

Wetlands birds in the transboundary floodplains of north-western Bangladesh and their conservation urgency

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Keywords: Floodplain, Wetlands, Conservation, Birds, Transboundary

Abstract

In perspective of the conservation of biodiversity in Bangladesh, transboundary river floodplains are ecologically important but those are beyond protected landscapes particularly in the western part of Bangladesh. The present study was conducted on bird community structure, habitat associations, seasonal dynamics, and conservation issues during July 2020 to June 2022 using direct field observations methods at urban, rural and beel ecosystems of the Chapainawabganj district- a transboundary floodplain of northwestern Bangladesh. Within a comparatively small floodplain landscape, 5,243 individuals representing 172 bird species, 57 families, and 17 orders were recorded, making up nearly 25% of the country's avifauna. Estimators of species richness predicted that the sampling for data collection was about more than 90%. Beel habitats had the highest species diversity and abundance, according to habitat-based analyses ($H = 4.154$, $D_s = 0.975$). This habitat comprises mudflats, shallow water bodies, and surrounding vegetation where 93.6% of the documented species appeared during the winter, including 66 migratory species. The conservation value of the area was highlighted by the documentation of nationally threatened species, including *Clanga hastata* (EN) and *Mycteria leucocephala* (CR). Anthropogenic pressures, such as hunting, agricultural netting, wetland conversion, pollution, and growing urbanization have been increased on the floodplain ecosystem, despite its high biodiversity value. The present study shows that unprotected transboundary wetlands significantly contribute to regional ecological connectivity and serve as vital refugia for migratory and resident birds.

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Introduction

Transboundary landscape worldwide creates an exceptional biodiversity conservation zone which is known as transboundary conservation area between the political boundaries of two or more nations (Kotru *et al.*, 2020). These areas are expected to hold more than half of the total existing species globally due to less anthropogenic stressors (Mason *et al.*, 2020). Till now, 227 global transboundary conservation areas are playing a significant role for conserving biodiversity (Chettri *et al.*, 2007; Kandel *et al.*, 2018; Prakash & Verma, 2022). In this context transboundary areas are playing a significant role for providing support and ensuring safety from anthropogenic activities to biodiversity especially for avifauna (Yong *et al.*, 2018). Additionally, during the time of migration those places become resting or breeding spots often acting as hotspots for migratory birds (Chettri *et al.*, 2007). Anthropogenic pressures globally modify the natural status of the habitat influencing changes in the community composition of avifauna and fling the habitat specialized species into existential crisis. Whereas the transboundary area boosts to protect the natural habitat as well as the habitat specialized important species (Kandel *et al.*, 2018).

Wetlands and its associated habitat, for example floodplains are recognized to be the most productive form of the ecosystem due to its ecological and socio-economic significance (Arya *et al.*, 2020). The enormous diversity and numerous food webs that floodplains sustain make their biodiversity crucial, although its biodiversity is woefully underappreciated (Sarker and Borah, 2018). Floodplains, with their rich diversity of flora and fauna, are regarded as "hotspots" for wildlife. Ganges is considered one of the major river systems of Bangladesh and the Ganges floodplain creates an exceptional types of wetlands ecosystem with charland, riverine grassland, beel, baor, canal, etc. which is the home of a good number of wetland specialist birds (Bayley, 1995; Shome *et al.*, 2025a). In the northwestern portion of Bangladesh, area of Ganges floodplain shares the political boundary with India and a number of beels are associated with this specially in the Chapainawabganj district. Several studies in Bangladeshi transboundary areas have been done (e.g. transboundary Sundarbans by Gopal and Chauhan 2018, avifauna of northwestern Panchagarh by Emrose *et al.* 2024, transboundary human-wildlife conflict studies by Islam and Wang 2024, transboundary elephant poaching by Chakma *et al.* 2025). Unfortunately, a little concern has paid on the wetlands and forest habitats of outside protected areas, which are converted into agricultural lands, human settlements, industrial areas, shrimp and fish farms due to the vast expansion of human population particularly during the last fifty years due to the increasing human demand (Alam *et al.*, 2017; IUCN Bangladesh, 2015).

Bangladesh is the home to diverse wildlife species and a number of iconic and threatened wildlife species occupy different geographical areas of the country (Khan, 2018). Transboundary areas of eastern Bangladesh are enriched with hilly forest, hill streams, and exceptional types of habitats to different groups of wildlife that are not observed in others areas of Bangladesh (Khan, 2015). The eastern part also represents a network of protected

areas touching the transboundary areas (Khan, 2018). But the scenario is different in the western parts of Bangladesh. The Ganges-Brahmaputra floodplain habitat has created enriched habitats for wetland associated wildlife species. However, there is no designated protected areas or any visible conservation initiatives have not been taken in these areas (Shome et al., 2025a; b). Therefore, anthropogenic stressors are gradually increasing in those areas and ultimately Bangladesh lost its important wildlife species from those areas. Many bird species complete seasonal movements, dispersal, and other activities across large areas, making transboundary habitat connectivity essential for maintaining viable population. This type of habitat often supports complementary areas for completing life cycles and can function as ecological corridors for birds.

