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Diversity and Habitat of Waterfowl in the Wetland Ecosystems of Bajaur and Kurram Districts, Pakistan

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SUMMARY

This study assessed the species diversity, habitat distribution, and conservation challenges of waterfowl in Bajaur and Kurram Districts of Khyber Pakhtunkhwa, Pakistan. The point transect sampling method was used to conduct the survey. Kernel Density Estimation (KDE) was used to calculate point density of waterfowl observations and point density of water bodies. Heatmaps were used to visualize observed and potential habitats. During the survey, 71 waterfowl from 5 species were sighted in Bajaur. In Kurram, 33 waterfowl from 7 species were observed. The Common Teal (*Anas crecca*) was the most abundant species sighted in both districts. Hunters from the local communities reported 14 different species of waterfowl in Bajaur and 16 in Kurram, including the Vulnerable Ferruginous Duck (*Aythya nyroca*). They also perceived the Common Mallard (*Anas platyrhynchos*) as the most at-risk species in both districts. Overall, Kurram was found to have greater species diversity and a more balanced distribution compared to Bajaur. High probability zones for waterfowl occurrence were calculated as 14.63 km² in Bajaur and 18.44 km^2 in Kurram, while low probability zones were 54.85 km² and 168.1 km², respectively. Major hotspots were Raghagan and Talay Dam in Bajaur, and Munda and Malikhel Dam in Kurram. The perceived abundance of waterfowl had declined as there were significant reductions in the number of waterfowl hunted overall compared to the previous year. Illegal hunting and urbanization were seen as major threats. Conservation efforts were ineffective in enforcing sustainable hunting practices. Reduced anthropogenic disturbances during lockdowns caused by the Coronavirus pandemic were perceived as beneficial to waterfowl populations, which indicates the benefits of reduced human disturbances in wildlife habitats. Engagement with locals and enforcement of sustainable, community-based wildlife management practices are needed for effective conservation. Hotspots identified during the study must be developed into wildlife reserved areas with stricter hunting regulations.

Keywords: Biodiversity, Conservation, GIS, Waterfowl, Wetlands

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INTRODUCTION

Waterfowl are aquatic birds within the order Anseriformes, which includes three families: Anatidae (ducks, geese, and swans), Anseranatidae (magpie geese), and Anhimidae (screamers) (Owen and Black, 1990). The families Podicipedidae (grebes) and Rallidae (coots) are not related to Anseriformes but are often included in broader definitions of waterfowl and frequently featured in waterfowl surveys (Akbar et al., 2006). There are over 170 waterfowl species worldwide and 32 documented in Pakistan (Dalby et al., 2014; Tasleem, 2021). Waterfowl inhabit a diverse range of freshwater and coastal ecosystems, including wetlands, estuaries, and shallow-water habitats (Erwin, 1996; Kingsford and Norman, 2002). The majority of waterfowl species belong to the Anatidae family, which includes 169 species and 48 taxa, mostly originating from the Northern Hemisphere (Livezey, 1997). 28.4% of these species have been classified as threatened by the IUCN (International Union for Conservation of Nature) (Kear, 2005). Waterfowl species show seasonal migratory behavior, traveling thousands of kilometers between breeding and wintering grounds (Åkesson, 2003). Seasonal migration is crucial for their reproduction (Stafford et al., 2014). These birds play essential ecological roles, contributing to seed dispersal, nutrient cycling, and maintaining ecosystem balance by feeding on aquatic plants and invertebrates (Green and Elmberg, 2014). Their foraging habits control insect populations and help in pest management (Rohrer, 2021). Waterfowl are bioindicators of environmental health, indicating changes in wetland ecosystems due to habitat alterations (Amat and Green, 2010) . Waterfowl contribute to recreation industries such as hunting and birdwatching. In the United States, waterfowl hunting generated $1.5 billion in expenditures in 2011 and provided thousands of employment opportunities (U.S. Fish and Wildlife Service, 2011). Preserving wetlands and crucial breeding habitats for waterfowl, is essential to sustaining these economic benefits (Gan and Luzar, 1993; U.S. Fish & Wildlife Service, 2020). Waterfowl face substantial threats globally, including illegal hunting, habitat loss, and climate change (Brandis et al., 2019; Kamp et al., 2015). Unregulated hunting and overharvesting are among the leading causes of population decline (Kamp et al., 2015; Rija et al., 2020). Habitat degradation and water pollution, particularly of wetlands, further exacerbate these declines (Long et al., 2007).

In Pakistan's Khyber Pakhtunkhwa region, particularly in District Bajaur and District Kurram, there is a notable research gap concerning the habitat and species diversity of waterfowl. The region lies along the International Migratory Bird Route Number 4, or the Indus Flyway, a vital migratory route for birds traveling from Siberia to Pakistan (Umar et al., 2018). High-altitude wetlands in these areas are understudied despite their importance as migratory stopovers and breeding sites (Khan and Baig, 2017). Advancements in Geographic Information System (GIS) and Remote Sensing (RS) technologies provide new opportunities for improved wildlife habitat assessments (Kushwaha and Roy, 2002). Techniques such as Kernel Density Estimation (KDE) can identify critical conservation areas by analyzing spatial patterns in waterfowl observations (Sussman et al., 2019). Remote sensing and GIS techniques have been employed to evaluate habitat suitability for waterfowl in different regions, including China's Caohai Lake wetland (Liu et al., 2022). These techniques have also been applied to flood zonation mapping, water quality analysis,

and change detection in wetland ecosystems (Prasad et al., 2002). In this paper, we aim to analyze the spatial distribution of waterfowl, identify critical areas for conservation, assess the biodiversity and status of waterfowl species within the study area and investigate the perceptions of local hunters towards waterfowl conservation.

