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Avian assemblages in two contrasting oxbow lakes of the lower Gangetic delta, West Bengal, India: A comparative approach

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Abstract A comparative study was conducted to assess the species composition, diversity and abundance of avifauna in and around two contrasting oxbow lakes from lower Gangetic delta of West Bengal, India: Purbasthali lake (PL) and Hansadanga lake (HL). Comprehensive avian surveys were carried out for one year (January 2024 to December 2024) using fixed-radius point count method, followed by some analytical approaches. PL supported a markedly richer avian assemblage, with 82 species across 23 families, compared with 45 species across 19 families in HL. Family-level dominance also differed, as Anatidae dominated PL, while Ardeidae prevailed in HL, as reflected in Relative Diversity (RD_i) values. Both lakes were dominated by carnivores, with transitional-zone species most frequent, especially in PL. Species richness and diversity were highest during post-monsoon months in both the lakes due to influx of migratory waterbirds. Winter migrants were more abundant in PL (51.2% of species) compared to HL (28.9%). Diversity indices and multivariate community analyses further demonstrated that PL, owing to its semi-lotic hydro-environmental condition, supports richer and more functionally diverse bird communities with greater migrant abundance than the closed-lentic HL. The current findings emphasize the ecological significance of semi-lotic oxbow lakes like PL as vital refuges for migratory and threatened waterbirds in the lower Gangetic delta, warranting strengthened conservation and management. In contrast, the degraded condition of closed-lentic oxbow lakes such as HL highlights the urgent need for ecological restoration and sustainable interventions to enhance their capacity to support diverse bird assemblages.

Keywords: oxbow lakes, Purbasthali lake, Hansadanga lake, avifauna, diversity

Összefoglalás Összehasonlító vizsgálatot végeztünk a madárfauna fajösszetételének, diverzitásának és abundanciájának felmérésére két különböző holtágban és környékén az indiai Nyugat-Bengálban, az alsó Gangesz deltájában, nevezetesen a Purbasthali-tónál (PL) és a Hansadanga-tónál (HL). Átfogó madárfelméréseket végeztünk egy éven keresztül 2024 januárja és 2024 decembere között, fix sugarú pontszámlálási módszerrel, majd különböző analitikai megközelítést alkalmaztunk. A PL területén sokkal gazdagabb madárközösség volt 23 családba tartozó 82 fajjal, mint a 19 madárcsalád 45 faját felmutató HL-ben. A családszintű dominancia is eltérő volt, mivel a PL-ben az Anatidae dominált, míg a HL-ben az Ardeidae volt túlsúlyban, amint azt a relatív diverzitás (RDi) értékei is tükrözik. Mindkét tóban a ragadozók, azok közül is az átmeneti zónában élők voltak a leggyakoribbak, különösen PL területén. A fajgazdagság és a diverzitás a monszun utáni hónapokban volt a legmagasabb mindkét tónál a vonuló vízimadarak beáramlása miatt. A téli vonulók nagyobb számban voltak PL-ben (a fajok 51,2%-a) a HL-hez képest (28,9%). A diverzitási indexek és a többváltozós közösségelemzések továbbá kimutatták, hogy a PL, lassú folyású hidro-környezeti állapotának köszönhetően, gazdagabb és funkcionálisan változatosabb madárközösségek jelenlétét teszi lehetővé több vonuló fajjal, mint a zárt vízterű HL. A jelenlegi eredmények hangsúlyozzák a PL-hez hasonló lassú folyású holtágak ökológiai jelentőségét, mint létfontosságú menedékhelyeket a vonuló és veszélyeztetett vízimadarak számára az alsó Gangesz-deltában, ami indokolttá teszi a fokozott védelmet és kezelést. Ezzel szemben a HL-hez hasonló zárt vízterű holtágak leromlott állapota rávilágít az ökológiai helyreállítás és a fenntartható beavatkozások sürgős szükségességére, hogy fokozzák a változatos madárközösségek fenntartására való képességüket.

Kulcsszavak: holtágak, Purbasthali-tó, Hansadanga-tó, madárvilág, diverzitás

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Introduction

Lakes as well as wetlands are considered not only the world's most prolific, fertile, land-interactive, and intricate ecosystems, but they also harbour a massive amount of floral and faunal diversity, including the waterbirds (Mandal *et al.* 2021a, Ranade & Chakraborty 2024). A considerable number of floodplain wetlands, mostly oxbow lakes, have been formed in the southern part of the state of West Bengal, India, due to the meandering nature of River Ganga along its tributaries and distributaries and these wetlands are locally named as 'beel' or 'bnour' (Ganesan & Khan 2008). Based on morphology and connectivity aspects, these oxbow lakes mostly are of three types: open-lotic, semi-open semi-lotic and closed-lentic (Glińska-Lewczuk 2009). Although lakes and wetlands cover a relatively small proportion of Earth's surface (~6%), they support disproportionately high biodiversity, and nearly 40% of global floral and faunal species are directly or indirectly dependent on them (Anand *et al.* 2023, Alamo 2024). Waterbirds use the wetlands as a microhabitat (Ryeland *et al.* 2021); moreover, they play a critical role in maintaining biotic connections and ecosystem stability through scavenging, pest control, seed dispersal, deposition and external loading of vital nutrients (Adhurya *et al.* 2020, Mukherjee *et al.* 2020). Besides, due to their extreme sensitivity to environmental changes, birds can be utilized as 'bio-indicators' (Yang *et al.* 2020).

Nearly 64% of wetlands worldwide have been degraded since the early 20th century due to urbanization and agricultural intensification (Ballut-Dajud *et al.* 2022). In this context, assessing waterbird diversity, richness, population structure, and spatio-temporal dynamics in wetland habitats has become increasingly crucial for understanding ecosystem responses to anthropogenic stresses (Araneda *et al.* 2025). A number of works (Khirani-Betrouche & Moulaï 2022, Kumar & Alam 2023, Shahbaz *et al.* 2023, Yang *et al.* 2025) have been carried out worldwide on species composition, community structure and migration of wetland birds with a variety of interests and perspectives. Being one of the 17 megadiverse nations, India is home to a sizable number of avifauna including waterbirds. Out of the approximately 11,131 avian species recorded globally (Christidis *et al.* 2025), the Indian subcontinent supports 1,332 species, accounting for about 11.97% of global avian diversity (Praveen *et al.* 2020). The state of West Bengal in India alone harbours 929 bird species, which corresponds to approximately 8.35% of global avian species (Manna *et al.* 2024). In the state of West Bengal, 110 species of wetland associated birds were documented, among which 41 species were resident and 69 were winter migrants (Mukherjee *et al.* 2021). Any alteration to wetland ecosystems, thus, has profound consequences for avifaunal assemblages and associated biodiversity (Li *et al.* 2022).