From this context, this study attempted to focus on baseline study for avifauna in the northwestern floodplain of the Ganges. Therefore, Gomastapur Upazila of Chapainawabganj district was selected because, being situated in the floodplain of the Ganges River, it represents diverse ecosystems including rural, urban, and beel (wetland) environments. A survey of birds was conducted in that area because birds serve as an indicator group for wildlife, and their community structures play a key role in monitoring the health of an ecosystem which ultimately aids in taking proper conservation planning (Shome et al., 2020). The present study aims to uncover the avian species composition, their ecosystem usage, and habitat preferences. It also aims to evaluate the conservation significance of the transboundary area for birds and identify any nationally or globally threatened species. The findings of this research will play a significant role by providing baseline data on avian diversity and their ecology for the conservation of the transboundary floodplain areas.

Materials and Methods

Study area and period: This study was carried out during July 2020 to June 2022 in Gomastapur upazila of Chapainawabganj district (24.73°N 88.20°E) which is a transboundary landscape of North-west Bangladesh situated on the bank of the river Punarvaba and Mohananda in the Ganges floodplain (Fig. 1) (Alam et al., 2017). This upazila is correspondent with eight administrative unions and covers a total 318.13 km² area (BBS, 2021). Natural (beels, river, canal, grassland) and modified habitats (manmade forest, agricultural land, human-habitation, road) were found in this upazila. There is a small town in the municipality area which has huge anthropogenic activities that impact the environment. According to the habitat structure and anthropogenic stressors study area was divided into three sites such as (1) Rural Area (R) which are manmade forest, fallow land, agricultural land, human settlement, roadside, home state garden, mango garden, pond, ditch, (2) Urban Area (U) which includes residential area, commercial area, dumping side, bus and train station, govt office, green spaces, construction activities and (3) Beel area (B) which includes large beels (Choroil beel, Ramdash beel, Damas beel), adjacent agricultural land and trees, grassland, floodplain.

During the COVID-19 pandemic, we avoided traveling from Dhaka to the research areas for the purpose of surveys and data collection, and at that time, local field surveyors helped us with collecting data. The total survey period was divided into three phases: Pre-winter (September to November), Winter (December to February) and Post-winter (March to May) (Bhendekar et al., 2024). The observation was done in the early morning (6.00 am-8.00 am) and afternoon (04.00 pm- 06.00 pm) (Bibby et al., 2000; Sutherland 2006). We spent 8 days per time-season for data collection. Nocturnal bird survey was conducted during night. Bird photographs were taken using a D7100 DSLR Camera with 200-500 mm VR lens in order to identify observed species. The taxonomic identification of birds during the observation period was done followed by several books (Ali and Ripley 1983, IUCN Bangladesh 2015, Khan 2015; 2018). Data regarding species, individual number, microhabitat, threats and activity was recorded following the transect line sampling method (Bibby et al., 2020). A total of 30 transect lines were studied in the study area where 10 were in each site. The size of each line was 200 m in length and 20 m width on both sides. In beel area, boat surveys were done for collecting data on water birds. No river survey was conducted during this study. Local people including our field guides, bird photographers and fishermen were interviewed for collecting the detailed information about threatened species of bird.

Data analysis: According to the presence of birds in during the survey period, observation status was estimated as very common (VC) 80-100%, common (C) 50 - 79%, uncommon (FC) 20 - 49% and few (F) 10 - 19% (Khan, 2015; Jaman et al., 2023). The relative abundance of particular bird species was calculated following the formula-

$$\text{Relative abundance} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals of all species}} \times 100$$

We calculated Shannon-Wiener index (1949), Simpson's index (1949) of diversity and evenness (quantifies how numerically equal the community is) in the study area using following formulas-

Shannon-Wiener Index, $H = -\sum (P_i) \ln P_i$

Evenness, $E = H/\ln (S)$ (natural log)

(where, n_i = number of individuals of a species; N = the total number of individuals; $P_i = (n_i/N)$ number of individuals of a species/ total number of individuals of all species).

Species richness of avifauna in the study area was estimated using four non-parametric richness estimators: first-order Jackknife, second-order Jackknife, Bootstrap, and Chao 2, which were calculated using the PAST software package (Chao and Shen, 2003).