MATERIALS AND METHODS

THE STUDY AREA

Study Site One

Bajaur District, formerly a part of the Federally Administered Tribal Areas (FATA), is now a district of the Khyber Pakhtunkhwa (KP) province of Pakistan. It encompasses seven tehsils: Mamund, Khar, Salarzai, Utmankhel, Nawagai, Barang, and Bar Chamarkand, covering an area of approximately 1,344 km² (Food and Agriculture Organization of the United Nations, 2016). Bajaur lies between 34.75°N to 34.95°N latitude and 71.40°E to 71.65°E longitude. Bajaur is bordered by Afghanistan's Kunar province to the northwest, Lower Dir to the northeast, and Mohmand District to the south. Koh-e-More is the highest mountain peak, with an elevation of 2,400 m. There are three major rivers flowing through Bajaur, namely Bajaur River (or Rud), Panjkora River, and Jandool River (or Jandool Khwarh). Large water bodies include Raghagan Dam and Talay Dam. District Bajaur is characterized by a semi-arid to arid climate, with hot summers and mild winters. The highest temperatures are recorded in July and August, often reaching up to 38°C. In winter, average temperatures range from 10°C to -5°C. The region receives an average annual rainfall of 850 mm, with most of it falling during the summer months (Ullah et al., 2023). Bajaur is home to a total of 238 plant species belonging to 208 genera and 89 families (Ali et al., 2022). The forests in Bajaur are predominantly Sub-tropical Chir Pine and Sub-tropical Broad-Leaved forests (Federally Administered Tribal Areas Secretariat, 2014). There are 83 native bird species belonging to 40 families and 15 orders found in District Bajaur (Khan and Gabol, 2023).

Study Site Two

Kurram District was also formerly part of the FATA. It was integrated into KP with agency status following the 25th Constitutional Amendment on May 24, 2018. It has three tehsils, namely Upper Kurram, Central Kurram, and Lower Kurram. Kurram is bordered by Paktia, Nangarhar, and Khost provinces of Afghanistan. The valley spans over an area of 3,380 km² from 33°20' to 34°10' N latitude and 69°50' to 70°50' E longitude. To the northeast, it meets District Orakzai and Khyber, while District Hangu lies to the east, and North Waziristan borders it to the southeast. The northern boundary is defined by the Koh-e Sufaid range, part of the Western Himalayas. Sikaram is the highest peak at 4,728 meters elevation. The Kurram River flows through the entire length of the valley. Large water bodies include Munda (or Maidani) Dam and Malikhel Dam (Figure 1). Kurram has a moderate climate. In the summer season, mean maximum temperature reaches 31°C, and the mean minimum temperature stays above 17°C. The winter season has minimum temperature often

falling below 0°C. Snowfall is common from December through March, varying with the elevation of different localities. Data from the Parachinar meteorological station, recorded over a period of 41 years from 1970 to 2010, indicates an average annual precipitation of 848 mm (Hussain, 2018). Most of the precipitation is received in the form of rain and snow from December to February (Muhammad et al., 2023). Kurram has 365 plant species in 244 genera and 86 families. The major vegetation types include dry subtropical scrubs, moist-temperate forests, dry-temperate forests, sub-alpine forest and alpine pasture (Muhammad et al., 2023). There are a total of 336 bird species found in Kurram (Whitehead, 2008).