Physio-geographically Purbasthali (Mandal & Siddique 2018) and Hansadanga are oxbow lakes, lies in Gangetic alluvial plains. However, a few works have been conducted on Purbasthali lake (Chowdhury 2017, Debnath *et al.* 2018, Chakraborty *et al.* 2021) vis-à-vis water quality, avifaunal aggregation, diversity and migratory waterbird abundance; and some limited investigations were carried out in Hansadanga lake (Das & Chakrabarty 2008, Das & Das 2015) merely on limnological and geographical aspects. To date there is no such available information on the ornithofauna in Hansadanga lake and its environments. To address this knowledge gap, the present study has been designed to provide a comparative account of these two contrasting oxbow lakes of the lower Gangetic basin, focusing on waterbirds and other wetland-associated bird species in relation to habitat structure, foraging guilds, and global conservation status. Particular emphasis is also placed on documenting seasonal dynamics of avifaunal assemblages across the lakes representing distinct hydro-ecological regimes. Through integration of species-level observations with community-level analyses, the study seeks to elucidate how avifaunal diversity and community structure differ between semi-open semi-lotic and closed-lentic oxbow lake systems of the Gangetic floodplain.

Material and Methods

Study areas and sampling sites

The Purbasthali lake or 'Chupi Char' (local name) (coordinates: 23°25′56″ N – 23°27′50″ N and 88°19′35″ E – 88°21′58″ E, at an elevation of 14 m), is basically a semi-open semi-lotic type (holds a thin connection with the main river at its south-eastern side) oxbow lake in the western bank of River Bhagirathi (The Ganga). The lake is situated along the border between district Nadia and Purba-Barddhaman in the lower Gangetic delta of the state West Bengal (Mandal *et al.* 2021a) *(Figure 1)*. It covers an area of 3.2 km^2 with the depth ranges from 2.5–6 m (Chakraborty *et al.* 2021). The Hansadanga lake or 'Hansadanga Beel' (local name) (coordinates: 23°27′41″ N – 23°26′52″ N and 88°28′22″ E – 88°27′25″ E at an elevation of 12 m), is a closed-lentic type (lost its connection to the main river) oxbow lake, situated at the western bank of the River Jalangi, which is basically a tributary of River Bhagirathi (The Ganga). The lake is located near the "Tropic of Cancer" in the Krishnanagar-II block of the Nadia district in the Indian state of West Bengal *(Figure 1)*. Total area of the lake is approximately 0.42 km^2 with average depth of 1.98 m (Das & Das 2015).

Tropical climate pattern (ambient temperature: 17–40 °C; annual rainfall >1,500 mm) was observed during the entire study (District Environment Plan 2024–25). Based on habitat variation and accessibility, three sampling sites for each study area (for PL: 23°26′04″ N/ 88°21′41″ E, 23°26′50″ N/ 88°19′41″ E and 23°27′11″ N/ 88°21′19″ E; and for HL: 23°26′57″ N/ 88°28′11″ E, 23°27′13″ N/ 88°27′31″ E and 23°27′42″ N/ 88°27′38″ E) were taken into consideration for data collection *(Figure 1)*. The location map of the study areas and sampling sites were prepared through QGIS software version 3.40.2.

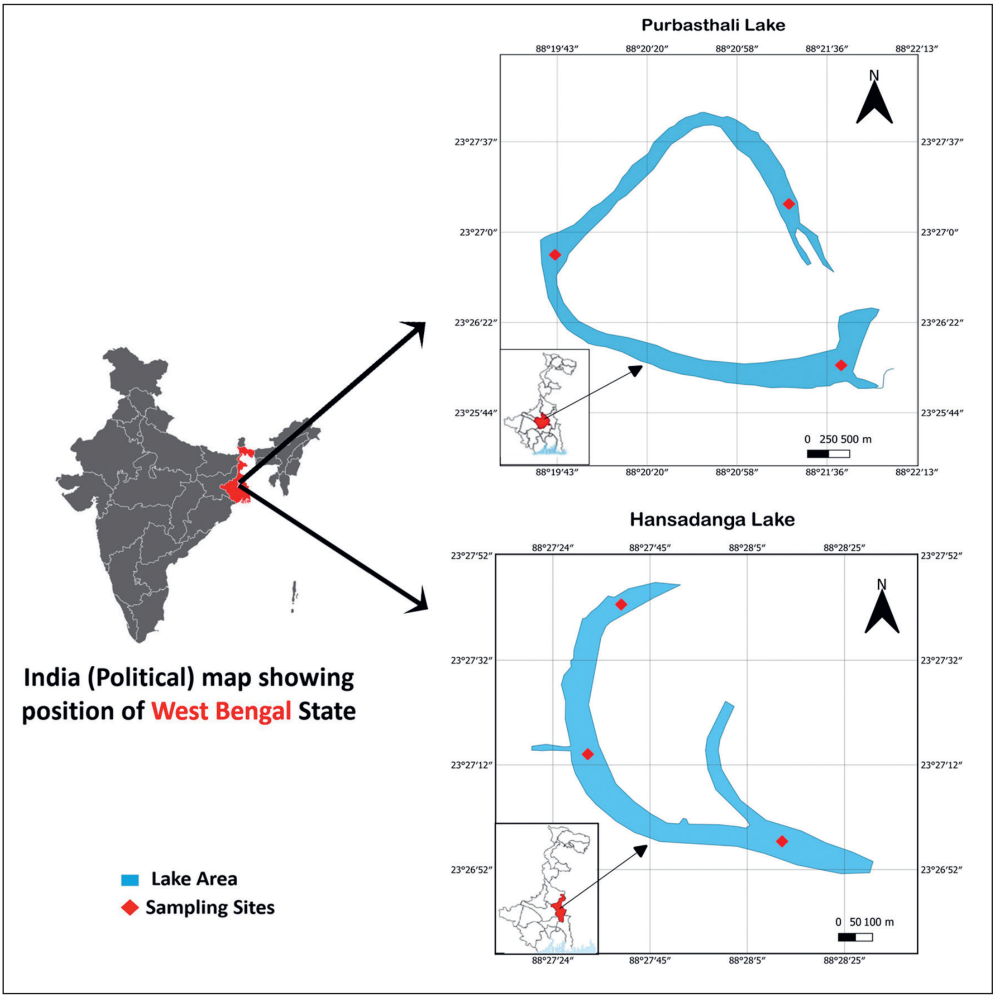

Figure 1. Location of study areas and sampling sites
1. ábra A vizsgálati területek és a mintavételi helyek elhelyezkedése