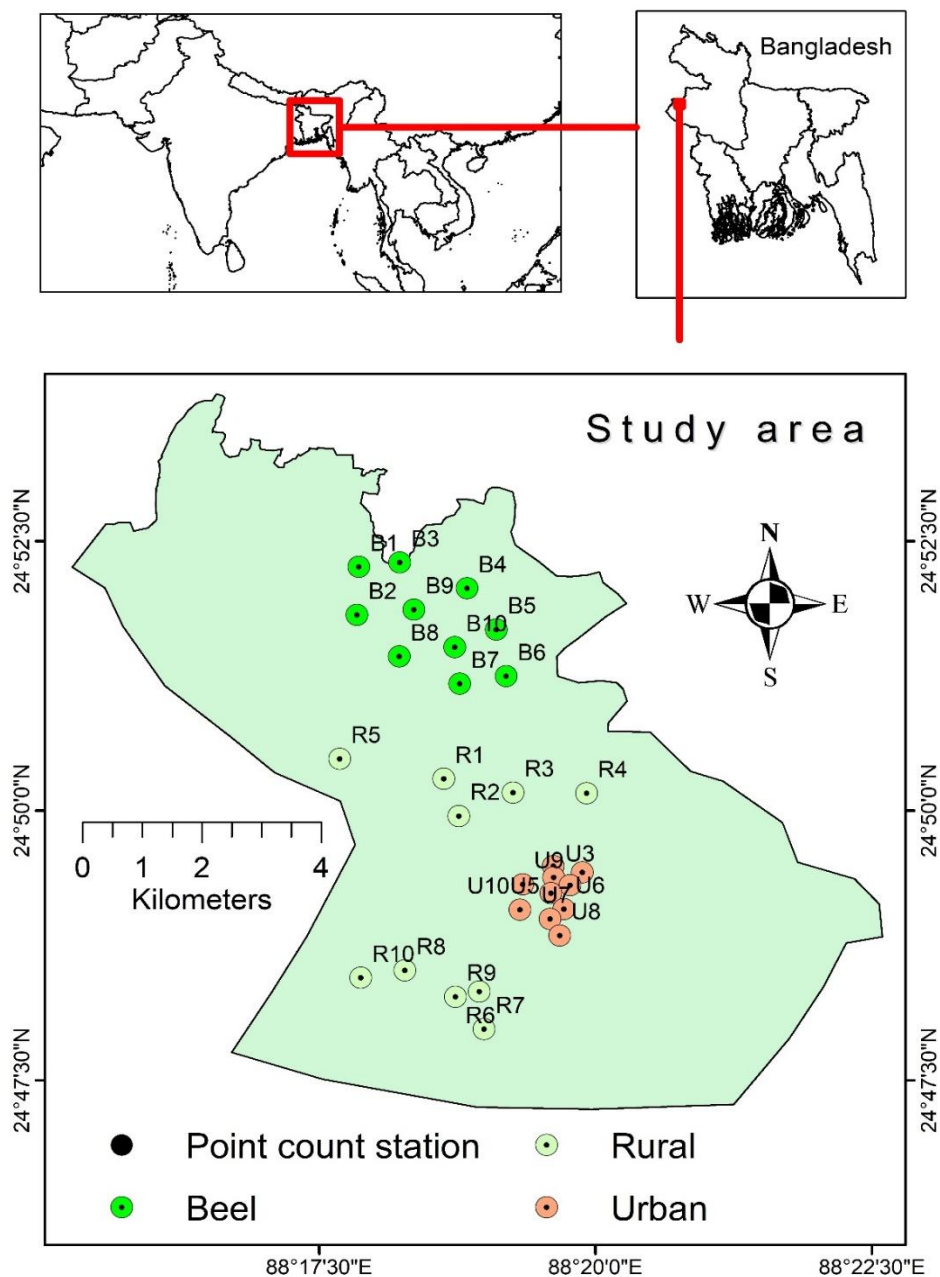


Fig. 1. Map of study area.

These estimators were generated through a resampling approach based on 1,000 randomized iterations with replacement, allowing the estimation of bird species richness and associated standard deviations from the observed dataset. The overall estimated species richness was determined by calculating the mean value of the four richness estimators, providing a combined approximation of the expected number of species within the study area. The estimated number of species (x), was calculated by averaging these four factors according to Ficetola *et al.* (2014).

A cluster analysis or habitat similarity plot for microhabitats was created using the Bray-Curtis index (Bray and Curtis, 1957) as well as a Non-metric Multi-Dimensional Plot (NMDs) for the two study sites. A rank abundance plot was created following Whittaker (1965) to depict dominance patterns. Among the five micro-habitats, correlation between habitats was performed by taking the species diversity as an independent variable and the habitats as the dependent variable. For statistical analyses of the collected data MS Excel, R- ggplot2 package (version 4.0.5, R Core Team 2020), and PAST (version 4.07) were used.

Results and Discussion

Species Composition: A total of 172 avian species with 5243 counted individuals under 17 orders and 57 families were observed from the study area during the study period. Among the recorded bird species, non-passerine species were the highest (108 Species, 62.80%) and the rest were passerine birds (64 Species, 37.20%). The highest number of bird species were under the order Passeriformes (64 Species, 54.86%) followed by Charadriiformes (27 Species, 15.70%) and Accipitriformes (14 Species, 8.14%). The bird diversity of the family Anatidae (16 Species, 9.30%) Accipitridae (14 Species, 8.13%) and Scolopacidae (13 Species, 7.55%) were higher than other groups. The number of resident bird species (106 species 61.60%) were majority in number and the rest 66 species (38.40%) were migratory. Based on the richness estimator's prediction, diversity of avian species varied from 189 to 202 which is relatively similar to the observed results (approximately 90% similarities). This predicted result indicates that species sampling was adequate in the study area.

The research found a high avian diversity of 172 species, which indicates one of the most species-rich wetlands based non-protected habitat complexes in northwest Bangladesh. Bangladesh is the home of over 700 bird species (Grimmett *et al.*, 2021), and the recorded species represent approximately one-fourth (24.6%) of the country's avifauna within a small floodplain-based ecosystem. This high species representation highlights the significant ecological value of this small geographic area (Khan, 2018). Comparative analysis with other major wetland ecosystems of Bangladesh further indicates that Gomastapur Upazila supports a remarkably rich bird community, emphasizing its importance as a key avian habitat within the floodplain landscape (Fig. 2).