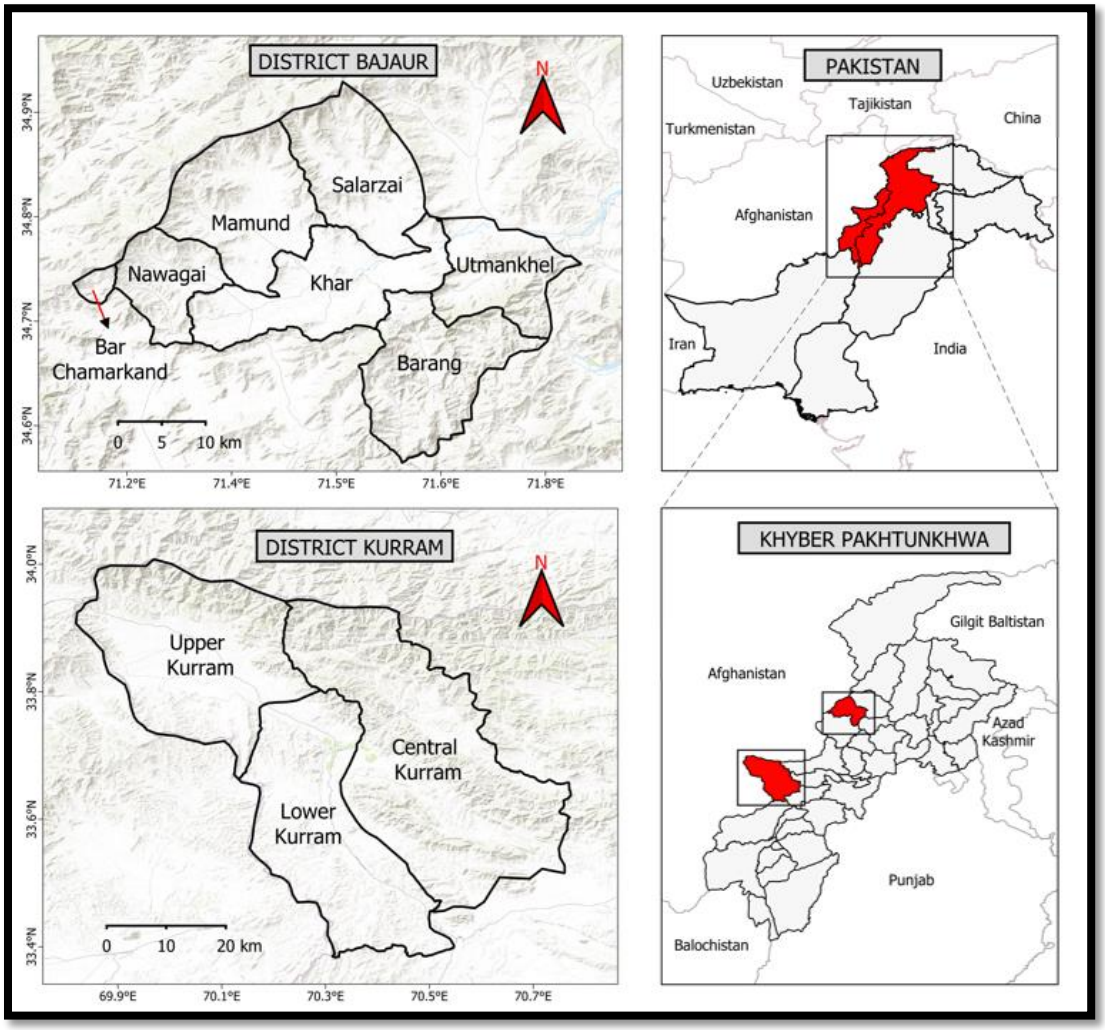

Figure 1: Map of study area showing District Bajaur and District Kurram.

METHODOLOGY

The study was conducted during the spring season, coinciding with the migration of waterfowl back to their wintering grounds. Data collection spanned four weeks, from March 2 to March 25, 2024. Initial site visits were carried out in Bajaur from March 2 to March 12, 2024. Subsequent sites in Kurram were visited from March 14 to March 25, 2024. The survey method was opportunistic (or ad-hoc) surveys and point transect

method around water bodies. Surveys were conducted in all weather conditions, starting before dawn and ending at dusk. A total of 13 survey points in Bajaur and 14 in Kurram were surveyed, with detailed observations recorded on pre-made data sheets. Parameters such as GPS coordinates, waterfowl species, counts, elevation, habitat type, direction, and distance from the observer, were recorded. Survey sites were selected based on input from local wildlife officials and hunters.

The Spot-lens mobile application was utilized for GPS data collection. Observations were made using Vortex (50x magnification) binoculars, while photographic documentation was performed with a Canon DSLR camera paired with a high-magnification zoom lens. Waterfowl species identification relied on illustrated field guides and the "Duck Hunting Calls" mobile application. Questionnaires were taken from experienced waterfowl hunters who were mostly middle aged and had been practicing hunting for more than two years. Demographic data was taken such as types of waterfowl hunted, insights on hunting practices and availability, factors affecting waterfowl populations, and local perceptions toward waterfowl conservation.

GIS operations were performed using QGIS (version 3.24.1), with some tasks completed through ArcGIS Pro (version 3.4) and Google Earth Pro (version 7.3.6.9796). The WGS-84 / UTM zone 42N (EPSG: 32642) Coordinate Reference System (CRS) was employed throughout the analysis. To display the actual positions of waterfowl observations, GPS coordinates were offset based on the recorded direction and distance from the observer. Coordinates of waterfowl sightings were used to generate heatmaps via the Kernel Density Estimation (KDE) tool in QGIS (version 3.24.1), assigning weights based on the number of waterfowl sighted at each location. The pixel size was 0.0001 km2, and the set radius was 1.5 km. This radius was chosen as it was the maximum observed distance of a waterfowl from a water body during the survey.

Heatmaps indicating point density of water or potential waterfowl habitats were generated through a series of steps. Initially, the Normalized Difference Water Index (NDWI) was calculated using Sentinel-2 raster images taken between February and March 2024. Then, water bodies were extracted from NDWI rasters using threshold values; converting these into vector polygons in QGIS; generating random points within these polygons according to their relative sizes (point density); and finally dividing the heatmap into areas of high and low probability using Raster Calculator in QGIS. Areas of high probability were defined as those with point densities exceeding 50% of the maximum threshold value, while areas of low probability were defined by point densities falling below 50% of the maximum threshold. This method was chosen because water bodies that are larger, closely located, and interconnected typically sustain increased densities and a wider variety of waterfowl (Meagher, 2019; Murphy et al., 1984; Sebastián-González et al., 2010). A pixel-based approach was used for area calculation with a consistent pixel size of 0.01 km x 0.01 km (0.0001 km^2). The "Raster Layer Unique Values Report" tool was used in QGIS to get pixel counts for observed habitat and potential habitat. Later, these pixel counts were converted into area (in km^2) by multiplying them with pixel size. Final map layouts were made in ArcGIS Pro (version 3.14).