Data collection and identification

A year-long (January 2024 to December 2024) bird survey was carried out following the principles specified by Ali and Ripley (1987). Fixed radius point-count method (100 m radius with a 360º arc) was applied in this study to record the field data (Sutherland *et al.* 2005, Issa 2019). Each bird count persisted for 20 minutes, and field visits were conducted fortnightly on open-water (OW) and transitional zones (TZ) with the help of a traditional boat (locally known as "*dingi*"). The birds of adjacent agricultural fields and nearby trees (NT) were surveyed by walking through the areas. Five sampling points were considered randomly for each sampling site at 200 m distance to avoid data overlapping during bird count. Samplings were carried out during morning (6:00 AM – 10:00 AM) and evening time (4:00 PM – 6:00 PM) at each sampling point, generally when the birds were most active (Kumar & Gupta 2013, Ghosh *et al.* 2021). Observations were made with the help of Olympus 8–16 × 40 zoom DPS I Binocular and Laser Rangefinder (600 m; model: MiLESEEY-PF210) and photographed by Nikon D7000 DSLR camera and Nikon AF-S Nikkor 200–500 mm F/5.6E ED VR lens for documentation. Birds were identified with the help of the following literatures (Ali & Ripley 1987, Sangha 2021, Majumder *et al.* 2022). A few inconspicuous bird species were also recognized through their calls (Aynalem & Bekele 2008).

Data analysis

Relative Diversity Index (RD_i) of different bird families was assessed using the formula (La Torre-Cuadros *et al.* 2007):

$$RD_i = \frac{n}{N} \times 100$$

where, n = number of bird species in a family and N = total number of recorded bird species. Relative abundance was determined based on the frequency of each day's bird sighting as described by Khan (2005): very common (VC) – recorded on 75–100% of visits, common (C) 50–74%, uncommon (UC) 25–49%, and rare (RA) <25%. The dispersal pattern was categorised as: resident birds (R), winter visitors (WV) and summer visitors (SV) (Aarif *et al.* 2017, Majumder *et al.* 2022). Recorded bird species were also classified into five feeding guilds: carnivore (CAR) – feeds on vertebrates, omnivore (OMN) – feeds on both plants and animals, insectivore (INS) – feeds on insects, granivore (GRA) – feeds on seeds, grains etc., and vermivore (VER) – feeds on earthworms and other worm-like animals (Sangha 2021). IUCN status and global population trend (GPT) were recognized as per IUCN (2025) version 2025-1.

Data from each sampling sites were arranged to obtain different diversity indices as follows.

Shannon–Wiener index (H′) (Shannon & Weaver 1949):

$$H' = -\sum_{i=1}^{N} Pi \ln(Pi)$$

where, Pi = proportion of each species in the sample, and ln(Pi) = natural logarithm of Pi.

Simpson's Index (D) (Simpson 1949):

$$D = 1 - \frac{\sum n\,(n-1)}{N\,(N-1)}$$

where, n = total number of organisms of a particular species, and N = total number of organisms of all species.

Pielou's evenness index (J′) (Pielou 1966):

$$J' = \frac{H'}{H_{max}}$$

where, H′ = Shannon–Wiener diversity index, and H_{max} = natural logarithm of total number of species.

Margalef's Richness Index (RI) (Margalef 1958):

$$RI = \frac{S-1}{ln\,(N)}$$

where, S = number of species, and N = total number of individuals in the sample.

To assess differences in avian community composition between the two lakes, a PERMANOVA was performed using Bray–Curtis dissimilarities. Subsequently, hierarchical clustering was conducted to examine the temporal structuring of avian assemblages across months within each lake. Prior to analysis, the avian abundance data matrix was log-transformed as log(x+1). Clustering was carried out using the UPGMA method. The indicator value ($IndVal_{ij}$) is derived as the product of two complementary components. The first component measures the performance of species 'i' in terms of its abundance across all groups and is referred to as specificity (A_{ij}). The second component measures the performance of the same species in terms of its presence or absence within site group 'j', and is referred to as fidelity (B_{ij}). These two components are multiplied and then scaled to 100, resulting in the indicator value of the species *i* for cluster *j*, expressed as a percentage (%). The statistical significance of $IndVal_{ij}$ scores was assessed using 999 Monte Carlo Permutations (Dufrene & Legendre 1997, Podani & Csányi 2010).

$$\mathrm{IndVal_{ij}} = 100\,(\mathrm{A_{ij}} \times \mathrm{B_{ij}}).$$

Species considered typical indicators of a particular habitat condition were those with an IndVal ≥ 50% and a P-value of 0.001 (Moreno *et al.* 2009, Mercado-Gómez *et al.* 2023). Different statistical analyses were conducted using PAST statistical software version 5.0 (Hammer *et al.* 2001) and graphical representations were prepared with the help of Origin 2025 (version 10.2).

Results

A year-long study on avifaunal diversity of Purbasthali lake (PL) of West Bengal, India revealed the presence of 82 species of birds, distributed over 23 families and 10 orders, whereas the Hansadanga lake (HL) comprised a total of 45 bird species, distributed over 19 families and 10 orders *(Table 1)*. In PL, Charadriiformes was the most species-rich

Table 1. Checklist of avifauna recorded in and around of the Purbasthali (PL) and Hansadanga Lake (HL) [Occurrence – Y: Present; Residential status – R: Resident, WV: Winter visitor, SV: Summer visitor; Habitat – OW: Open-water, TZ: Transitional zones, NT: Nearby trees; Relative abundance – VC: Very common, C: Common, UC: Uncommon, RA: Rare; IUCN status: LC: Least concern, NT: Near threatened, EN: Endangered, VU: Vulnerable; Feeding guild: CAR: Carnivore, OMN: Omnivore, INS: Insectivore, GRN: Granivore, VER: Vermivore; GPT – Global population trend: ST: Stable, IN: Increasing, DE: Decreasing, UN: Unknown]

1. táblázat A Purbasthali- (PL) és a Hansadanga-tó (HL) környékén megfigyelt madárfajok listája (Előfordulás – Y: előfordult; Vonulási státusz – R: állandó, WV: téli vendég, SV: nyári vendég; élőhely – OW: nyílt-víz, TZ: átmeneti zónák, NT: közelben fák; Relatív abundancia – VC: nagyon gyakori, C: gyakori, UC: szórványos, RA: ritka; IUCN státusz: LC: nem veszélyeztetett, NT: közel fenyegetett, EN: veszélyeztetett, VU: sebezhető; Táplálkozási csoport: CAR: ragadozó, OMN: mindenevő, INS: rovarevő, GRN: magevő, VER: féregevő; GPT – Globális populáció trendje: ST: stabil, IN: növekvő, DE: csökkenő, UN: ismeretlen)