This richness is comparable to the records from Charland in Padma river of Rajshahi (279 species), Marjat baor (182 species) and exceeds several other wetlands and riverine habitats such as Shoipara beel (96 species) and the Jamuna River (69 species) (Khan & Naher, 2009; Alam et al., 2012; Reza et al., 2014; Hasan et al., 2017; Amin et al., 2020; Jaman et al., 2023a,b; Emrose et al., 2024). However, larger and internationally recognized ecosystems like Tanguar Haor (219 species) have still supported greater avian richness due to their extensive habitat heterogeneity and high protected status (Alam et al., 2012). However, comparatively higher species richness at Gomastapur indicates that nearby habitats and smaller floodplain wetlands may serve as significant havens for migratory and resident bird species. These results underline the importance of inland wetlands in northwest Bangladesh for conservation and the necessity of focused management techniques in order to protect these biodiversity-rich habitats.

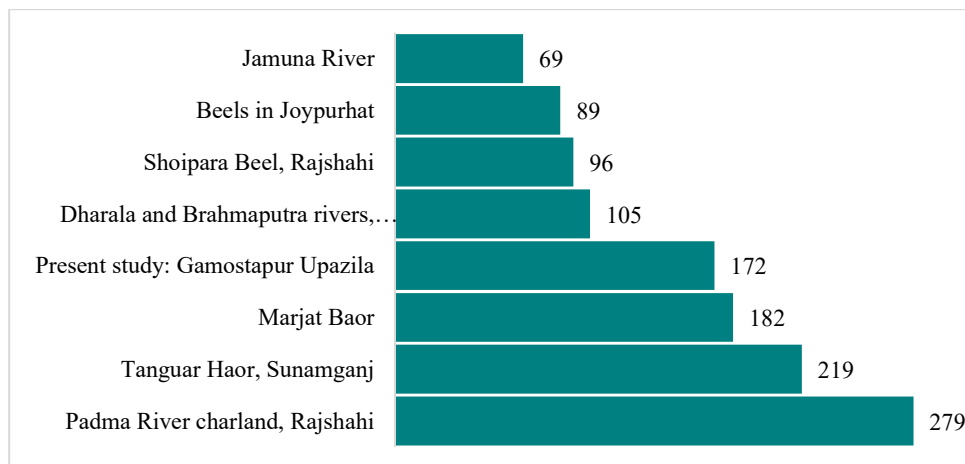


Fig. 2. Number of recorded bird species from different wetlands in Bangladesh according to different studies (Khan & Naher, 2009; Alam et al., 2012; Reza et al., 2022; Hasan et al., 2017; Amin et al., 2020; Emrose et al., 2024; Jaman et al., 2023a,b).

Among the three study sites, the highest species diversity (128 species, 74.14%) and individuals ($n = 3244$) was observed from the beel area. In the avian communities among three study sites. In addition to this, the wetland specialist bird diversity and population under the order Charadriiformes, Anseriformes, Accipitriformes, Pelecaniformes was higher in the beel area than other sites whereas birds under Passeriformes order was higher in both urban and rural sites (Fig. 3).

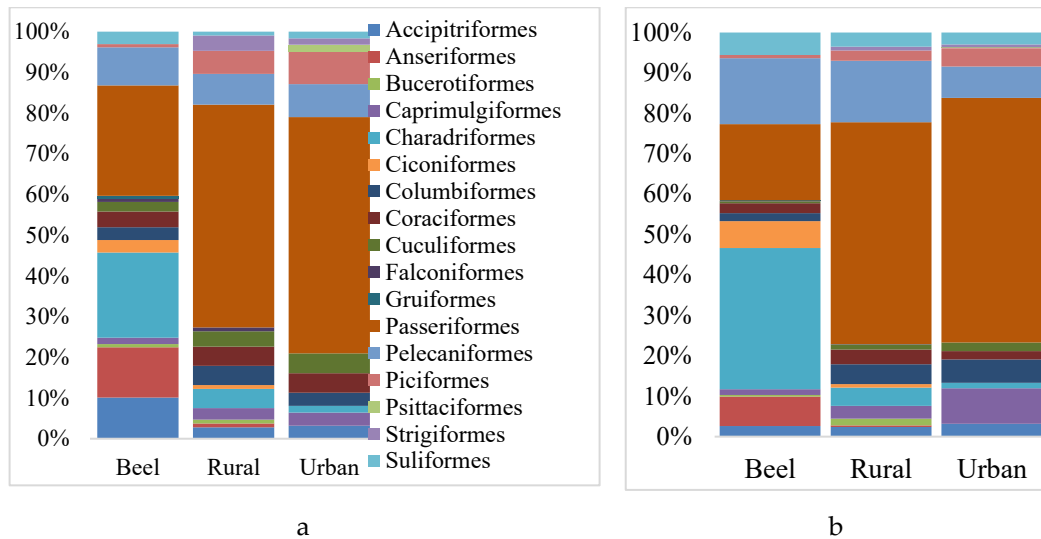


Fig. 3. Avian species richness **(a)** and abundance **(b)** according to different orders from three sites.

The importance of floodplain based aquatic habitats is reflected by the higher proportion of non-passerine aquatic habitat dependent birds (62.80%) like; waders (Charadriiformes) and waterfowl (Anseriformes), recorded from the wetlands in the floodplain area (Fig. 3). The seasonal connection between Bangladesh and India through the Ganges floodplain may increase food availability and habitat diversity, supporting both migratory and resident bird communities (Shome *et al.*, 2025b; Emrose *et al.*, 2024). The diversity indices also showed the highest value in beel area ($H = 4.154$, $D_s = 0.975$), whereas the urban area showed the highest evenness ($E = 0.700$) value. In total, 43 species of birds were found sharing all three sites, while 63 species found particularly in the beel site and 26 species in the rural site (Fig. 4).

