sciendo

Ornis Hungarica 2026. 34(1): 369–384.
DOI: 10.2478/orhu-2026-0026

Diversity dynamics of waterbirds along the bird migration flyways: Insights from lotic and lentic wetlands in eastern India

Arkajyoti MUKHERJEE[1,4#], Sagar ADHURYA[2,4#]*, Manish Kumar CHATTOPADHYAY[3,4#], Saikat ADHURYA[4], Sankha MISRA[4], Ajoy Kumar DAWN[4], Arindam ROY[4], Diptesh GOSWAMI[4], Anupam KHAN[5], Bidyut SARKAR[5] & Gourav Dhar BHOWMICK[1]

Received: June 09, 2025 – Revised: November 11, 2025 – Accepted: November 24, 2025

Mukherjee, A., Adhurya, S., Chattopadhyay, M. K., Adhurya, S., Misra, S., Dawn, A. K., Roy, A., Goswami, D., Khan, A., Sarkar, B. & Bhowmick, G. D. 2026. Diversity dynamics of waterbirds along the bird migration flyways: Insights from lotic and lentic wetlands in eastern India. – Ornis Hungarica 34(1): 369–384. DOI: 10.2478/orhu-2026-0026

Abstract Wetlands in Paschim Bardhaman, West Bengal, India, represent vital habitats for migratory and resident waterbirds along the East Asian–Australasian and Central Asian Flyways. This study assessed waterbird diversity across 11 lotic and lentic wetlands from 2020 to 2025, analysing species richness, abundance, and diversity indices. Using modified total count methods, 78 species were recorded, with Durgapur Barrage and Burnpur Riverside showing the highest abundance and richness, respectively. Alpha-diversity indices revealed significant site-level variations, while beta-diversity analyses highlighted distinct species compositions, particularly at species-poor sites like Nachan Dam. Cluster analysis grouped sites based on species abundance, revealing both ecological similarity and distinctiveness. The widespread dominance of Lesser Whistling-Duck and localized records of rare species such as Falcated Duck and Common Merganser underscore the conservation significance of both high- and low-diversity wetlands. The findings stress the importance of a landscape-scale conservation strategy integrating habitat heterogeneity, anthropogenic impacts, and flyway connectivity. Long-term monitoring and habitat-specific management are essential to ensure the ecological integrity of these transitional wetlands during rapid urban and industrial expansion.

Keywords: wetlands, waterbirds, Paschim Bardhaman, beta-diversity, abundance, richness

Összefoglalás A nyugat-bengáli Paschim Bardhamanban található vizes élőhelyek létfontosságú területet jelentenek a vonuló és állandó vízimadarak számára a kelet-ázsiai–ausztrál-ázsiai és a közép-ázsiai madárvonulási útvonalak mentén. Ez a tanulmány a vízimadarak diverzitását vizsgálta 11 lotikus és lentikus vizes élőhelyen 2020 és 2025 között, elemezve a fajgazdagságot, a tömegességet és a diverzitási mutatókat. Módosított teljes számlálási módszerrel 78 fajt regisztráltak, melyek során a legmagasabb abundanciát és fajgazdagságot a Durgapur-gát és a Burnpur-folyópart mutatta. Az alfa-diverzitás indexek jelentős területi szintű eltéréseket mutattak, míg a béta-diverzitásra vonatkozó elemzések a fajösszetételre világítottak rá, különösen a fajszegény területeken, mint például a Nachan-gáton. A klaszteranalízis a fajgazdagság alapján csoportosította a helyszíneket, ami az ökológiai hasonlóságot és a különbözőségeket egyaránt feltárta. A bengáli fütyülőlúd széles körű dominanciája és az olyan ritka fajok, mint a sarlós réce és a nagy bukó lokális előfordulása kiemeli mind a nagy, mind az alacsony változatosságú vizes élőhelyek természetvédelmi jelentőségét. Az eredmények hangsúlyozzák az élőhelyek heterogenitását, az antropogén hatásokat és a repülési útvonalak összekapcsolhatóságát integráló, táji léptékű védelmi stratégia fontosságát. A hosszú távú megfigyelés és az élőhelyspecifikus gazdálkodás alapvető fontosságú ezen átmeneti vizes élőhelyek ökológiai integritásának biztosításához a gyors városi és ipari terjeszkedés közepette.

Kulcsszavak: vizes élőhelyek, vízimadarak, Paschim Bardhaman, béta-diverzitás, abundancia, fajgazdagság

[1] Agricultural & Food Engineering Department, Indian Institute of Technology, Kharagpur-721302, West Bengal, India
[2] Department of Zoology, Government General Degree College at Mangalkote, Purba Bardhaman-713132, West Bengal, India
[3] Seacom Skills University, Kendradangal, Bolpur, Birbhum 731236, West Bengal, India
[4] Durgapur Wildlife Information and Nature Guide Society, Durgapur, Paschim Bardhaman-713206, West Bengal, India
[5] West Bengal Forest Department, Kolkata-700106, West Bengal, India
* corresponding author, e-mail: sagaradhurya@gmail.com (# authors can be considered as the first author for their equal contributions)

Introduction

Wetlands are among the world's most productive ecosystems, yet they face mounting threats from anthropogenic pressures and environmental change (Froneman *et al.* 2001). Widespread reclamation for agriculture, rapid urbanization, and unregulated development have contributed to their alarming degradation, with nearly half lost since the early 20th century (McKinney 2002). These ecosystems are crucial for resident and migratory waterbirds, providing sites for feeding, breeding, roosting, and nesting. Wetland degradation has significantly contributed to global decline in waterbird populations (Zakaria & Rajpar 2013). In turn, waterbirds support ecological balance through seed dispersal, pest control, and nutrient cycling, making them effective bioindicators of wetland health. Assessing their diversity offers vital insights into ecosystem integrity.

Bird community composition is shaped by habitat features, which vary across regions. Habitat heterogeneity, especially in vegetation and water availability, enhances avian richness (Sebastian-Gonzalez & Green 2014). Conversely, habitat fragmentation and land-use change often lead to biodiversity loss (Xu *et al.* 2024). As sensitive ecological indicators, birds help assess both qualitative and quantitative habitat conditions (Adhurya *et al.* 2020, Mukherjee *et al.* 2021, 2022).