Shannon's Diversity Index was calculated separately for each district based on observed field data to quantify species diversity within the community. Shannon's Biodiversity Index (H) was calculated in Excel using the formula: **$H = -\sum (Pi * Ln Pi)$,** where Pi is the proportion of each species relative to the total number of individuals, Ln is the natural logarithm, $-\sum$ is the negative sum, and H is the biodiversity index. The Evenness Index (E) was calculated to assess the uniformity of species distribution within each district. It was determined using the formula: **$E = H / Ln(S)$**, where H is the diversity index, Ln is the natural logarithm and (S) is total number of species.

RESULTS

WATERFOWL OBSERVATIONS

A total of 5 species of waterfowl were observed in Bajaur though direct sightings. The Common Teal (*Anas crecca*) was recorded 38 times. The Common Moorhen (*Gallinula chloropus*) was recorded 17 times. The Common Coot (*Fulica atra*) was observed 7 times. The Common Pochard (*Aythya ferina*) was recorded 7 times. The Northern Shoveller (*Spatula clypeata*) was observed 2 times.

A total of 7 species of waterfowl were observed in Kurram. The Common Teal (*Anas crecca*) was observed 9 times. The Common Mallard (*Anas platyrhynchos*) was observed 8 times. The Northern Pintail (*Anas acuta*) was observed 8 times. The Common Pochard (*Aythya ferina*) was noted 5 times. The Common Moorhen (*Gallinula chloropus*), the Gadwall (*Mareca strepera*), and the Ruddy Shelduck (*Tadorna ferruginea*) were each observed only 1 time. (Figure 2) (Table 1).

Table 1: Waterfowl species sighted in Bajaur and Kurram during the survey.

Name of Species	Scientific Name	Sightings (Bajaur)	Sightings (Kurram)
Common Teal	*Anas crecca*	38	9
Common Moorhen	*Gallinula chloropus*	17	1
Common Coot	*Fulica atra*	7	0
Common Pochard	*Aythya ferina*	7	5
Common Mallard	*Anas platyrhynchos*	0	8
Gadwall	*Mareca strepera*	0	1
Northern Shoveller	*Spatula clypeata*	2	0
Northern Pintail	*Anas acuta*	0	8
Ruddy Shelduck	*Tadorna ferruginea*	0	1
Total		71	33

Shannon's Diversity Index

In Bajaur, the Shannon's Diversity Index (H) is 1.2355, and the Evenness (E) is 0.7675 (Table 2). In Kurram, the Shannon's Diversity Index (H) is 1.8228, and the Evenness (E) is 0.9369, indicating higher species diversity and a more even distribution than district Bajaur (Table 3).