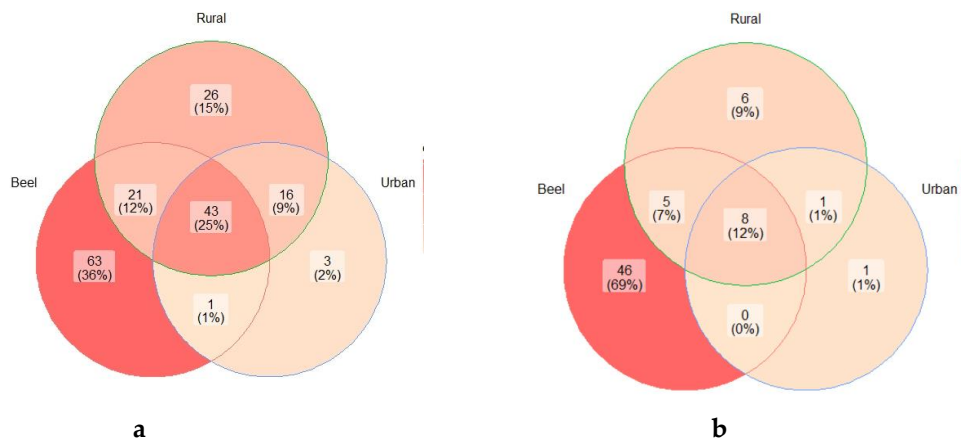
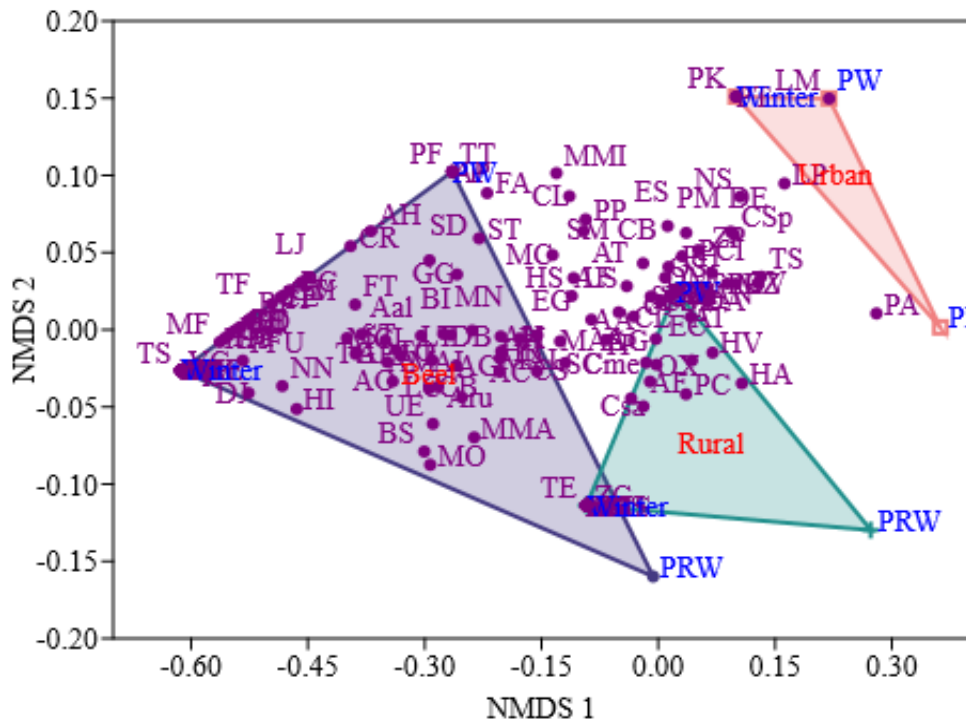


Fig. 4. Number of all common and unique species **(a)** and migratory species **(b)** in the three sites.

The Shannon diversity and Simpson's index are both much greater in beel habitats than in the rural and the urban sites. These two indices indicate a more complex community structure and a well-developed food web within the wetlands-based habitat. The higher values reflect greater ecological complexity, suggesting diverse avian species interactions and a more stable aquatic ecosystem. Wetlands mosaics contained shallow water zones, mudflats, floating plants, and surrounding tree cover microhabitats that jointly accommodated foraging for waders, piscivores, raptors, and arboreal insectivores (Wang et al., 2025; Secondi et al., 2026).



The Bray-Curtis similarity analysis showed that homestead forests and tree-associated beel habitats had a close similarity in bird community composition. This suggests that semi-natural and human-modified vegetation patches can function as connected habitats, supporting species movement and ecological connectivity across the landscape (Fig. 8). This

supports the idea that small-scale habitat elements can make the whole landscape more resilient (Mori & Isbell, 2024).

Observation status and relative abundance: Among the recorded species, the relative abundance of Black-winged Stilt (*Himantopus himantopus*) was the highest ($n = 436$, 8.31%). The other most abundant bird species were *Anastomus oscitans* ($n = 173$, 3.29%), *Nycticorax nycticorax* ($n = 166$, 3.16%), *Ploceus philippinus* ($n = 161$, 3.07%), *Dicrurus macrocercus* ($n = 154$, 2.93%) (Fig. 6). Among the three study sites, the urban sites signify the slightly uneven distribution of species compared to other two study sites (Fig. 6). Among the recorded birds, 29 (16.86%) were very common, 19 (11.04%) common, 62 (36.04%) uncommon, and 62 (36.04%) were few.