Bird diversity is commonly measured as alpha (species richness within a habitat) and beta (species turnover between habitats) diversity. These metrics reflect how factors such as habitat structure, water quality, and food availability influence species distribution (Almeida *et al.* 2018).

This study focuses on wetlands of Paschim Bardhaman, located between the Ajay, Damodar, and Barakar rivers, and features diverse landscapes shaped by the degraded plateau and plateau-fringe fan zones (Bandhopadhyay *et al.* 2014). Rocky hillocks, lateritic soils, and varied hydrological features support significant wetland formations. However, extensive deforestation and urban expansion, driven by coal mining and industry, have transformed the region.

The district has a transitional climate with hot summers, monsoonal rains, and mild winters. Annual rainfall averages around 1,408 mm (Ghorai *et al.* 2018). Land cover changes between 1993 and 2015 show a marked increase in settlements and a decline in vegetation (Hati *et al.* 2025).

Historical bird records by Gauntlett (1971, 1985) documented nearly 300 species in the region, highlighting its importance for both resident and migratory waterbirds, while a recent study has reported 73 bird species from a wetland in Durgapur (Adhurya *et al.* 2019).

The present study aims to compile a comprehensive checklist of waterbirds from eleven significant lotic and lentic wetlands within the Paschim Bardhaman district, which serve as important wintering grounds along the East Asian–Australasian Flyway (EAAF) and the Central Asian Flyway (CAF). It further evaluates spatial patterns in species richness and abundance, and examines changes in waterbird diversity over the period from 2020 to 2025. Given the district's unique geographical positioning and ecological characteristics, the findings of this study are expected to enhance understanding of avifaunal dynamics in transitional landscapes and inform evidence-based wetland conservation efforts.

Material and Methods

Study area

Eleven lotic and lentic wetlands were selected for the present study. These sites are Burnpur riverside (W1), Chittaranjan wetland complex (W2), Choti Raniganj (W3), Durgapur barrage (W4), Gunjan ecological park (W5), IISCO ash pond (W6), Maithon dam (W7), Mudir bandh (W8), Nachan dam (W9), Sukho bandh (W10), and Vaska (W11). Details of the wetlands are represented in *Table 1*, and locations are depicted in *Figure 1*.

Table 1. Description of the study sites
1. táblázat A vizsgálati helyek leírása

Sl. No.	Name	Code	Location	Description
1	Burnpur Riverside	W1	23.6301283 86.9709935	The Burnpur stretch of the Damodar River features an interlaced river system, characterized by exposed sandbanks, gravel beds, and grasslands. These open habitats provide ideal foraging grounds for winter migratory waders. The adjacent grassland patches can also support ground-nesting or grassland-associated residents and migrants. Water levels fluctuate seasonally, exposing nutrient-rich substrates that enhance invertebrate abundance, crucial for feeding migratory shorebirds.
2	Chittaranjan Wetland Complex	W2	23.8682571 86.9071555	This is a wetland complex located within the urban matrix of Chittaranjan town, hydrologically connected to the Ajay River system. These wetlands comprise a network of reservoirs and embankments, providing permanent freshwater habitats amid urban pressure. Despite anthropogenic influences, it supports a high diversity of migratory anatids during winter. The connectivity with the Ajay River facilitates periodic influxes of nutrients, enriching the habitat's trophic dynamics. Commercial fishing and the unscientific management of the wetland vegetation are the major problems.

Sl. No.	Name	Code	Location	Description
3	Choti Raniganj	W3	23.7662575 86.9732974	An artificial water body, Choti Raniganj, is primarily managed for extensive fish farming. The seasonal nature of the water body creates a dynamic aquatic-terrestrial interface that is particularly attractive to waterbirds. Post-monsoon drawdown periods expose mudflats, providing feeding sites for migratory waders. Fish farming activities may indirectly support piscivorous bird species through increased prey availability.
4	Durgapur Barrage	W4	23.4760583 87.3031139	Durgapur Barrage, located on the Damodar River in the border of Bankura and Paschim Bardhaman districts, serves as a seasonal habitat for various waterbird species, especially during winter. The reservoir and its adjacent wetlands attract migratory and resident birds, offering foraging and roosting opportunities. Its mix of shallow and deep waters supports a diversity of species, including waders and ducks. Major Problems are disturbance from human activities such as fishing, boating, and illegal sand mining, pollution from industrial and domestic wastewater, fluctuating water levels disrupting bird foraging zones, and habitat degradation due to encroachment and lack of conservation management.
5	Gunjan Ecological Park	W5	23.6706350 87.0267016	This is a semi-natural water body within a curated ecological park setting. Surrounded by a patch of semi-deciduous tree cover, the site experiences moderate anthropogenic disturbance due to recreational use. However, the mosaic of aquatic vegetation and woodland edge offers suitable microhabitats for waterbirds during winter. The presence of semi-natural patches and regulated human activity makes it a moderately favorable site for wintering species that tolerate human presence.
6	IISCO Ash Pond	W6	23.6344079 86.9515660	Situated within the Burnpur Steel Plant premises, this industrial water body functions primarily as a sedimentation pond. Although engineered for industrial utility, it holds potential as a valuable roosting and foraging site for waterbirds. The relatively undisturbed water surface, especially in winter, can serve as a nocturnal roosting refuge. One bank, fringed with *Typha* vegetation, further enhances its suitability by providing cover and potential nesting habitat.
7	Maithon Dam	W7	23.8151268 86.8455940	Maithon Dam, situated on the Barakar River, serves as an important wintering habitat for a variety of waterbirds, including migratory ducks and waders, thanks to its expansive reservoir, mudflats, and vegetated margins. The majority of the area is located in Jharkhand. Despite its ecological value, the site faces several threats such as fluctuating water levels due to hydropower operations, disturbance from recreational activities like boating, pollution from nearby settlements and industries, and gradual loss of shoreline vegetation due to erosion and encroachment.