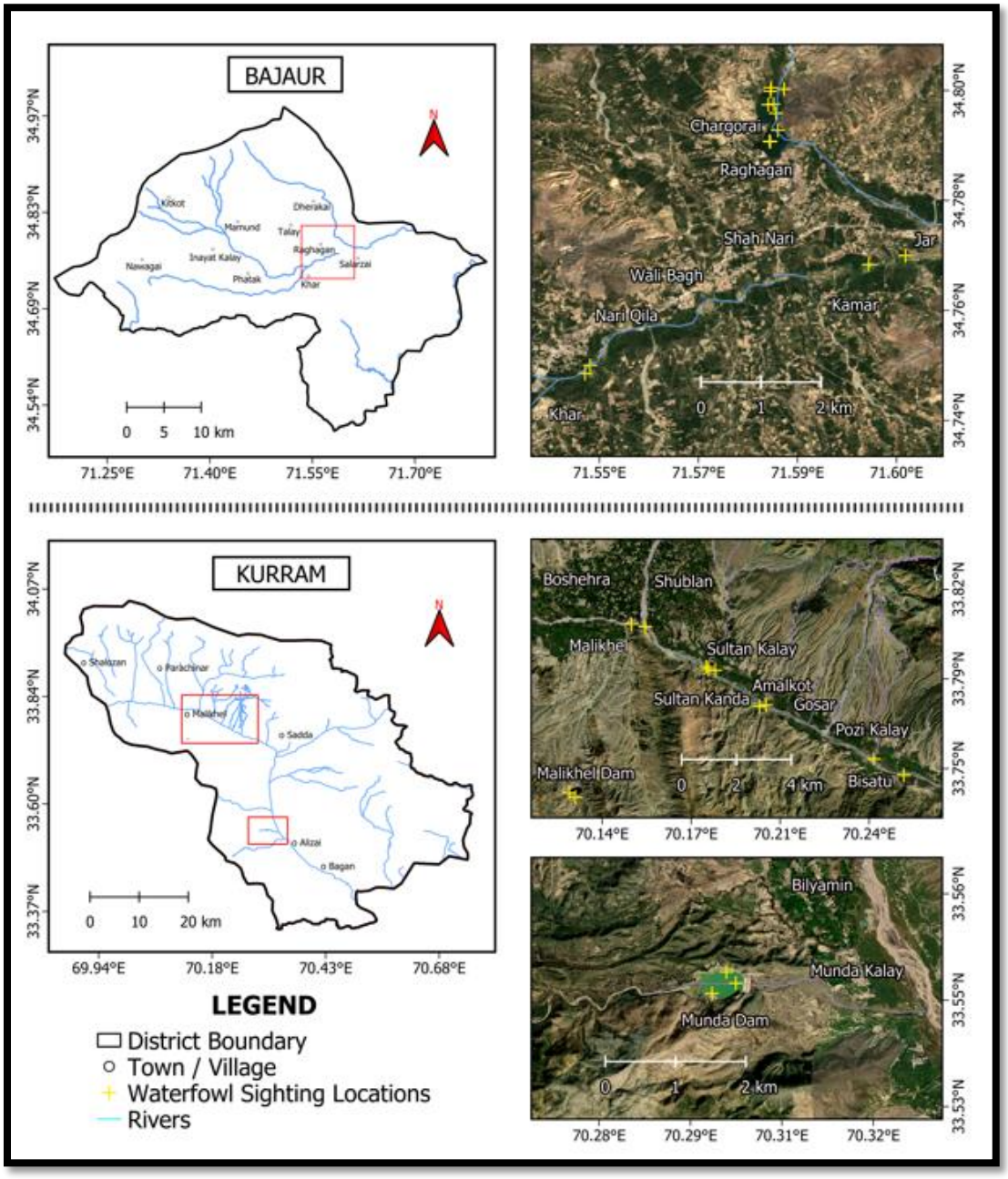

Figure 2: Map showing waterfowl sightings in District Bajaur and District Kurram.

Habitat and Hotspot Mapping

The analysis identified areas with varying probabilities of waterfowl presence, categorized into zones of high probability (areas representing large water bodies or water bodies in close proximity with each other which are preferred feeding and staging grounds for waterfowl) and low probability zones (areas where waterfowl may be found flying or passing over suggesting sporadic or less preferred habitat) (Figures 3).

Table 2: Shannon's Diversity Index and Evenness of waterfowl sightings in Bajaur.

English Name	Scientific Name	Family	Count (ni)	Proportion (Pi)	LogPi	PiLogPi
Common Teal	*Anas crecca*	Anatidae	38	0.5352	-0.6271	-0.3358
Common Moorhen	*Gallinula chloropus*	Rallidae	17	0.2394	-1.4296	-0.3422
Common Coot	*Fulica atra*	Rallidae	7	0.0986	-2.3159	-0.2284
Common Pochard	*Aythya ferina*	Anatidae	7	0.0986	-2.3159	-0.2284
Northern Shoveler	*Anas clypeata*	Anatidae	2	0.0282	-3.5651	-0.1007
Total	**Species = 5**		**71**	**1**		**-1.2355**
Shannon's Diversity Index **H = -∑ (Pi × ln Pi)**						**1.2355**
Evenness **E = H / ln(S)**						**0.7675**

Table 3: Shannon's Diversity Index and Evenness of waterfowl sightings in Kurram.

English Name	Scientific Name	Family	Count (ni)	Proportion (Pi)	LogPi	PiLogPi
Common Teal	*Anas crecca*	Anatidae	9	0.4091	-0.8946	-0.3661
Northern Pintail	*Anas acuta*	Anatidae	8	0.3636	-1.0116	-0.3677
Common Pochard	*Aythya ferina*	Anatidae	5	0.2273	-1.4816	-0.3367
Common Mallard	*Anas platyrhynchos*	Anatidae	8	0.3636	-1.0116	-0.3677
Gadwall	*Anas strepera*	Anatidae	1	0.0455	-3.091	-0.1405
Ruddy Shelduck	*Tadorna ferruginea*	Anatidae	1	0.0455	-3.091	-0.1405
Common Moorhen	*Gallinula chloropus*	Rallidae	1	0.0455	-3.091	-0.1405
Total	**Species = 7**		**33**	**1**	**-**	**-1.8228**
Shannon's Diversity Index **H = -∑ (Pi × ln Pi)**						**1.8228**
Evenness **E= H / ln(S)**						**0.9369**