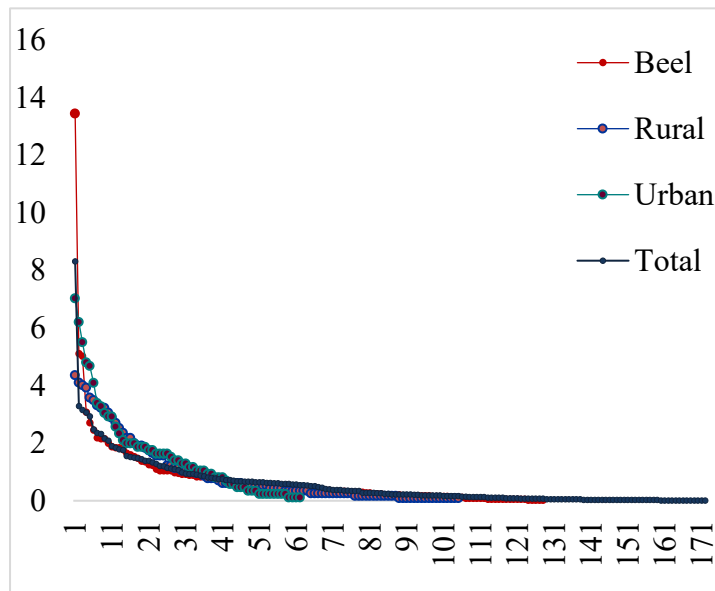


Fig. 6. Rank abundance plot of bird species recorded from the three study site.

The habitats are characterized with a suitable shallow-water foraging grounds which was indicated by the high abundance of *Himantopus himantopus*. The rank-abundance curve's dominance patterns demonstrate moderate evenness, but urban sites showed higher numerical equitability ($E = 0.700$), probably as a result of less niche specialization and homogenization of species assemblages. This pattern is consistent with findings from global urban ecology, which show that fewer but more evenly distributed generalist species are found in urban habitats.

Seasonality: Significant variations in species richness ($\chi^2 = 58.132$, $df = 2$, $p < 0.0001$) and abundance ($\chi^2 = 1591.6$, $df = 2$, $p < 0.0001$) of birds were observed in the study area among three seasons. The richness (161 species, 93.60%) and abundance ($n = 3000$, 57.21%) bird

species were observed highest during the winter season (Fig. 7a). The diversity indices also showed the highest value in this season ($H = 4.35$, $Ds = 0.983$). In the pre-winter season, the evenness ($E = 0.482$) value was the highest (Table 3). During the winter, in the beel site bird richness (119 species) and abundance ($n = 2100$) was the highest among the three study sites (Fig. 7b). From the study area 48 species of bird were observed throughout the year where 63 species of bird recorded particularly in winter (Fig. 7c).