Sl. No.	Name	Code	Location	Description
8	Mudir Bandh	W8	23.6608367 87.3090333	Mudir Bandh is a seasonal freshwater impoundment, dependent largely on monsoonal recharge. Used extensively for fish farming, the water body supports a combination of shallow and deeper zones. These microhabitats attract various bird species during winter. When water levels recede in winter, exposed edges and muddy margins provide excellent feeding grounds for wading species. Agricultural runoff may enhance productivity, but it also influences water quality.
9	Nachan Dam	W9	23.6182125 87.3188655	Nachan Dam, located near Durgapur in West Bengal, is a relatively small yet ecologically significant waterbody that supports a variety of waterbirds, particularly during the winter months. This large irrigation reservoir is mainly fed by monsoon precipitation. Its shallow zones, mudflats, and patches of emergent vegetation provide suitable foraging and roosting habitats for species like herons, egrets, storks, and migratory ducks. The dam's relatively low human disturbance makes it a quiet refuge for avifauna, though increasing encroachment and water pollution pose emerging threats.
10	Sukho Bandh	W10	23.6435346 87.2372727	Sukho Bandh, an artificial wetland hydrologically and ecologically similar to Mudir Bandh, supports both irrigation and aquaculture activities. Seasonal water level fluctuations create a dynamic wetland environment, while the surrounding agricultural mosaic enhances habitat heterogeneity, benefiting edge-dwelling and generalist bird species. Periodic exposure of mudflats in late winter offers critical foraging grounds for migratory shorebirds. However, rapid urbanization in the surrounding areas poses a growing threat through habitat loss, pollution, and increased human disturbance.
11	Vaska	W11	23.6574654 87.2951736	Located within or adjacent to mango orchards, this monsoon-dependent water body is part of an agro-wetland landscape. The interface of cultivated orchards and seasonal wetlands creates a mixed habitat. The presence of surrounding fruit trees also provides food sources and roosting sites for insectivorous and frugivorous migrants during the winter.

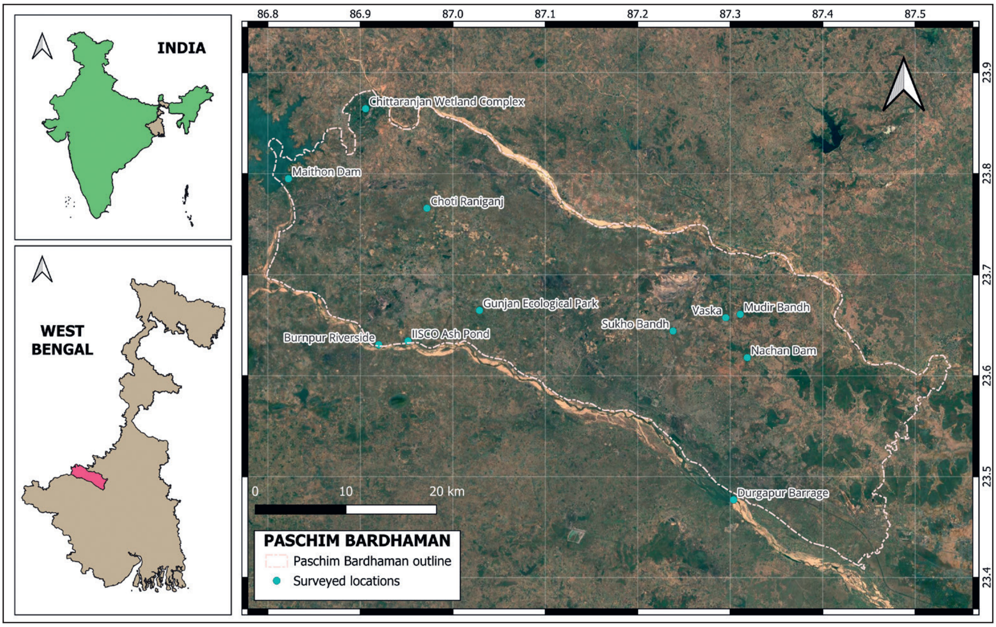

Figure 1. Location of the study sites. The map on the top left indicates the relative location of the state of West Bengal in the map of India. The map on the bottom left indicates the relative location of the Paschim Bardhaman district in the map of West Bengal. The map on the right side shows the study sites in the satellite map of the Paschim Bardhaman district

1. ábra A vizsgálati helyszínek elhelyezkedése. A bal felső térkép Nyugat-Bengál állam Indián belüli, a bal alsó térkép a Paschim Bardhaman körzet Nyugat-Bengálián belüli elhelyezkedését mutatja. A jobb oldali térképen a vizsgálati helyszínek műholdfelvételei láthatók

Bird count

Each of the 11 study sites was surveyed over three consecutive days during the peak wintering period in eastern India (1–31 January from 2020 to 2025) to record waterbird abundance and distribution by two teams of experts (CMS Technical Series 2014). At wetlands ≤100 m wide, observers walked one to five 1-km transects, depending on wetland length, covering all accessible sides. Six fixed observation points, spaced 200 m apart, were established on each transect. For larger wetlands (>100 m wide), surveys were conducted using a country boat along 100 m-spaced imaginary grid lines, with observations made from 200 m intervals, recording birds within a 50 m radius on either side of the line (Mukherjee *et al.* 2022). Surveys were conducted independently by three trained observers at three time intervals: 06:00–07:00, 12:00–13:00, and 17:00–18:00. Flying birds were recorded separately (Bibby *et al.* 1998), and weather conditions were noted at the start of each session. Daily counts were averaged to obtain a representative site-level abundance. This approach minimized short-term weather and observer variability while ensuring temporal comparability across years within the defined mid-winter window.

Equipment used included a TruePlus 360 Laser Range Finder, Nikon Fieldscope (25–75×82 ED), Bushnell Equinox Z (4.5×40) night vision, and Nikon Action (10×50) binoculars. Raw counts were averaged site-wise to generate abundance indices (Gibbons & Gregory 2006). Species identification and nomenclature followed Grimmett *et al.* (2011).

Diversity calculations

The alpha-diversity was analysed to assess species richness within individual habitats and the beta-diversity to evaluate changes in species composition across habitats, following Whittaker (1972). Alpha-diversity was quantified using the Shannon–Wiener index (H′), which is sensitive to rare species (Pielou 1969), along with Simpson's dominance index (D_{simp}), Pielou's evenness index (J′), and Margalef's richness index (D_{marg}). These indices were calculated using PAST v4.17, each offering complementary insights into community structure: H′ and D_{simp} reflect proportional abundance (favouring rare vs. common species, respectively), J′ indicates species evenness, and D_{marg} combines richness and abundance. Chao1 was used to calculate the estimated species richness based on singleton and doubleton species. The Chao1 estimator provides a lower-bound estimate of species richness by adjusting observed richness for unseen taxa based on the number of singleton (f_1) and doubleton (f_2) species in the sample. The estimator is defined as

$$\hat{S}_{Chao1} = S_{obs} + \frac{f_1^2}{2f_2}$$

where S_{obs} is the observed number of species. Chao1 is particularly useful when rare species are present and sampling is incomplete (Chao 1987).