Order	Family	Common name	Scientific name	Acronym	Occurrence		Residential status	Habitat	Relative abundance	IUCN status	Feeding guild	GPT
					PL	HL						
Anseriformes	Anatidae	Lesser Whistling Duck	*Dendrocygna javanica*	DJA	Y	Y	R	OW	VC	LC	OMN	DE
		Common Teal	*Anas crecca*	ACR	Y	-	WV	OW	RA	LC	OMN	UN
		Northern Pintail	*Anas acuta*	AAC	Y	-	WV	OW	RA	LC	OMN	DE
		Gadwall	*Mareca strepera*	MTR	Y	-	WV	OW	RA	LC	OMN	IN
		Ruddy Shelduck	*Tadorna ferruginea*	TFE	Y	-	WV	OW	UC	LC	OMN	UN
		Red-crested Pochard	*Netta rufina*	NRU	Y	Y	WV	OW	C	LC	OMN	UN
		Greylag Goose	*Anser anser*	AAN	Y	-	WV	OW	RA	LC	OMN	IN
		Cotton Pygmy Goose	*Nettapus coromandelianus*	NCO	Y	Y	WV	OW	VC	LC	OMN	UN
		Garganey	*Spatula querquedula*	SQU	Y	-	WV	OW	C	LC	OMN	DE
		Northern Shoveler	*Spatula clypeata*	SCL	Y	-	WV	OW	UC	LC	OMN	DE
		Eurasian Wigeon	*Mareca penelope*	MPE	Y	-	WV	OW	C	LC	OMN	DE
		Tufted Duck	*Aythya fuligula*	AFU	Y	-	WV	OW	C	LC	OMN	ST
		Common Pochard	*Aythya ferina*	AFE	Y	Y	WV	OW	UC	VU	OMN	DE
		Ferruginous Duck	*Aythya nyroca*	ANY	Y	-	WV	OW	RA	NT	OMN	DE
Gruiformes	Rallidae	Eurasian Coot	*Fulica atra*	FAT	Y	Y	WV	OW	C	LC	OMN	IN
		Common Moorhen	*Gallinula chloropus*	GCH	Y	-	R	TZ	C	LC	OMN	ST
		Grey-headed Swamphen	*Porphyrio poliocephalus*	PPO	Y	Y	R	TZ	VC	LC	OMN	ST
		White-breasted Waterhen	*Amaurornis phoenicurus*	APH	Y	Y	R	TZ	VC	LC	OMN	UN
		Watercock	*Gallicrex cinerea*	GCI	Y	-	SV	TZ	UC	LC	OMN	DE

Order	Family	Common name	Scientific name	Acronym	Occurrence		Residential status	Habitat	Relative abundance	IUCN status	Feeding guild	GPT
					PL	HL						
Podicipediformes	Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	PRU	Y	Y	R	OW	VC	LC	CAR	DE
Charadriiformes	Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*	HHI	Y	Y	R	TZ	C	LC	CAR	ST
	Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	VIN	Y	Y	R	TZ	VC	LC	OMN	UN
		Grey-headed Lapwing	*Vanellus cinereus*	VCI	Y	-	WV	TZ	UC	LC	OMN	ST
		River Lapwing	*Vanellus duvaucelii*	VDU	Y	-	WV	TZ	RA	NT	OMN	DE
		Yellow-wattled Lapwing	*Vanellus malabaricus*	VMA	Y	Y	R	TZ	UC	LC	OMN	ST
		Pacific Golden Plover	*Pluvialis fulva*	PFU	Y	Y	WV	TZ	C	LC	INS	DE
		Ruff	*Philomachus pugnax*	PPU	Y	-	WV	TZ	RA	LC	INS	DE
		Lesser/Siberian Sand Plover	*Charadrius mongolus*	CMO	Y	-	WV	TZ	UC	EN	CAR	DE
		Greater Sand Plover	*Charadrius leschenaultii*	CLE	Y	-	WV	TZ	C	LC	CAR	DE
		Little Ringed Plover	*Charadrius dubius*	CDU	Y	Y	WV	TZ	C	LC	INS	ST
		Kentish Plover	*Charadrius alexandrinus*	CAL	Y	-	WV	TZ	UC	LC	INS	DE
	Rostratulidae	Greater Painted Snipe	*Rostratula benghalensis*	RBE	Y	-	R	TZ	UC	LC	OMN	UN
	Jacanidae	Bronze-winged Jacana	*Metopidius indicus*	MIN	Y	Y	R	TZ	C	LC	OMN	UN
		Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	HCH	Y	Y	R	TZ	C	LC	OMN	UN
	Scolopacidae	Black-tailed Godwit	*Limosa limosa*	LLI	Y	-	WV	TZ	RA	NT	INS	DE
		Wood Sandpiper	*Tringa glareola*	TGL	Y	-	WV	TZ	C	LC	INS	ST
		Green Sandpiper	*Tringa ochropus*	TOC	Y	Y	WV	TZ	RA	LC	OMN	IN
		Common Sandpiper	*Tringa hypoleucos*	THY	Y	Y	WV	TZ	C	LC	INS	DE
		Common Redshank	*Tringa totanus*	TTO	Y	-	WV	TZ	C	LC	INS	UN
		Common Greenshank	*Tringa nebularia*	TNE	Y	-	WV	TZ	UC	LC	INS	ST
		Common Snipe	*Gallinago gallinago*	GGA	Y	Y	R	TZ	C	LC	VER	DE
	Glareolidae	Oriental Pratincole	*Glareola maldivarum*	GMA	Y	-	R	TZ	UC	LC	INS	ST
		Small Pratincole	*Glareola lactea*	GLA	Y	-	R	TZ	C	LC	INS	UN