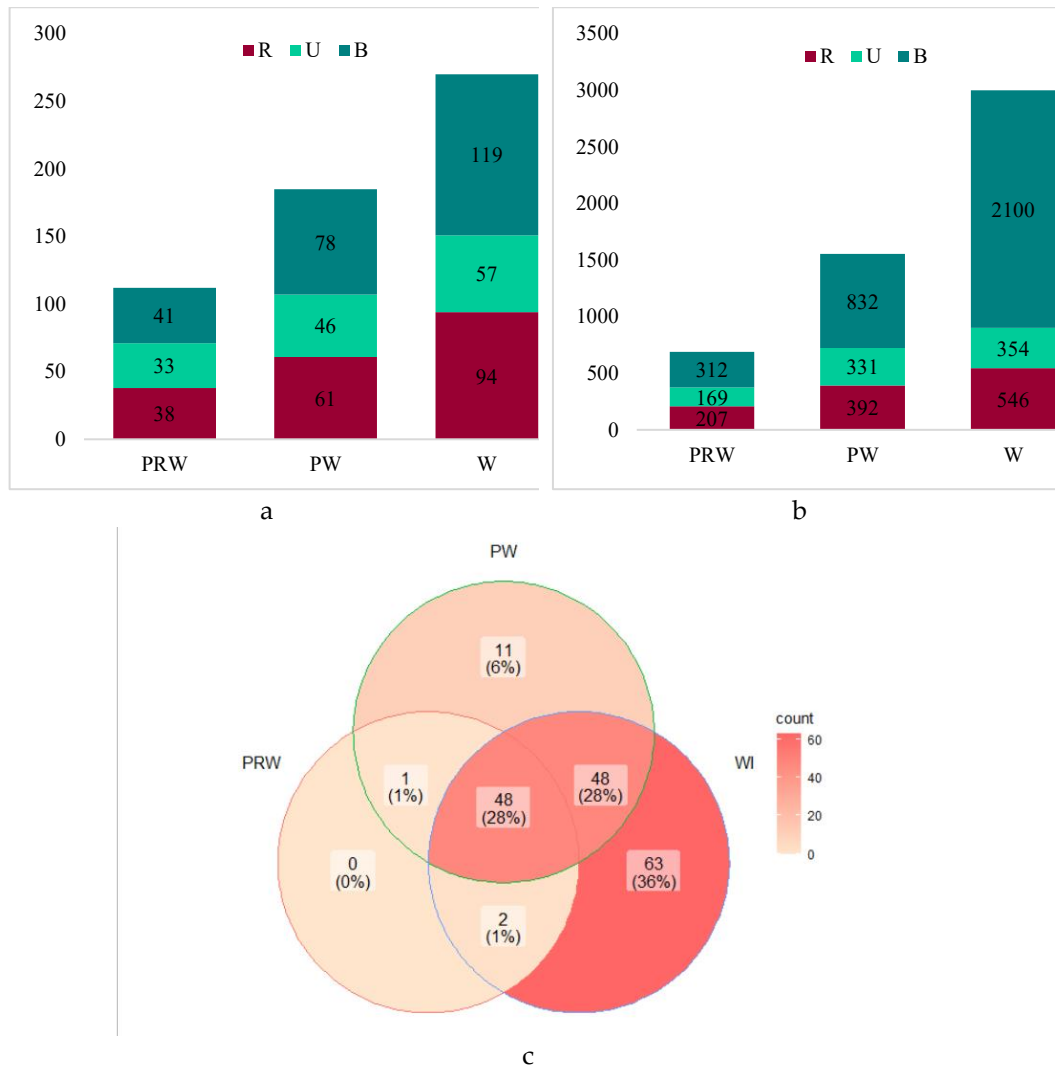


Fig. 7. Season-wise Species richness (a), abundance (b) and number of common and unique species (c) (PRW- Pre-winter, PW-Post Winter and W-Winter).

Among the total species found, 93.6% of species were recorded during the winter season, which had a significant impact on both species' richness ($\chi^2 = 58.132$, $p < 0.0001$) and abundance ($\chi^2 = 1591.6$, $p < 0.0001$). The study area's significance as a wintering and stopping ground along the Central Asian Flyway is confirmed by the presence of 66 migratory species, including globally vulnerable taxa like *Clanga hastata* (Endangered) and *Mycteria leucocephala* (Critically Endangered nationally). Coastal and riverine systems of Bangladesh have been represented by the similar seasonal maxima in floodplain wetlands (Shome *et al.*, 2025b, Rabbi *et al.*, 2011), indicating that interior beels are as important but somewhat under-represented in conservation planning.

Habitability: Among three micro habitats, aquatic habitat holds the highest number of avian diversity (129 species) along with the abundance ($n = 3488$) as well as diversity index shows the highest value ($H = 4.15$, $Ds = 0.969$). In the terrestrial habitat, species were most evenly ($E = 0.630$) distributed. Among the six micro-habitats, shallow water-body holds 75 species and 2025 individuals of avifauna which was the highest. The highest diversity value of bird species was detected in the agricultural land (Table 1).

Table 1. Diversity indices of bird in the study area

Type	Category	S	A	Ds	H	E
Site	Beel	128	3244	0.9774	4.154	0.4925
	Rural	105	1145	0.9688	4.142	0.6051
	Urban	62	854	0.9705	3.771	0.7007
Season	PRW	50	688	0.9715	3.728	0.8321
	PW	107	1555	0.97	4.256	0.6594
	W	161	3000	0.983	4.352	0.4821
Macro-Habitat	Aquatic	129	3488	0.9694	4.15	0.4915
	Arboreal	67	1114	0.9638	3.648	0.5732
	Terrestrial	58	641	0.9645	3.599	0.6304
Micro-habitat	AL	57	488	0.9664	3.661	0.6822
	FP	41	902	0.9597	3.406	0.7351
	HF	65	1056	0.9643	3.65	0.592
	SHW	75	2035	0.9336	3.492	0.4379
	TAB	28	500	0.858	2.588	0.4752
	US	15	262	0.9037	2.484	0.7993

[**Note-** Species richness (S), Species abundance (A); Simpson's Index (Ds); Shannon-Weiner Index (H); Evenness (E); PRW- Pre-winter, PW-Post Winter and W-Winter; AG- Agricultural land, HF- Homestead forest, SW- Swallow water body, US- Urban settlements, TAB- Tree associated with beel, FP- Floating plant]

Avian communities between homestead forest and Tree associated beels habitats, Agricultural land and floating plant habitat shared more species which are similar and formed small clusters in similarity plot (Fig. 8).

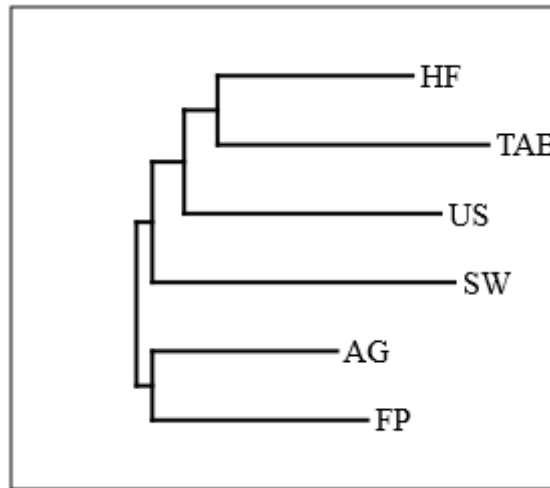


Fig. 8. Similarity profile test among microhabitats using the Bray-Curtis index [Note- AG- Agricultural land, HF- Homestead forest, SW- Swallow water body, US- Urban settlements, TAB- Tree associated with beel, FP- Floating plant].