For beta-diversity, we used Whittaker's index (βw) for presence/absence data scaled from 0 (complete similarity) to 1 (maximum dissimilarity) (Baselga 2010). βw is suited for species list comparisons, and it may be influenced by dominant species (Chao *et al.* 2006).

Statistical analyses

Hierarchical cluster analysis of waterbird assemblages across the eleven wetlands was performed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) based on normalized species-wise abundance data, employing the Euclidean similarity index to quantify inter-site dissimilarity, which is suitable for analyses emphasizing absolute abundance patterns.

Differences in total species abundance among wetlands were evaluated using one-way ANOVA followed by Tukey's Honestly Significant Difference (HSD) post-hoc test ($p < 0.05$) (Derrac *et al.* 2011). Abundance data were $\log_{10}(x + 1)$ transformed to meet assumptions of normality and homoscedasticity, which were verified using Shapiro–Wilk and Levene's tests, respectively. *Table 2* presents adjusted *p*-values from pairwise comparisons between wetlands (W1–W11). These results indicate the strength and direction of abundance contrasts across sites under a common sampling framework; they are interpreted as comparative rather than inferential indicators of community difference. As this analysis aims to identify relative abundance differences rather than to model temporal dynamics, no further model-based testing was performed at this stage. We acknowledge that temporal and observer effects may influence absolute values, but the results robustly describe spatial differentiation among wetlands during the peak winter period.

Table 2. Pairwise comparison of species abundance between the wetlands. *Denotes significant differences, level of significance at $p < 0.05$ (W1-Burnpur Riverside, W2-Chittaranjan Wetland Complex, W3-Choti Raniganj, W4-Durgapur Barrage, W5-Gunjan Ecological Park, W6-IISCO Ash Pond, W7-Maithon Dam, W8-Mudir Bandh, W9-Nachan Dam, W10-Sukho Bandh, W11-Vaska)

2. táblázat A különböző vizes élőhelyek madárfajai abundanciájának páronkénti összehasonlítása. * jelöli a szignifikáns különbségeket $p < 0.05$ szinten (W1-Burnpur Riverside, W2-Chittaranjan Wetland Complex, W3-Choti Raniganj, W4-Durgapur Barrage, W5-Gunjan Ecological Park, W6-IISCO Ash Pond, W7-Maithon Dam, W8-Mudir Bandh, W9-Nachan Dam, W10-Sukho Bandh, W11-Vaska)

	W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**
W2	0.43080									
W3	0.00002*	0.000090*								
W4	0.41450	0.977500	0.000001*							
W5	0.00040*	0.000030*	0.0864	0.00004*						
W6	0.00008*	0.000003*	0.8744	0.000004*	0.0611					
W7	0.00010*	0.000090*	0.0562	0.00001*	0.8454	0.0387*				
W8	0.00002*	0.000008*	0.5187	0.000001*	0.0183*	0.6261	0.0106*			
W9	0.000001*	0.000009*	0.2240	0.000001*	0.0034*	0.2901	0.0018*	0.5683		
W10	0.000001*	0.000001*	0.3658	0.000001*	0.0088*	0.4555	0.0049*	0.7956	0.7554	
W11	0.000004*	0.000002*	0.6072	0.000002*	0.0258*	0.7219	0.0154*	0.8956	0.4828	0.6963

Results

Species richness and abundance

A total of 78 species of waterbirds and wetland-associated birds were recorded across the eleven study sites during the survey period. The family Anatidae accounted for the highest species richness, with 15 species documented. Of the total species recorded, 41 were winter migrants, while the remaining were resident or local migrant species. Notably, the Common Pochard *(Aythya ferina)* is listed as Vulnerable on the IUCN Red List, while the Asian Woolly-necked Stork *(Ciconia episcopus)* and Lesser Adjutant *(Leptoptilos javanicus)* are classified as Near Threatened.

During the entire study period, the highest overall bird abundance was recorded at the Durgapur Barrage (W4), followed by the Chittaranjan Wetland Complex (W2), Sukho Bandh (W10), and the lowest at Nachan Dam (W9), Gunjan Ecological Park (W5). The highest abundance of waterbirds (3,252 individuals) was recorded in the Durgapur Barrage (W4) in 2022, followed by 2020 (2,949). In terms of species richness, the Burnpur Riverside (W1) recorded the highest number of species (63), followed by W4 (60) and W2 (59). Conversely,