Order	Family	Common name	Scientific name	Acronym	Occurrence		Residential status	Habitat	Relative abundance	IUCN status	Feeding guild	GPT
					PL	HL						
Ciconiiformes	Ciconiidae	Asian Openbill Stork	*Anastomus oscitans*	AOS	Y	Y	R	TZ	VC	LC	CAR	UN
		Lesser Adjutant Stork	*Leptoptilos javanicus*	LJA	Y	-	WV	TZ	RA	NT	CAR	UN
Suliformes	Phalacrocoracidae	Little Cormorant	Phalacrocorax niger	PNI	Y	Y	R	OW	VC	LC	CAR	UN
		Indian Cormorant	*Phalacrocorax fuscicollis*	PFC	Y	Y	R	OW	C	LC	CAR	UN
		Great Cormorant	*Phalacrocorax carbo*	PCR	Y	-	WV	OW	RA	LC	CAR	IN
Pelecaniformes	Threskiornithidae	Eurasian Spoonbill	*Platalea leucorodia*	PLE	Y	-	WV	TZ	RA	LC	CAR	UN
		Black-headed Ibis	*Threskiornis melanocephalus*	TME	Y	-	R	TZ	C	LC	CAR	IN
		Glossy Ibis	*Plegadis falcinellus*	PFA	Y	-	WV	TZ	UC	LC	CAR	DE
	Ardeidae	Little Egret	*Egretta garzetta*	EGA	Y	Y	R	TZ	VC	LC	CAR	IN
		Intermediate Egret	*Ardea intermedia*	AIN	Y	Y	R	TZ	VC	LC	CAR	DE
		Great White Egret	*Ardea alba*	AAL	Y	-	WV	TZ	C	LC	CAR	UN
		Purple Heron	*Ardea purpurea*	APU	Y	-	WV	TZ	C	LC	CAR	DE
		Grey Heron	*Ardea cinerea*	ACI	Y	-	R	TZ	UC	LC	CAR	UN
		Indian Pond Heron	*Ardeola grayii*	AGR	Y	Y	R	TZ	VC	LC	CAR	UN
		Black-crowned Night Heron	*Nycticorax nycticorax*	NNY	Y	Y	R	TZ	C	LC	CAR	DE
		Black Bittern	*Ixobrychus flavicollis*	IFL	Y	-	R	TZ	RA	LC	CAR	UN
		Yellow Bittern	*Ixobrychus sinensis*	ISI	Y	Y	R	TZ	UC	LC	CAR	UN
		Cattle Egret	*Bubulcus ibis*	BIB	Y	Y	R	TZ	VC	LC	CAR	IN
Accipitriformes	Pandionidae	Osprey	*Pandion haliaetus*	PHA	Y	-	WV	OW	C	LC	CAR	IN
	Accipitridae	Black Kite	*Milvus migrans*	MMI	Y	Y	R	NT	C	LC	CAR	ST
Coraciiformes	Alcedinidae	Common Kingfisher	*Alcedo atthis*	AAT	Y	Y	R	NT	UC	LC	CAR	DE
		White-throated Kingfisher	*Halcyon smyrnensis*	HSM	Y	Y	R	NT	VC	LC	CAR	IN
		Pied Kingfisher	*Ceryle rudis*	CRU	Y	Y	R	NT	C	LC	CAR	UN
		Stork-billed Kingfisher	*Pelargopsis capensis*	PCA	Y	Y	R	NT	UC	LC	CAR	DE
	Meropidae	Asian Green Bee-eater	*Merops orientalis*	MOR	Y	Y	R	NT	VC	LC	INS	IN

Order	Family	Common name	Scientific name	Acronym	Occurrence		Residential status	Habitat	Relative abundance	IUCN status	Feeding guild	GPT
					PL	HL						
Passeriformes	Dicruridae	Black Drongo	Dicrurus macrocercus	DMA	Y	Y	R	NT	VC	LC	CAR	UN
	Laniidae	Brown Shrike	*Lanius cristatus*	LCR	Y	Y	WV	NT	RA	LC	CAR	DE
		Long-tailed Shrike	*Lanius schach*	LSC	Y	Y	WV	NT	UC	LC	CAR	UN
	Hirundinidae	Barn Swallow	*Hirundo rustica*	HRU	Y	Y	WV	NT	VC	LC	INS	DE
	Sturnidae	Bank Myna	*Acridotheres ginginianus*	AGI	Y	Y	R	TZ	C	LC	OMN	IN
	Estrildidae	Indian Silver Bill	*Lonchura malabarica*	LMB	Y	Y	R	NT	C	LC	GRN	ST
		Scaly-breasted Munia	*Lonchura punctulata*	LPU	Y	Y	R	NT	UC	LC	GRN	ST
		Tricoloured Munia	*Lonchura malacca*	LMA	Y	Y	R	NT	UC	LC	GRN	ST
	Motacillidae	Western Yellow Wagtail	*Motacilla flava*	MFL	Y	-	WV	TZ	C	LC	INS	DE
		Grey Wagtail	*Motacilla cinerea*	MCI	Y	Y	WV	TZ	UC	LC	INS	ST
		White Wagtail	*Motacilla alba*	MAL	Y	Y	WV	TZ	VC	LC	INS	ST
		White-browed Wagtail	*Motacilla maderaspatensis*	MMA	Y	Y	R	TZ	C	LC	INS	ST
		Citrine Wagtail	*Motacilla citreola*	MCT	Y	-	WV	TZ	RA	LC	INS	IN
		Paddyfield Pipit	*Anthus rufulus*	ARU	Y	Y	R	NT	C	LC	INS	ST

order (23 species), while Passeriformes was found to be the most species-rich (12 species) order in HL.

RD_i study of different bird families *(Figure 2)* revealed that, Anatidae (14 species, RD_i=17.07) was the most diverse family in PL, where Ardeidae (six species, RD_i=13.33) showed the highest diversification in HL. On contrary, the lowest RD_i value (RD_i=1.22, single species) was represented by nine families (Accipitridae, Dicruridae, Hirundinidae, Meropidae, Pandionidae, Podicipedidae, Recurvirostridae, Rostratulidae, and Sturnidae) in PL. In case of HL, the lowest value (RD_i=2.22, single species) was indicated by eight families (Accipitridae, Ciconiidae, Dicruridae, Hirundinidae, Meropidae, Podicipedidae, Recurvirostridae, and Sturnidae).

Relative abundance measures revealed that in PL 17 species (20.73%) were found very common, 30 species (36.59%) were common, 20 species (24.39%) were uncommon, and 15 species (18.29%) were found rare to the lake of the total 82 bird species. Besides, of the total 45 avian species recorded from HL, 17 species (37.78%) fell into the category of very common and common, nine species (20%) were uncommon, and two species (4.44%) were found to be rare to the lake during the study *(Table 1, Figure 3)*. Rank-abundance curve *(Figure 4)* revealed that, Lesser Whistling Duck *(Dendrocygna javanica)* was the