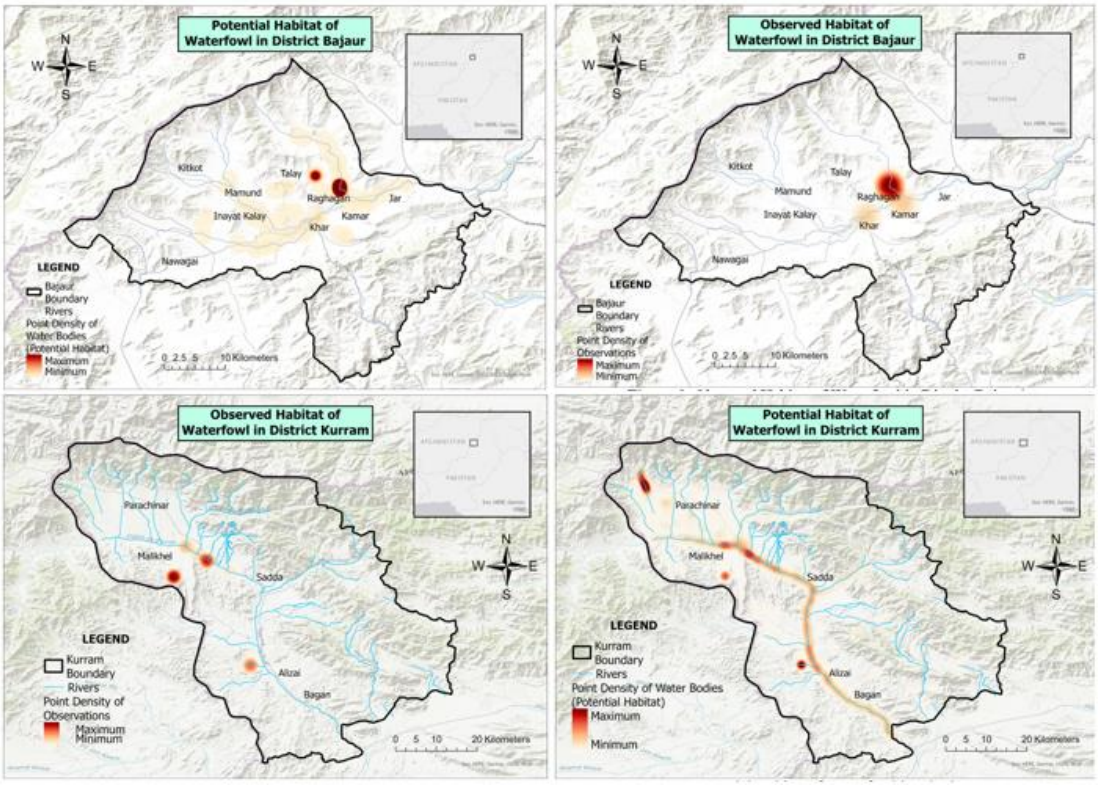

Figure 3: Potential Habitat of Waterfowl in District Bajaur and Kurram.

In Bajaur total areas of high probability were 14.63 km^2 areas of low probability were 54.85 km^2 giving a total potential habitat of 69.48km^2. In Kurram total areas of high probability were 18.44 km^2 areas of low probability were 168.1 km^2 giving a total potential habitat of 186.54 km^2 (Table 4). The Table 5 shows town and village names of high probability and low probability habitats for waterfowl in both districts (Table 5).

Table 5: Locations in District Bajaur and Kurram marked as potential waterfowl habitat.

Category	Bajaur Areas	Kurram Areas
Areas of High Probability	Raghagan Dam, Talay Dam, Khwaga China	Munda Dam, Malikhel Dam, Amal Kot, Sultan Kanda, Sultan Kaly, Ahmadzai, Pewar, Alam Khel
Areas of Low Probability	Jar, Dherakai, Redawno, Phatak, Khar, Chewatra, Lara Dagai, Pashat, Chargo, Nazakai, Kamar, Mulla Kaly, Gardai, Qazafi, Inayat Kaly, Chamarmung Khwar, Khair Abad, Chinagai, Mano Khwar	Abdullah Kaly, Akakhel, Alizai, Arawali, Arkhel, Bagzai, Bagan, Bangash Kalay, Bilyamin, Bisatu, Buto Kala, Chapare Kaly, Chota Durrani, Dad Qamar, Daulat Khel, Dandar Boshehra, Eid Gul Kaly, Gosar, Ibrahimzai, Jilamai, Khanano Kalay, Khapianga, Khar Kalay, Kot Ghundai, Makhizai, Manduri Bangash, Madi Shamu, Mahoora, Munda Kaly, Muzaffar Kot, Paraw Kaly, Pozay Kaly Sameer, Ramaki Kalay, Sadda, Shashoo, Shublan, Thotkaas, Tangi, Topyako, Wochat Kalay, Yaqubi, Zera.

Waterfowl species reported

Local hunters reported 14 different species of waterfowl in District Bajaur and 16 species in District Kurram. All these species are detailed in Table 5 along with their reporting frequency in each district. Bajaur and Kurram shared 14 waterfowl species with the exception of two: The Common Shelduck (*Tadorna tadorna*) and the Whooper Swan (*Cygnus cygnus*), which were only reported in Kurram (Table 6).

Table 6: Waterfowl species reported by local hunters in District Bajaur and Kurram.

English Name	Scientific Name	Family	Bajaur	Kurram
Common Pochard	*Aythya ferina*	Anatidae	Yes	Yes
Common Coot	*Fulica atra*	Rallidae	Yes	Yes
Common Shelduck	*Tadorna adorn*	Anatidae	No	Yes
Common Teal	*Anas crecca*	Anatidae	Yes	Yes
Common Moorhen	*Gallinula chloropus*	Rallidae	Yes	Yes
Eurasian Wigeon	*Anas penelope*	Anatidae	Yes	Yes
Ferruginous Duck	*Aythya nyroca*	Anatidae	Yes	Yes
Gadwall	*Anas streptera*	Anatidae	Yes	Yes
Garganey	*Spatula querquedula*	Anatidae	Yes	Yes
Little Grebe	*Tachybaptus ruficollis*	Podicipedidae	Yes	Yes
Common Mallard	*Anas platyrhynchos*	Anatidae	Yes	Yes
Northern Pintail	*Anas acuta*	Anatidae	Yes	Yes
Northern Shoveler	*Anas clypeata*	Anatidae	Yes	Yes
Ruddy Shelduck	*Tadorna ferruginea*	Anatidae	Yes	Yes
Tufted Duck	*Aythya fuligula*	Anatidae	Yes	Yes
Whooper Swan	*Cygnus fuliguline*	Anatidae	No	Yes

NUMBER OF WATERFOWL HUNTED PREVIOUS YEAR VS CURRENT YEAR

In both District Bajaur and District Kurram, local hunters reported a decrease in number of birds hunted by on previous year compared to the current year. The Figure 4 shows number of birds hunted on y-axis and serial no of hunters on x-axis.