The highest species richness (129 species) and abundance ($n = 3488$ indiv.) were found in aquatic macro-habitats, confirming the productivity and resource concentration of wetlands (Jaman et al., 2023a). But terrestrial and arboreal habitats also made a significant contribution to provide foraging ground for raptors and passerines. The comparatively high diversity of agricultural lands suggests that traditional agro-ecosystems can support multifunctional bird communities when ponds, hedgerows, and tree stands are scattered across the study sites (Benton et al., 2003). These results are consistent with the conservation biology concept of "working landscapes," which integrates agricultural production with biodiversity conservation (Polasky et al., 2005). Interestingly, despite lower richness, urban areas showed the highest evenness values. This suggests that while urban expansion reduces specialist species, it allows adaptable species to persist with relatively stable population distributions (Shome et al., 2022). However, continued infrastructure development and pollution could shift this balance toward biotic homogenization if unmanaged.

Threatened Status, threats, and Conservation challenges: Among the observed avian species one species was Critically Endangered (*Mycteria leucocephala*), one Endangered (*Clanga hastata*), five Vulnerable (*Anser erythropus*, *Aquila heliaca*, *Clanga clanga*, *Leptoptilos javanicus*, *Threskiornis melanocephalus*), four Near Threatened (*Anhinga melanogaster*, *Ichthyophaga ichthyaetus*, *Limosa limosa*, *Pernis ptilorhynchus*), two Data Deficient (*Circus*

spilonotus, *Lymnocyrtus minimus*), one Not Assessed (*Pseudibis papillosa*) and rest were Least concern according to the IUCN Bangladesh assessment (2015). The presence of seven nationally threatened birds among 38 species indicates high conservation value of the study area. All the mentioned avian species are wetlands habitat specialist birds which also indicates the conservation urgency of wetlands and associated habitat.

From the study area different types of threats were observed like hunting, use of agricultural net for protecting crops, pollution and urban expansion. In the study area, field observation expressed that in the rural and the urban site agricultural net use cause threats for a number avian species and in the rural area affected avian diversity was comparatively higher specially forest habitat specialist group like Owl, Woodpecker, Drongo, Parakeet, Nightjar, Dove, Pigeon, Bulbul, Mayna, Starling, etc. In the beel area according to the local people aquatic specialist bird species like, migratory duck, ibis, stork, grebe, waders are declining and vanishing rapidly

Protected areas in Bangladesh cover only a limited fraction of its forest or terrestrial habitat where inland wetland ecosystems are totally ignored, and many biologically rich floodplain habitats remain outside formal management frameworks. In line with global assessments of transboundary conservation effectiveness, integrating Gomastapur's wetlands into a broader cross-border conservation strategy could enhance ecological connectivity and climate resilience.

Community-based co-management, strict regulation of hunting and net trapping, wetland zoning, and maintenance of native tree cover around beels should have conservation priorities. Given the high winter influx of migratory birds, seasonal protection measures during peak migration months would be particularly effective. Moreover, landscape-level monitoring using remote sensing and long-term ecological surveys could refine adaptive management strategies.

Plate 1. Birds photos captured during field study



Himantopus himantopus



Ardea purpuria



Calidris minuta



Limosa limosa



Anastomas oscitans



Flock of waders

*Ardea albus**Anhinga melanogaster**Ardea cinerea**Tadorna ferruginea*

Conclusions

The Gomastapur's transboundary floodplain is an ecologically important habitat in terms of avian biodiversity conservation perspective due to the high bird biodiversity values (172 species) along with the seven wetlands specialist nationally threatened avian species. It has conservation obligations due to rapid increase of wetland degradation and decrease in the number of migratory birds. Transboundary wetlands of the Ganges floodplain serve as significant biodiversity hotspots, migratory refugia, and ecological buffers within a human-dominated environment, as evidenced by the high species richness, extensive fluctuation of seasonality, and presence of vulnerable taxa. These results demonstrate the necessity of expanding Bangladesh's bird conservation goals to include strategically significant floodplain mosaics in addition to protected areas. To conserve avifaunal diversity in this quickly evolving landscape, it may be crucial to preserve wetlands in their natural state especially during the winter season. In addition, for the

protection of migratory birds it is necessary to improve cross-border cooperation, increase local awareness, and apply science-based habitat management.

Authors' Contribution

Ashikur Rahman Shome: Conceptualization; data curation; investigation; methodology; formal analysis; software; visualization; writing original draft; writing–review and editing, **Md. Fazle Rabbe:** Conceptualization; data curation; investigation; methodology; formal analysis; software; visualization, writing–review and editing, **Md. Mahabub Alam:** Conceptualization; data curation; investigation; methodology, **Md. Tanvir Mia:** Data curation; investigation, **Shakila Nargis:** Data curation; investigation, review and editing, **Nabila Zaman Joty:** Data curation; investigation, review and editing and **Mohammad Firoj Jaman:** Conceptualization; data curation; investigation; funding acquisition; project administration; resources; supervision; validation; methodology; formal analysis; software; visualization, writing–review and editing.

Acknowledgement

The authors express their sincere gratitude to the Chairman, Department of Zoology, University of Dhaka, for granting permission to use the facilities of the Wildlife Laboratory. The authors also gratefully acknowledge the financial support provided by the Ministry of Science and Technology, Government of the People's Republic of Bangladesh, for conducting this research.

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(Manuscript Received on 16 March, 2026; Accepted on 28 June, 2026)