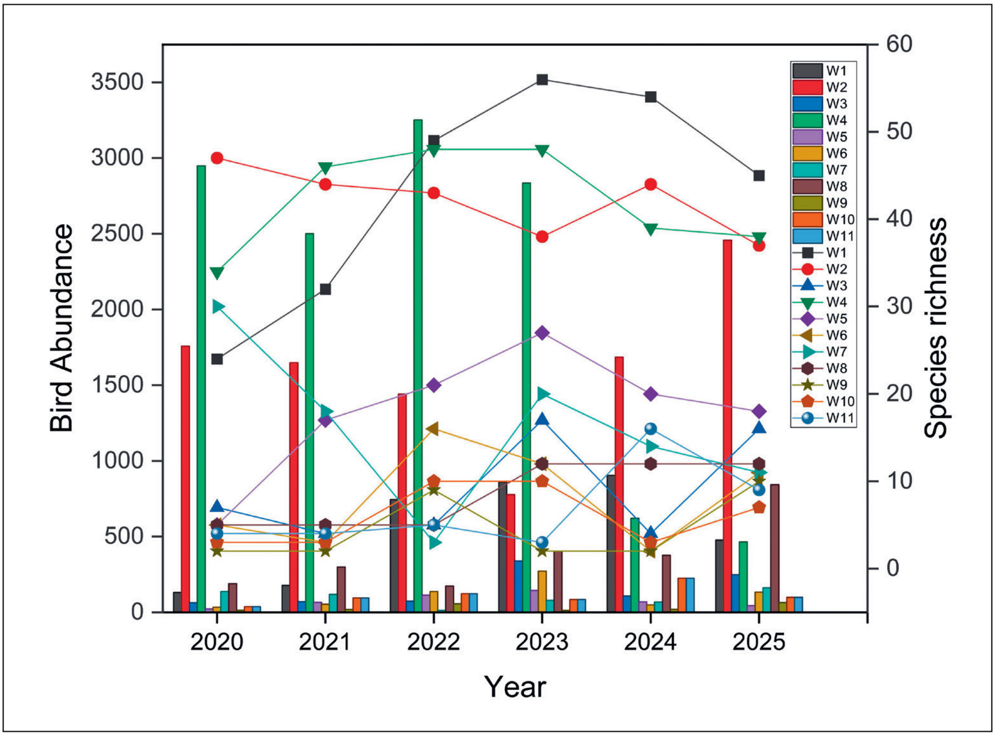

Figure 2. Year-wise variation in species richness and abundance in the study sites
2. ábra A fajgazdagság és a tömegesség évenkénti változása a vizsgált területeken

the lowest species richness was observed at W9 (13), W10 (15), and Mudir Bandh (W8) (17). Year-wise variations in abundance and species richness across the study sites are represented in *Figure 2*. Pairwise differences in species abundance among study sites are represented in *Table 2.* Pairwise Tukey HSD tests revealed clear spatial heterogeneity in species abundance among the eleven wetlands. Several sites, notably Choti Raniganj (W3), Durgapur Barrage (W4), and Maithon Dam (W7), differed significantly from multiple others ($p < 0.05$), underscoring distinct community assemblages. The small p-values reflect consistent between-site contrasts under standardized sampling conditions and thus, denote consistent spatial patterns.

Diversity indices

The highest Simpson's diversity index (D_{simp}) was recorded at W10 (0.834), followed by W8 (0.675). In contrast, the lowest D_{simp} values were observed at W5 (0.057) and W7 (0.093). The evenness index (J′) exhibited an inverse pattern, with W5 showing the highest evenness (0.755), while W4 had the lowest (0.100). The highest Shannon diversity index (H′) was recorded at W1 (3.524), followed by W5 (3.216). W10 and W8 exhibited the lowest diversity, with H′ values of 0.440 and 0.762, respectively. Similarly, species richness measured by Margalef's index (D_{marg}) was highest on the W1 (9.896) and lowest at W10 (2.189). The

Chao1 richness estimator also peaked at W1, indicating a higher estimated species richness. Waterbird community attributes are tabulated in *Table 3*.

The present study revealed that Whittaker's index of beta-diversity on presence/absence data (βw) was the highest (0.73) between W6 and W10 *(Table 4)*. The βw was also comparable between the W2 and W9 (0.69) and W4 and W9 (0.67), W7 and W9 (0.67), and

Table 3. Community attributes of waterbirds in different wetlands during the total study tenure (W1-Burnpur Riverside, W2-Chittaranjan Wetland Complex, W3-Choti Raniganj, W4-Durgapur Barrage, W5-Gunjan Ecological Park, W6-IISCO Ash Pond, W7-Maithon Dam, W8-Mudir Bandh, W9-Nachan Dam, W10-Sukho Bandh, W11-Vaska)

3. táblázat A különböző vizes élőhelyeken előforduló madarak közösségi jellemzői (W1-Burnpur Riverside, W2-Chittaranjan Wetland Complex, W3-Choti Raniganj, W4-Durgapur Barrage, W5-Gunjan Ecological Park, W6-IISCO Ash Pond, W7-Maithon Dam, W8-Mudir Bandh, W9-Nachan Dam, W10-Sukho Bandh, W11-Vaska)

Sl. No.	Community attributes	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11
1	Species richness	63	59	21	60	33	22	36	17	13	15	18
2	Mean Abundance	526	1604	143	2078	64	107	81	374	24	600	102
3	D_{simp}	0.046	0.390	0.422	0.313	0.057	0.385	0.093	0.675	0.191	0.834	0.301
4	H'	3.524	1.949	1.545	1.790	3.216	1.511	2.907	0.762	2.147	0.440	1.635
5	J'	0.538	0.119	0.223	0.100	0.755	0.206	0.508	0.126	0.659	0.104	0.290
6	D_{marg}	9.896	7.859	4.03	7.723	7.694	4.494	7.965	2.701	3.776	2.189	3.676
7	Chao 1	63.17	59	26.69	60.5	33.99	22	36.99	17	13	15	18

Table 4. Beta-diversity or species turnover of birds between study sites (W1-Burnpur Riverside, W2-Chittaranjan Wetland Complex, W3-Choti Raniganj, W4-Durgapur Barrage, W5-Gunjan Ecological Park, W6-IISCO Ash Pond, W7-Maithon Dam, W8-Mudir Bandh, W9-Nachan Dam, W10-Sukho Bandh, W11-Vaska)

4. táblázat A madarak béta diverzitása vagy fajváltozása a különböző vizsgálati területeken (W1-Burnpur Riverside, W2-Chittaranjan Wetland Complex, W3-Choti Raniganj, W4-Durgapur Barrage, W5-Gunjan Ecological Park, W6-IISCO Ash Pond, W7-Maithon Dam, W8-Mudir Bandh, W9-Nachan Dam, W10-Sukho Bandh, W11-Vaska)

	W1									
W2	0.18	**W2**								
W3	0.55	0.48	**W3**							
W4	0.14	0.23	0.51	**W4**						
W5	0.33	0.33	0.44	0.31	**W5**					
W6	0.53	0.46	0.53	0.54	0.38	**W6**				
W7	0.33	0.26	0.51	0.31	0.33	0.52	**W7**			
W8	0.60	0.55	0.26	0.56	0.36	0.49	0.55	**W8**		
W9	0.66	0.69	0.35	0.67	0.52	0.60	0.67	0.27	**W9**	
W10	0.67	0.62	0.44	0.65	0.63	0.73	0.61	0.56	0.64	**W10**
W11	0.60	0.56	0.38	0.59	0.41	0.45	0.63	0.26	0.42	0.45

W1 and W10 (0.67). However, the lowest βw was recorded between W1 and W4 (0.14) and W1 and W2 (0.18) *(Table 4)*.