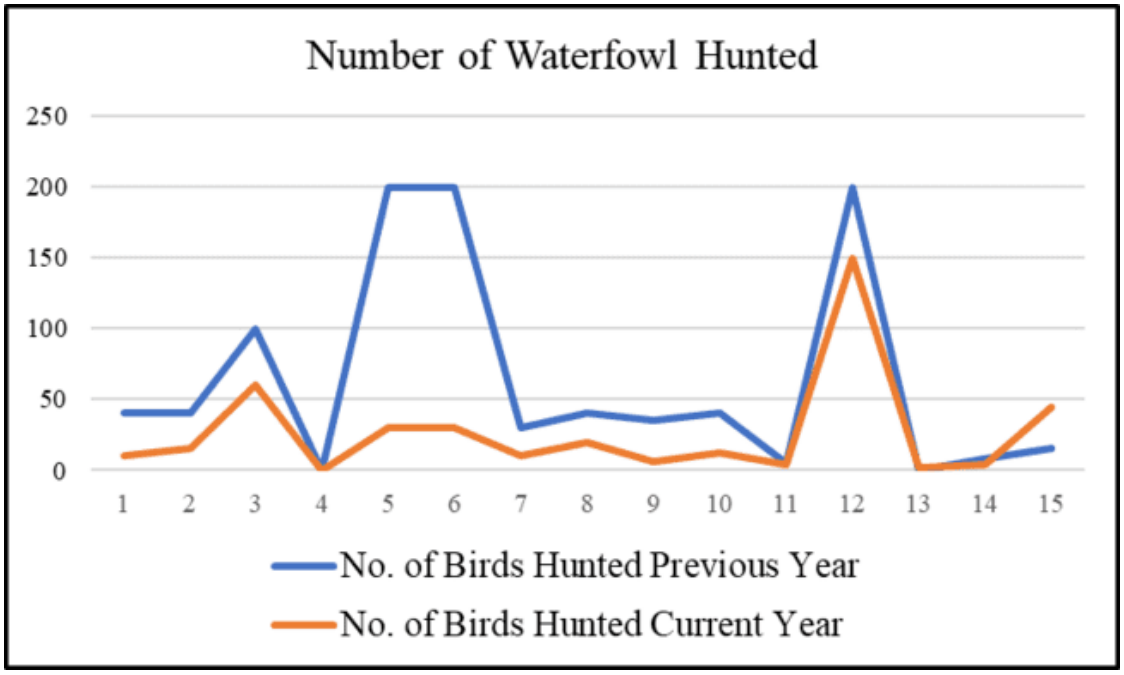

Figure 4: Number of waterfowl hunted in District Bajaur and District Kurram.

Threats

Major threats to waterfowl populations were identified by local hunters as illegal hunting, urbanization, water pollution, birds of prey and climate change (Figure 5).

YEAR OF MAXIMUM PERCEIVED WATERFOWL ABUNDANCE

53.3% of local hunters identified 2021 as the year with the highest perceived waterfowl abundance and number of birds hunted, while 26.7% pointed to 2020, and 20% indicated the previous year i.e. 2023.

EFFECT OF WEATHER ON WATERFOWL ABUNDANCE

Majority of the local hunters (86.7%) agreed that rainy conditions lead to more perceived waterfowl abundance and hunting opportunities. 13.3% agreed on cloudy weather.

EFFECT OF LAND USE CHANGES

Majority (60%) of respondents reported that changes in land use, such as mining and urbanization, had negative impacts on waterfowl populations. Others (40%) viewed land use changes as positive for waterfowl, like the creation of artificial ponds for agricultural practices such as rice farming.

Figure 5: Glimpses of threats to waterfowl, Top Left: Waterfowl decoys for hunting, Kamar Dag, Bajaur, Top Right: Common Teal hunted in Raghagan Dam, Bajaur, Bottom Left: Common Pochard hunted at Munda Dam, Kurram, Bottom Right: Hunting in Eid Gah Kalay, Lower Kurram.

EFFECTIVENESS OF CURRENT CONSERVATION PRACTICES

Majority (73.3%) of respondents expressed a negative opinion of the wildlife department's operations and reported in-effective conservation practices. Some (26.7%) held a softer view of the department but still perceived current conservation practices as needing improvement.

DISCUSSION

The higher diversity index of 1.8228 and evenness of 0.9369 for District Kurram compared to diversity index of 1.2339 and evenness of 0.7666 for District Bajaur may be due to several reasons. The first being the larger potential habitat of waterfowl for District Kurram, assessed from point density of water, at 186.54 km² with higher probability zones of 18.44 km² compared to Bajaur at 69.48 km² with higher probability zones of 14.63 km². This reasoning is supported by several studies. Water bodies, including artificial ones like farm ponds, are crucial habitats for waterfowl (Froneman et al., 2001). Water body size positively affects species richness and abundance (Murphy and Dinsmore, 2018). Larger, closely situated and more interconnected water bodies support higher numbers and greater diversity of waterfowl (Meagher, 2019; Murphy et al., 1984; Sebastián-González et al., 2010). This is also reinforced by the finding that local hunters reported sightings of 16 different species of waterfowl in Kurram compared to 14 different species in Bajaur.