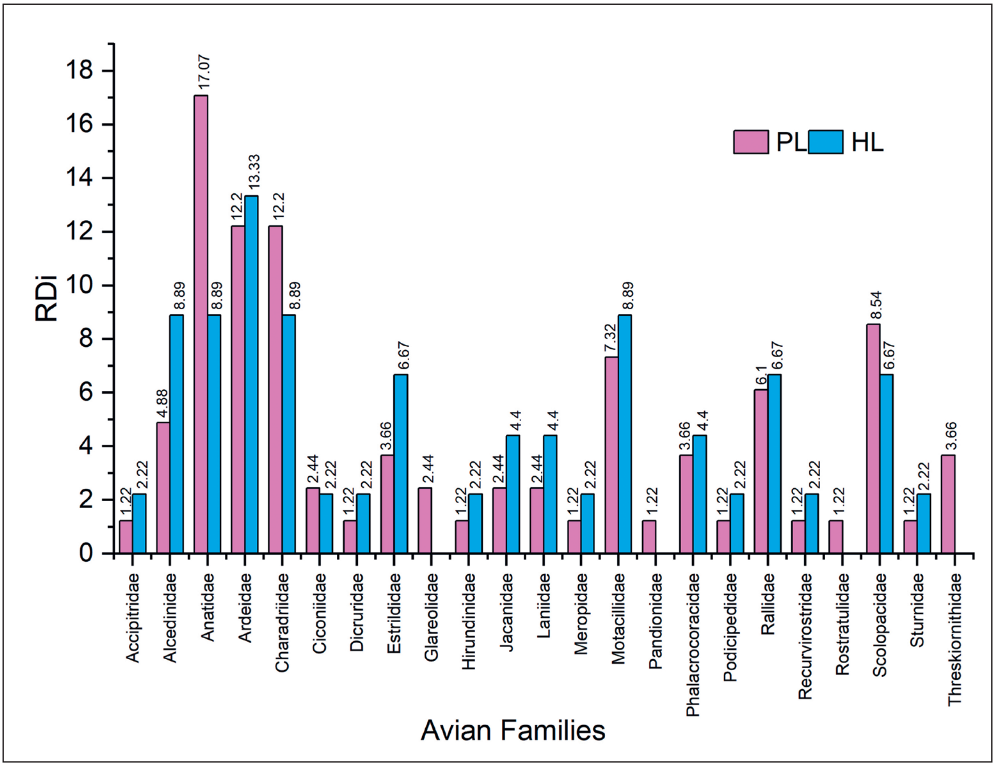

Figure 2. Relative diversity (RD_i) of various bird families in Purbasthali Lake (PL) and Hansadanga Lake (HL)

2. ábra Különböző madárcsaládok relatív diverzitása (RDi) a Purbasthali-tóban (PL) és a Hansadanga-tóban (HL)

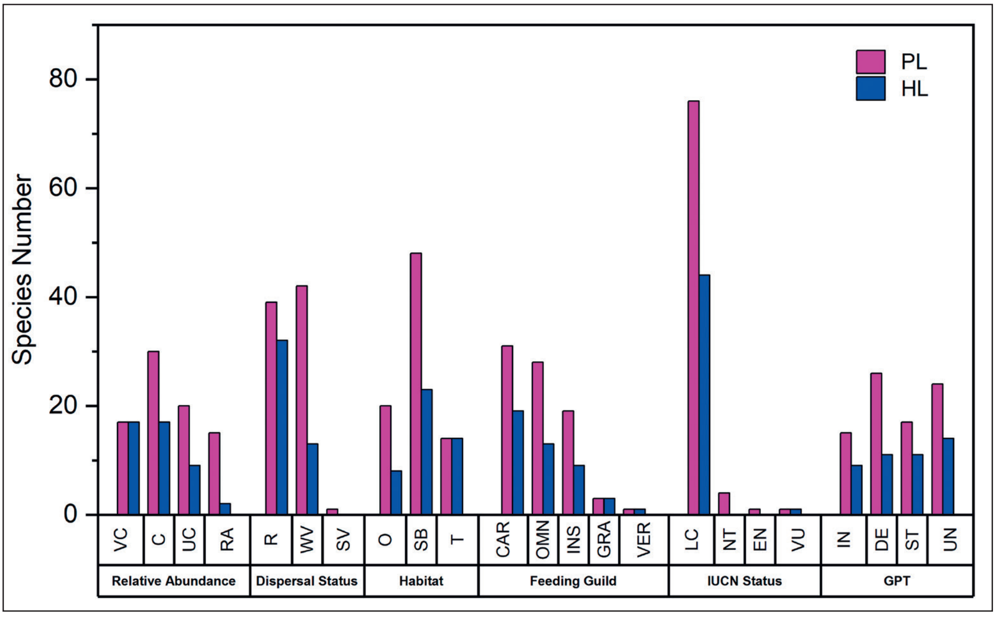

Figure 3. Status of avifauna in Purbasthali Lake (PL) and Hansadanga Lake (HL)
3. ábra A Purbasthali-tó (PL) és a Hansadanga-tó (HL) madárvilágának állapota

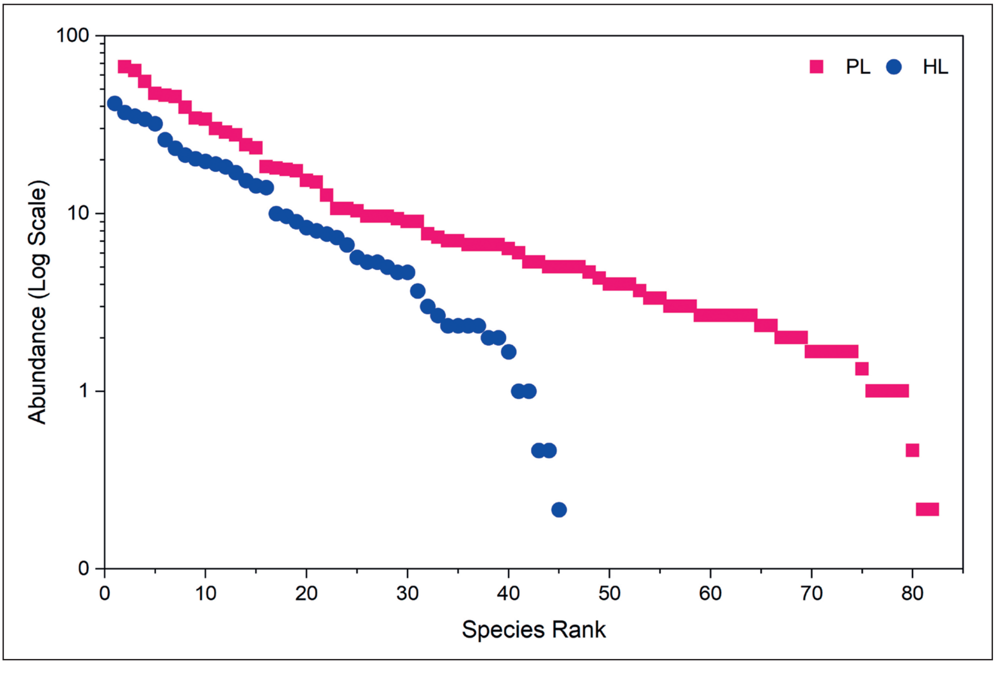

Figure 4. Rank abundance curve of avian fauna recorded in Purbasthali Lake (PL) and Hansadanga Lake (HL)
4. ábra A Purbasthali-tóban (PL) és a Hansadanga-tóban (HL) regisztrált madárfauna rangsoros abundancia görbéje