Cluster analysis based on the abundance of waterbirds

Three distinct clusters were identified and depicted in *Figure 3*. The primary cluster consisted of seven study sites with relatively similar linkage distances, indicating abundance similarity. The secondary cluster included two sites characterized by larger and more variable linkage distances. The tertiary cluster, comprising the W2 and W4, exhibited the highest linkage distances, suggesting these sites are the most distinct from the others.

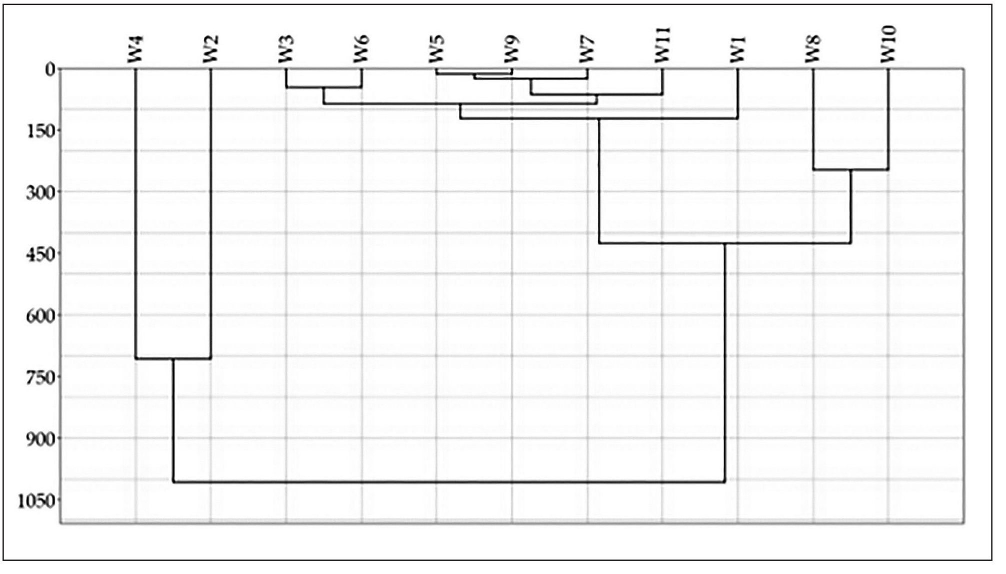

Figure 3. Hierarchical cluster analysis of study sites based on species abundance and diversity using the unweighted pair-group method (UPGMA) (W1-Burnpur Riverside, W2-Chittaranjan Wetland Complex, W3-Choti Raniganj, W4-Durgapur Barrage, W5-Gunjan Ecological Park, W6-IISCO Ash Pond, W7-Maithon Dam, W8-Mudir Bandh, W9-Nachan Dam, W10-Sukho Bandh, W11-Vaska)

3. ábra A vizsgált területek hierarchikus klaszteranalízise a fajok gyakorisága és diverzitása alapján a súlyozatlan párcsoportos módszerrel (UPGMA)

Abundant species and rare records

The Lesser Whistling-duck *(Dendrocygna javanica)* was the most abundant species across most wetlands during the study period, followed by the Small Pratincole *(Glareola lactea)*. Three other anatid species – Red-crested Pochard *(Netta rufina)*, Gadwall *(Mareca strepera)*, and Cotton Pygmy Goose *(Nettapus coromandelianus)* – were also commonly observed across multiple sites. The Barn Swallow *(Hirundo rustica)* was another species frequently recorded in high numbers.

In contrast, five species were recorded only once during the entire study period, each from a single site. A lone male Falcated Duck *(Mareca falcata)* was observed at the W2 in 2022, followed by two Northern Shovelers at the same site in 2024. A female Common Merganser *(Mergus merganser)* was recorded in 2025 from the W1. The W4 yielded some notable records, including Pallas's Gull *(Ichthyaetus ichthyaetus)* (2022), Black-headed Gull *(Chroicocephalus ridibundus)* (2024), and River Tern *(Sterna aurantia)* (2022), all of which were exclusive to this site.

Discussion

Birds migrating to the Indian subcontinent primarily follow two major migratory routes: the East Asian–Australasian Flyway (EAAF) and the Central Asian Flyway (CAF) (Li *et al.* 2009, Dhanjal-Adams *et al.* 2017, CAF National Action Plan – India 2018). The EAAF connects breeding grounds in northeast Asia to wintering sites across Southeast Asia and Australia (Li *et al.* 2019), while the CAF extends from the northernmost breeding areas in Russia to wintering grounds across West and South Asia, the Maldives, and the British Indian Ocean Territory (CAF National Action Plan – India 2018).

This study presents a comprehensive, six-year assessment (2020–2025) of waterbird diversity across eleven wetlands in Paschim Bardhaman, West Bengal, an ecologically transitional landscape influenced by extensive mining activity. The results reveal marked spatial variation in species richness, abundance, and diversity indices, shaped by differences in hydrological regimes, habitat structure, and anthropogenic pressures. These findings highlight the value of long-term, site-specific monitoring for understanding waterbird dynamics and informing conservation strategies along critical sections of the EAAF and CAF.

The W4 consistently supported the highest waterbird abundance, likely due to its expansive surface area, reliable water availability, and diverse microhabitats, including rock beds, mudflats, sand dunes, aquatic vegetation, and adjacent agricultural fields. Similarly, W1 and the W2 complex recorded high species richness, suggesting that these sites offer a combination of structural habitat diversity and optimal ecological resources that support both generalist and specialist species. Notably, Lesser Whistling-ducks were abundant in both W2 and W4 wetlands. W1 also harbored a steady population of Lesser Whistling-ducks. This locally migratory species was present across nearly all study sites, although its abundance varied. High densities of Lesser Whistling-ducks in the wetlands of southern West Bengal have also been reported by Nandi *et al.* (2004), indicating consistent regional preferences. However, despite their current importance, species richness in W1, W2, and W4 has shown a gradual decline over the study period. This trend may be attributed to increasing anthropogenic pressures and land use and land cover (LULC) changes in surrounding areas (Hati *et al.* 2025). In contrast, wetlands such as W9, W10, and W8 consistently exhibited low species richness and abundance, likely due to limited habitat complexity, higher human disturbance, and reduced water retention during the peak wintering season.

