, Investigation, Software, Writing – original draft, Writing – review & editing.

Funding

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Akhtar, N., Muhammad, R., Saeed, K., Khan, M. F., Shah, M., Zeb, J., et al. (2018). Distribution of wild mammalian fauna of Mahaban and Malka Valley District Buner. *Pakistan J. Zoology* 50, 775–777. doi: 10.17582/journal.pjz/2018.50.2.sc4

Altaf, M., Javid, A., Khan, A. M., Nazer, S., Iqbal, K. J., Haider, M. S., et al. (2023). Habitat preferences of wild mammalian species around river Chenab in Sialkot, Gujrat and Gujranwala Districts, Punjab, Pakistan. *Pakistan J. Zoology* 55, 1–7. doi: 10.17582/journal.pjz/20190922190944

Altaf, M., Javid, A., Munir, M., Ashraf, S., Umair, M., Iqbal, K., et al. (2014). Diversity of wild mammalian fauna of Chenab riverine forest, Punjab, Pakistan. *JAPS: J. Anim. Plant Sci.* 24, 1342–1347.

Altaf, M., Khan, A., Umair, M., and Irfan, M. (2012). Status of wild birds and mammals in urban habitats of Gujranwala, Punjab, Pakistan. *Punjab Univ. J. Zoology* 27, 9–12.

Anjum, S., Syeda, A. H., Jabeen, M., Zafar, A. M., Shaheen, A., and Arshad, M. (2023). Physiochemical analysis of river Sutlej, Sindh and the Arabian Sea to evaluate the water quality. *Pakistan J. Analytical Environ. Chem.* 24, 74–85. doi: 10.21743/pjaec/2023.06.07

Ceballos, G., Ehrlich, P. R., and Dirzo, R. (2017). Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proc. Natl. Acad. Sci.* 114, E6089–E6096. doi: 10.1073/pnas.1704949114

Christie, A. P., Amano, T., Martin, P. A., Shackelford, G. E., Simmons, B. I., and Sutherland, W. J. (2019). Simple study designs in ecology produce inaccurate estimates of biodiversity responses. *J. Appl. Ecol.* 56, 2742–2754. doi: 10.1111/1365-2664.13499

Fernandez-Sepulveda, J., and Martín, C. A. (2022). Conservation status of the world's carnivorous mammals (order Carnivora). *Mamm. Biol.* 102, 1911–1925. doi: 10.1007/s42991-022-00305-8

Harrison, D. A., and Sin, H. (2006). "What is diversity and how should it be measured," in *Handbook of Workplace Diversity* (London: Sage Publishing), 191–216.

Izsák, J., and Papp, L. (2000). A link between ecological diversity indices and measures of biodiversity. *Ecol. Model.* 130, 151–156. doi: 10.1016/S0304-3800(00)00203-9

Jahangeer, M., Awan, M. S., and Minhas, R. A. (2023). Diversity distribution, land used type of small and medium-sized mammals in ghamot national park the state biosphere reserve-Neelum, Pakistan. *World J. Biol. Biotechnol.* 8, 29–33. doi: 10.33865/wjb.008.03.1120

Kanwal, R., and Ashraf, S. (2021). Diversity and density of mammals in Chinji National Park, district. *Int. J. For. Sci.* 1, 1–11.

Khan, B., Ahmad, R., Ali, Z., Yasmeen, R., Azhar, M., Abid, F., et al. (2018). Study of vertebrate diversity at Lal Suhanra National Park, Pakistan. *JAPS: J. Anim. Plant Sci.* 28, 1725–1734.

Khan, M. Z., Ghalib, S. A., Khan, A. R., Zehra, A., Yasmeen, R., Hussain, B., et al. (2013). Current habitat, distribution and status of the mammals of Khirthar protected area complex, Sindh. *Can. J. Pure Appl. Sci.* 7, 2347–2356.

Khattak, R. H., Liu, Z., Teng, L., and Ur Rehman, E. (2021). The wild mammalian fauna of Nowshera District Khyber Pakhtunkhwa, Pakistan. *Pakistan J. Zoology*. 54(2), 721–727. doi: 10.17582/journal.pjz/20200519200539

MacDonald, Z. G., Nielsen, S. E., and Acorn, J. H. (2017). Negative relationships between species richness and evenness render common diversity indices inadequate for assessing long-term trends in butterfly diversity. *Biodiversity Conserv.* 26, 617–629. doi: 10.1007/s10531-016-1261-0

Morris, E. K., Caruso, T., Buscot, F., Fischer, M., Hancock, C., Maier, T. S., et al. (2014). Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. *Ecol. Evol.* 4, 3514–3524. doi: 10.1002/ece3.2014.4.issue-18

O'Bryan, C. J., Braczkowski, A. R., Beyer, H. L., Carter, N. H., Watson, J. E., and McDonald-Madden, E. (2018). The contribution of predators and scavengers to human well-being. *Nat. Ecol. Evol.* 2, 229–236. doi: 10.1038/s41559-017-0421-2

Rajashekara, S., and Venkatesha, M. (2015). Abundance of Indian grey mongoose herpestes edwardsii (É. Geoffroy saint-hilaire 1818)(Carnivora: herpestidae) in the Bengaluru region. *Zoo's Print* 30, 6–12.

Ripple, W. J., Estes, J. A., Beschta, R. L., Wilmers, C. C., Ritchie, E. G., Hebblewhite, M., et al. (2014). Status and ecological effects of the world's largest carnivores. *Science* 343, 1241484. doi: 10.1126/science.1241484

Roberts, T. J. (2005). *Field Guide to the Large and Medium-Sized Mammals of Pakistan* (Karachi, Pakistan: Oxford University Press).

Roberts, F. S. (2019). "Measurement of biodiversity: richness and evenness," in *Mathematics of Planet Earth: Protecting Our Planet, Learning from the Past, Safeguarding for the Future* (Switzerland: Springer Link), 203–224.

Safeer, B., Rasheed, Z., Altaf, M., Manzoor, I., and Yasrub, S. (2018). Assessment of human-Indian crested porcupine (Hystrix indica) conflict in district Bagh, Azad Jammu and Kashmir. *J. Wildlife Ecol.* 2, 01–12.

Sheikh, M. M., Manzoor, N., Adnan, M., Ashraf, J., and Khan, A. (2009). Climate profile and past climate changes in Pakistan. *Global Change Impact Stud. Center (GCISC)-RR-01*, 1–189.

Sial, M. A. (2024a). Diversity, richness, and evenness of birds in Rana Resort Forest, District Kasur, Punjab, Pakistan. *Environ. Monit. Assess.* 196, 460. doi: 10.1007/s10661-024-12596-0

Sial, M. A. (2024b). Ornithofauna diversity of tehsil Pakpattan, Punjab, Pakistan. *J. Bioresource Manage.* 11, 13. doi: 10.11648/j.eeb.20240901.13

Singh, M. (2013). *Mammals of South Asia*, (India: Universities Press), Vol. 1.

Stirling, G., and Wilsey, B. (2001). Empirical relationships between species richness, evenness, and proportional diversity. *Am. Nat.* 158, 286–299. doi: 10.1086/321317

van der Geer, A. (2008). "nigricollis, the Indian hare," in *Animals in Stone* (Boston: Brill), 324–327.