most abundant species in PL, followed by Little Grebe *(Tachybaptus ruficollis)* and Little Cormorant *(Phalacrocorax niger)*. Cattle Egret *(Bubulcus ibis)* was recorded as most abundant bird species in HL, followed by Barn Swallow *(Hirundo rustica)* and Asian Openbill Stork *(Anastomus oscitans)*. Lesser Adjutant Stork *(Leptoptilos javanicus)* and Green Sandpiper *(Tringa ochropus)* were recorded as least abundant bird species from PL and HL, respectively. In PL, open-water zone comprised 20 bird species (24.39%), whereas transitional zone and nearby trees comprised 48 species (58.54%) and 14 species (17.07%), respectively. In HL, open-water zone, transitional zone, and nearby trees contained eight species (17.78%), 23 species (51.11%) and 14 species (31.11%), respectively *(Table 1, Figure 3)*. According to the dispersal status *(Table 1, Figure 3)* in PL, 39 species (47.56%) were resident, 42 species (51.22%) were winter visitors and only one species (1.22%) was summer visitor. Furthermore, in HL, 32 species (71.11%) were resident, and 13 species (28.89%) were recorded as winter visitors. The feeding guild assessment *(Table 1, Figure 3)* showed that, 31 species (37.80%) in PL and 19 species (42.22%) in HL were carnivores; 28 species (34.15%) in PL and 13 species (28.89%) in HL were omnivores; 19 species (23.17%) in PL and nine species (20%) in HL were insectivores; three species (3.66%) in PL and three species (6.67%) in HL were granivorus and a single species with 1.22% was vermivorous in PL and also in HL with 2.22%. Out of 82 observed bird species in PL, Common Pochard *(Aythya ferina)* was vulnerable, Lesser/Siberian Sand Plover *(Charadrius mongolus)* was endangered, four species, Ferruginous Duck *(A. nyroca)*, River Lapwing *(Vanellus duvaucelii)*, Black-tailed Godwit *(Limosa limosa)*, and Lesser Adjutant Stork were near threatened, and the rest 76 species were categorized as least concern according to IUCN (2025). Whereas in HL, out of 45 recorded bird species, only Common Pochard was vulnerable, and 44 species were categorized as least concern *(Table 1, Figure 3)*.

The analysis of global population trend (GPT) in PL showed that, 13 species (15.85%) were increasing, 27 species (32.93%) were decreasing, 18 species (21.95%) were stable, and 24 species (29.27%) were unknown. In HL, seven species (15.56%) showed increasing

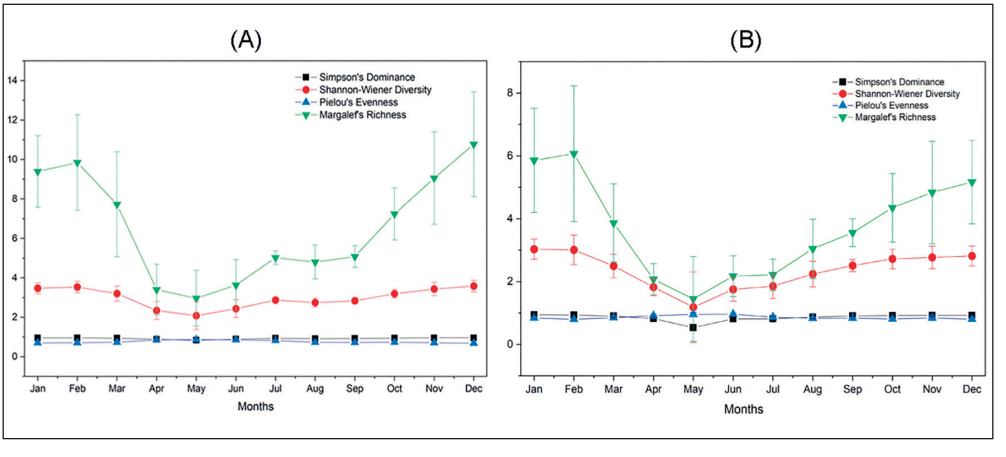

Figure 5. Month-wise diversity indices of avifauna recorded from Purbasthali Lake (A) and Hansadanga Lake (B)

5. ábra A Purbasthali-tó (A) és a Hansadanga-tó (B) madárfaunájának havi diverzitási indexei trend, 12 species (26.67%) showed decreasing trend, 12 species (26.67%) were stable and 14 species (31.11%) showed unknown status *(Table 1, Figure 3)*.

Figure 5 evinced that the Shannon–Wiener diversity index (H′) ranged from 2.08±0.70 (in May) to 3.58±0.30 (in December) in PL, and its value ranged from 1.18±1.12 (in May) to 3.03±0.32 (in January) in HL. In PL, lowest value of Simpson's index (D=0.84±0.11) was observed in the month of May, where its highest value (D=0.96±0.01) was recorded from the months of February, November, and December. Studies showed almost similar trend in HL, where lowest Simpson's index value (D=0.54±0.47) was noted in May and highest value (D=0.93±0.03) was recorded in February. Pielou's evenness index (J′) was considered to quantify how evenly the organisms in a community are distributed among different species. In case of PL, it showed its minimum value (J′=0.68±0.03) in December and its maximum (J′=0.87±0.06) in May during the study period, while in HL, J′ was lowest (J′=0.80±0.02) in February and highest (J′=0.96±0.04) in May. Margalef's index (RI) denotes the species richness of an area and its value ranged from 2.97±1.41 (in May) to 10.77±2.66 (in December) in case of PL. The lowest RI value (RI=1.45±1.35) was recorded form HL in May and its maximum value (6.07±2.16) in February during the entire study period.