Waterfowl sightings during the survey were higher during overcast conditions. Waterfowl abundance was also perceived by local hunters to be higher during rain or cloudy weather compared to other weather conditions. This could be attributed to several factors. Rain often leads to the creation of temporary ponds and flooded fields, expanding water sources and providing more feeding or staging grounds for

waterfowl (Anteau et al., 2012; Krapu et al., 1995). Rain and overcast weather can improve foraging opportunities by increasing insect activity (Poulsen, 1996). Waterfowl also tend to exhibit more active behavior during cloudy conditions, as the dim lighting may offer a sense of safety from predators, prompting greater movement (Fox et al., 2014).

A large proportion of hunters reported that 2021 was the year when waterfowl abundance was the highest. This trend may be attributed to the widespread lockdowns and reduced anthropogenic activities caused by the COVID-19 pandemic, which led to a temporary halt in many human activities, including hunting. A study conducted in South Wales, United Kingdom (Tuite et al., 1983) explains that water-based recreational activities can disturb waterfowl populations, altering their distribution and behavior. Reduced human presence can thus, lead to increased habitat availability and decreased disturbance, which positively affects avian populations (MacGregor et al., 2022).

During our survey, majority of locals reported that anthropogenic activities such as mining (which leads to water pollution) and urbanization had a negative impact on waterfowl populations. In line with this, a study in Hangzhou, China, revealed that waterbird species density and diversity decreased with increasing urbanization, citing factors such as water pollution, and human disturbance (Shui-Hua et al., 2000). However, in the same study, connectivity of water bodies improved in built-up areas, potentially benefiting waterfowl. This is also suggested by some of the local hunters during our study who perceived anthropogenic land use changes such as creation of ponds for agriculture and irrigation, as having positive impacts on waterfowl populations.

The newly established wildlife departments face significant challenges, including a shortage of trained staff, logistical issues, and public backlash against waterfowl conservation rooted in traditional tribal culture and hunting practices. While local communities have expressed interest in licensed hunting, the lack of mechanisms to enforce bag limits has turned licensing into a means of permitting excessive hunting, bordering on legalized poaching. Similarly, despite existing protected-area legislation, overhunting has led to substantial declines in wildlife populations throughout the world, with species in resource-poor countries most affected (Harrison et al., 2016; Rija et al., 2020). Immediate steps to address conservation issues in Bajaur and Kurram need to be taken. Stricter hunting regulations should be mandated such as enforcing bag limits and monitoring illegal hunting by positioning wildlife personnel on high alert during waterfowl season in strategic hotspots such as those identified by our study. New protected areas should be established in key waterfowl habitats identified in this study.

There exists a substantial communication gap between the wildlife department and local hunters in both districts which hinders conservation initiatives. A more collaborative approach between wildlife authorities and local communities needs to be established. Integrating indigenous knowledge with community-based conservation can improve wildlife management practices and enhance social-ecological resilience (Shokirov and Backhaus, 2020). Clearer promotion of ethical hunting practices and proper updates about wildlife laws must be extended to the local people by placing signboards, conducting regular meetings with hunters,

distributing awareness material (such as pamphlets), and running social media campaigns. Awareness programs about waterfowl conservation must be arranged in educational institutions to target the younger generation, especially teenagers.

CONCLUSION

This research provides the first extensive evaluation of waterfowl species in District Bajaur and District Kurram, assessing their diversity, potential habitat, critical hotspots, and conservation issues. There were notable differences in diversity between the two districts, with Kurram exhibiting a higher species diversity and more balanced species distribution compared to Bajaur. Critical waterfowl habitats were identified in both districts, with Kurram having a larger extent of potential habitat and high-probability zones. The study reported the Ferruginous Duck (*Aythya nyroca*) in both districts, which is classified as a vulnerable species by the International Union for Conservation of Nature (IUCN). Importantly, local hunters reported a decline in waterfowl populations, citing illegal hunting and urbanization as the primary threats. The most threatened waterfowl species perceived by local hunters in both districts was the Common Mallard (*Anas platyrhynchos*). The strong indications of population decline emphasize the unsustainable pressure on waterfowl populations. Current conservation efforts were perceived as ineffective by most respondents. While this research provides a solid foundation for understanding waterfowl distribution and conservation needs, it is limited by the short-term nature of data collection and the reliance on local hunters' perceptions, which may not capture the full extent of the situation. Future research should focus on long-term monitoring of waterfowl populations and involve more extensive ecological assessments across different seasons to get a more nuanced understanding. However, the security and law-and-order situation in the ex-FATA regions is not ideal and may not permit long-term and extensive surveys. The establishment of designated conservation areas, especially around waterfowl hotspots, is essential, such as Raghagan Dam, Talay Dam, and Khwaga China in Bajaur, while in Kurram, areas such as Munda Dam, Malikhel Dam, Amal Kot, Sultan Kanda, Sultan Kaly, Ahmadzai, Pewar, and Alam Khel. Such measures, coupled with stricter hunting regulations and habitat protection, are crucial for ensuring that waterfowl populations thrive in these regions.

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