Beta-diversity – the variation in species composition among sites within a region – is particularly important for understanding ecological patterns in regional biodiversity (Zmihorski *et al.* 2016). Beta-diversity analyses revealed high dissimilarity in species composition between several wetland pairs, particularly between W6 and W10, as well as in multiple comparisons involving W9. Notably, the complete absence of Lesser Whistling-ducks at W6 contrasted sharply with their dominance at W10. Similarly, W9, being the least species-rich site, exhibited high beta-diversity when compared with other species-rich wetlands. These findings highlight the marked heterogeneity of waterbird communities across the study area and underscore the ecological distinctiveness of certain sites (Mukherjee *et al.* 2022). Importantly, this reinforces the need for conservation strategies that extend beyond high-diversity wetlands to also include habitats supporting unique or isolated species assemblages, regardless of overall species richness.

Low βw values observed between W1, W4, and W2 indicate high similarity in species composition across these sites. This similarity is likely attributable to shared habitat features and hydrological connectivity. Notably, both W1 and W4 are situated along the Damodar River, which may facilitate the movement and distribution of similar waterbird assemblages. Additionally, these wetlands may function as critical nodes within the regional flyway network, providing essential stopover or wintering habitats (Mukherjee *et al.* 2021). Given their ecological importance and connectivity, these sites warrant high conservation priority to ensure the long-term persistence of migratory and resident waterbird populations in the region.

Clusters generated using the UPGMA reinforced observed patterns in species distribution and abundance. The W2 and W4 formed a distant tertiary cluster, primarily driven by the exceptionally high abundance of Lesser Whistling-duck at both sites. Similarly, W8 and W10 were grouped into a secondary cluster, likely due to the shared dominance of Lesser Whistling-duck and Red-crested Pochard.

Rare species sightings, including the Falcated Duck, Northern Shoveler *(Spatula clypeata)*, and Common Merganser, as well as regionally notable records from W4 (e.g. Pallas's Gull, Black-headed Gull, River Tern), emphasize the strategic importance of these wetlands along the EAAF and CAF. Such records highlight the need for heightened monitoring and site-specific protection, especially for wetlands supporting rare or vagrant species (Mukherjee *et al.* 2023).

The findings emphasize that even within a relatively small geographic area, avian community attributes varied significantly. Sites such as W1, W4, and W2 are critical for sustaining high avifaunal diversity and should be prioritized for conservation. Simultaneously, low-diversity sites like W9 and W10 should not be overlooked, as they may serve specific ecological roles or offer restoration potential.

Given the rapid pace of urbanization, industrial expansion, and hydrological alterations in Paschim Bardhaman, it is imperative to adopt a landscape-scale conservation strategy (Hati *et al.* 2025). Protecting a mosaic of wetland types will ensure the long-term viability of waterbird populations and the ecological services they support.

Conclusion

This assessment of waterbird diversity across eleven wetlands in Paschim Bardhaman reveals complex ecological dynamics shaped by habitat heterogeneity, anthropogenic influences, and hydrological conditions. The study highlights the critical conservation value of key sites such as W4, W1, and W2, which consistently supported high species richness and abundance, including both generalist and specialist taxa. However, the marked variation in beta-diversity, particularly involving species-poor sites like W9 and W6, underscores the broader ecological significance of even seemingly marginal habitats. The presence of rare and regionally important species further amplifies the strategic importance of these wetlands within major migratory flyways.

Collectively, the findings advocate for a nuanced, landscape-scale conservation approach that balances the protection of biodiversity hotspots with the management and restoration of less diverse but ecologically distinctive wetlands. Long-term, site-specific monitoring and integrated land-use planning will be essential to mitigate the adverse impacts of urbanization and industrialization, ensuring the resilience of avian communities and the ecosystem services they underpin in this rapidly transforming region.

Acknowledgements

Authors are thankful to Prof. Sanjoy Chakraborty, Principal, and Dr. Anjan Biswas of Government College of Engineering and Leather Technology (GCELT), Kolkata, Dr. Asitava Chatterjee, DFO, Kangsabati South Division, Purulia; Samiran Jha, Conservationist, Malda, for cooperation and necessary infrastructural support. Authors also extend their gratitude to members of WINGS, Mr. Subhadeep Saha, Mr. Saptarshi Mukherjee, Mr. Dibyendu Kumar Mondal, Mr. Suvodip Chakraborty, Mr. Satyajit Mondal, Mr. Nirjhar Banerjee, Mr. Shantanu Bhandary, Mr. Amar Kumar Nayak and Mr. Koushik Pan. AM is thankful to the Anusandhan National Research Foundation, Department of Science & Technology, India (PDF/2023/000416).

References

Adhurya, S., Adhurya, S. & Roy, U. S. 2019. Rapid degradation of wetlands and its impact on avifauna: A case study from Ambuja Wetland, West Bengal, India. – Indian Birds 15(2): 43–48.

Adhurya, S., Das, S. & Ray, S. 2020. Guanotrophication by Waterbirds in Freshwater Lakes: A Review on Ecosystem Perspective. – In: Roy, P. K., Cao, X., Li, X. Z., Das, P. & Deo, S. (eds.) Mathematical Analysis and Applications in Modeling. ICMAAM 2018. – Springer Proceedings in Mathematics & Statistics, vol. 302. Springer, Singapore DOI: 10.1007/978-981-15-0422-8_22

Almeida, B. A., Green, A. J., Sebastian-Gonzalez, E. & Anjos, L. 2018. Comparing species richness, functional diversity and functional composition of waterbird communities along environmental gradients in the neotropics. – PLoS One 13(7): e0200959. DOI: 10.1371/journal.pone.0200959

Bandhopadhyay, S., Kar, N. S., Das, S. & Sen, J. 2014. River Systems and Water Resources of West Bengal: A Review. – Geological Society of India, Special Publication No. 3., pp. 63–84.

Baselga, A. 2010. Partitioning the turnover and nestedness components of beta diversity. – Global Ecology and Biogeography 19(1): 134–143. DOI: 10.1111/j.1466-8238.2009.00490.x

Bibby, C. J., Jones, M. & Marsden, S. 1998. Expedition Field Techniques Bird Surveys. – BirdLife International, Cambridge

CAF National Action Plan-India 2018. India's National Action Plan for Conservation of Migratory Birds and their Habitats along Central Asian Flyway (2018–2023). – Ministry of Environment, Forests and Climate Change, Wildlife Division, Government of India

Chao, A. 1987. Estimating the population size for capture-recapture data with unequal catchability. – Biometrics 43(4): 783–791. DOI: 10.2307/2531532

Chao, A., Chazdon, R. L., Colwell, R. K. & Shen, T.-J. 2006. Abundance-based similarity indices and their estimation when there are unseen species in samples. – Biometrics 62(2): 361–371. DOI: 10.1111/j.1541-0420.2005.00489.x

CMS Technical Series 2014. A Review of Migratory Bird Flyways and Priorities for Management. – UNEP / CMS Secretariat, Bonn, Germany. CMS Technical Series No. 27.

Derrac, J., García, S., Molina, D. & Herrera, F. 2011. A practical tutorial on the use of nonparametric statistical tests as a methodology for comparing evolutionary and swarm intelligence algorithms. – Swarm Evolutionary Computation 1(1): 3–11. DOI: 10.1016/j.swevo.2011.02.002

Dhanjal-Adams, K. L., Klaassen, M., Nicol, S., Possingham, H. P., Chadès, I. & Fuller, R. A. 2017. Setting conservation priorities for migratory networks under uncertainty. – Conservation Biology 31(3): 646–656. DOI: 10.1111/cobi.12842

Froneman, A., Mangnall, M. J., Little, R. M. & Crowe, T. M. 2001. Waterbird assemblages and associated habitat characteristics of farm ponds in the Western Cape, South Africa. – Biodiversity Conservation 10: 251–270. DOI: 10.1023/A:1008904421948

Gauntlett, F. M. 1971. Durgapur Barrage as a water bird habitat. – The Journal of Bombay Natural History Society 68(3): 619–632.

Gauntlett, F. M. 1985. The birds of the Durgapur and Damodar valley. – The Journal of Bombay Natural History Society 82(2): 501–539.

Ghorai, D., Roy, S. & Ghosh, S. 2018. Climatic variability and its impact on agriculture in Paschim Bardhaman district, West Bengal. – International Journal of Research in Environmental Science 4(1): 23–30.

Gibbons, D. W. & Gregory, R. D. 2006. Birds. – In: Sutherland, W. J. (ed.) Ecological Census Techniques: A Handbook. – Cambridge University Press, pp. 227–259.

Grimmett, R., Inskipp, C. & Inskipp, T. 2011. Birds of the Indian Subcontinent. 2nd ed. – London: Oxford University Press & Christopher Helm

Hati, M., Krishnaiah, Y. V., Das, D., Mallick, M., Mondal, V., Panja, K., Rai, D. & Chakma, A. 2025. Impact of land use land cover change on land surface temperature of Paschim Bardhaman District, India. – Current World Environment 20(1): 310–328. DOI: 10.12944/CWE.20.1.24

Li, J., Hughes, A. C. & Dudgeon, D. 2019. Mapping wader biodiversity along the East Asian-Australasian flyway. – PloS One 14(4): e0215877. DOI: 10.1371/journal.pone.0215877

Li, Z. W. D., Bloem, A., Delany, S., Martakis, G. & Quintero, J. O. 2009. Status of Waterbirds in Asia – Results of the Asian Waterbird Census: 1987–2007. – Wetlands International, Kuala Lumpur, Malaysia

McKinney, M. L. 2002. Urbanization, biodiversity, conservation: The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. – Bioscience 52(10): 883–890. DOI: 10.1641/0006-3568(2002)052[0883: UBAC]2.0.CO;2

Mukherjee, A., Pal, S., Adhikari, S. & Mukhopadhyay, S. K. 2022. Physical habitat attributes influence diversity and turnover of waterbirds wintering at wetlands on Central Asian and East Asian-Australasian Flyways in Eastern India. – Wetlands 42(5): 50. DOI: 10.1007/s13157-022-01559-1

Mukherjee, A., Pal, S., Das, P. & Mukhopadhyay, S. K. 2021. Mid-winter diversity of waterbirds in West Bengal, India. – The Journal of the Bombay Natural History Society 118: 156–169. DOI: 10.17087/jbnhs/2021/v118/147142

Mukherjee, A., Pal, S., Das, P. & Mukhopadhyay, S. K. 2023. Time activity budget and foraging behavior: important determinants of resource sharing and guild structure in wintering waterbirds. – European Journal of Wildlife Research 69(2): 30. DOI: 10.1007/s10344-023-01648-4

Nandi, N. C., Bhuinya, S. & Das, S. R. 2004. Notes on mid-winter waterbird population of some selected wetlands of Bankura and Puruliya Districts, West Bengal. – Records of the Zoological Survey of India 102(1–2): 47–51.

Pielou, E. C. 1969. An Introduction to Mathematical Ecology. – Wiley InterScience. John Wiley & Sons, New York

Sebastian-Gonzalez, E. & Green, A. J. 2014. Habitat use by waterbirds in relation to pond size, water depth, and isolation: Lessons from a restoration in Southern Spain. – Restoration Ecology 22(3): 311–318. DOI: 10.1111/rec.12078

Whittaker, R. H. 1972. Evolution and measurement of species diversity. – Taxon 21(2–3): 213–251. DOI: 10.2307/1218190

Xu, J., Ling, Y., Sun, Y., Jiang, Y., Shen, R. & Wang, Y. 2024. How do different processes of habitat fragmentation affect habitat quality? – Evidence from China. – Ecological Indicators 160: 111880. DOI: 10.1016/j.ecolind.2024.111880

Zakaria, M. & Rajpar, M. N. 2013. Density and diversity of water birds and terrestrial birds in man-made marsh, Malaysia. – Sains Malaysiana 42(10): 1483–1492.

Żmihorski, M., Pärt, T., Gustafson, T. & Berg, Å. 2016. Effects of water level and grassland management on alpha and beta diversity of birds in restored wetlands. – Journal of Applied Ecology 53(2): 587–595. DOI: 10.1111/1365-2664.12588