The PERMANOVA revealed a high F-value (26.55) with a significantly low $P < 0.01$, indicating that between-group variation (i.e. between PL and HL) was substantially greater than within-group variation. This confirms a significant difference in avian community composition between the two lakes. The dendrograms *(Figure 6)* further highlighted lake-specific, month-wise structuring of avian assemblages, while also revealing a general seasonal pattern common to both lakes. In both systems, the monsoon and post-monsoon months (August–February) consistently clustered together, whereas the pre-monsoon months

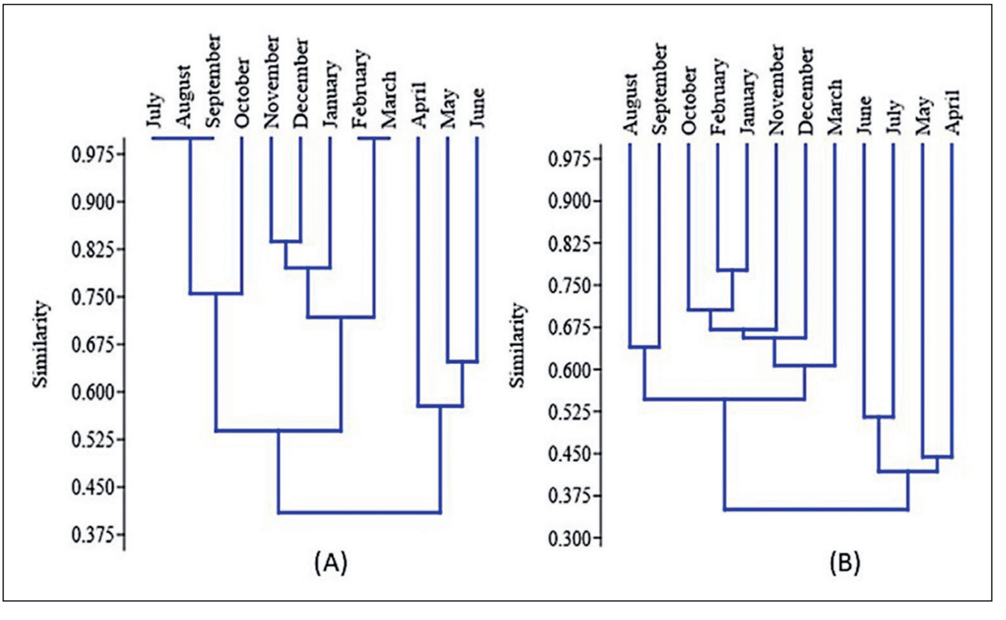

Figure 6. Month-wise hierarchical clustering in Purbasthali Lake (A) and Hansadanga Lake (B)
6. ábra Havi adatok hierarchikus klaszterezése a Purbasthali-tónál (A) és a Hansadanga-tónál (B)

(April–June) formed a distinct group. The indicator species analysis identified several bird species that were significantly associated with PL. Among these, the Lesser Whistling Duck, Great White Egret *(Ardea alba)*, Black-crowned Night Heron *(Nycticorax nycticorax)*, Yellow Bittern *(Ixobrychus sinensis)*, Oriental Pratincole *(Glareola maldivarum)*, Small Pratincole *(G. lactea)*, and Little Grebe exhibited high indicator values and were statistically significant. In contrast, no species were identified as significant indicators for HL.

Discussion

The present survey documented substantial differences in avifaunal richness and community structure between the two contrasting oxbow lakes. PL supported a considerably higher number of bird species (82 species, 23 families) compared to HL (45 species, 19 families). Family-level dominance patterns also varied, with Anatidae emerging as the most dominant family in PL, whereas Ardeidae dominated in HL, as reflected in their respective Relative Diversity (RD_i) values. Such dominance of Anatidae and Ardeidae has also been reported from other wetland habitats in West Bengal (Patra *et al.* 2010, Roy *et al.* 2016, Debnath *et al.* 2018, Mukherjee *et al.* 2021), suggesting that although the two lakes differ in richness and relative composition, their family-level dominance aligns with the broader regional trends. Comparable richness and composition patterns have likewise been documented in other wetlands within the same eco-region (Roy *et al.* 2011, Mandal *et al.* 2021b, Mukherjee *et al.* 2021, Modak *et al.* 2023).

A notable difference between the two lakes was the higher proportion of winter visitors (WV) in PL (51.22%) compared to HL (28.89%). The large number of winter migrants in PL suggests that its structural complexity, abundant feeding grounds, and suitable breeding habitats create conducive conditions for these species (Saygili *et al.* 2011). Migratory connectivity further explains this pattern, as winter migrants travel thousands of kilometres to utilize suitable stopover habitats in the Indian subcontinent (Newton 2024). Among WV, the Lesser Whistling Duck was especially widespread in PL, supported by nutrient-rich waters and diverse macrophyte stands that offer food, roosting, and nesting sites (Saha *et al.* 2020, Mukherjee *et al.* 2021). In contrast, HL, with its less favourable limnological conditions (Das & Chakrabarty 2007, Debnath *et al.* 2013, Chakraborty *et al.* 2021), appears less attractive to both local and migratory species.

Habitat guild analysis revealed the predominance of transitional zone (TZ) species over open-water (OW) and nearby tree (NT) species in both lakes, though with higher representation of transitional zone species in PL (58.54%) compared to HL (51.11%). Such distribution reflects the role of species-specific habitat preferences, food habits, and nesting requirements (Malik & Joshi 2013). Large areas of both lakes are under perennial crop cultivation, particularly during the summer months when the water level recedes. These dynamic ecotones (Danso Marfo *et al.* 2019) favour waders such as Asian Openbill Stork, Common Moorhen *(Gallinula chloropus)*, Grey-headed Swamphen *(Porphyrio poliocephalus)*, Black-headed Ibis *(Threskiornis melanocephalus),*which forage along exposed banks and agricultural plots rich in small invertebrates (Mandal *et al.* 2021a).

Ground-nesting species such as Small Pratincole, Red-wattled Lapwing *(V. indicus)*, River Lapwing, Greater Sand Plover *(Charadrius leschenaultii)* also benefit from these altered landscapes (Malik & Joshi 2013). Conversely, waterfowl such as Red-crested Pochard *(Netta rufina)*, Lesser Whistling Duck, Greylag Goose *(Anser anser)*, Cotton Pygmy Goose *(Nettapus coromandelianus)* favoured the larger open-water expanse of the lakes. In PL, open-water stretches devoid of macrophyte patches harboured comparatively greater Anatidae richness (Mandal *et al.* 2021b). Nearby tree zones around both lakes provided essential habitats for arboreal wetland-associated species like Black Kite *(Milvus migrans)*, White-throated Kingfisher *(Halcyon smyrnensis)*, Black Drongo *(Dicrurus macrocercus)*, Asian Green Bee-eater *(Merops orientalis)*, which rely on bordering bushes and vegetation for feeding and shelter.

The trophic composition of bird assemblages revealed a dominance of carnivores, followed by omnivores and insectivores. This pattern corresponds to the availability of fish, molluscs, crustaceans, and micro-invertebrates within the lakes and adjoining crop fields. Earlier works also highlighted the carnivorous inclination of winter migrants in Indian wetlands (Malik & Joshi 2013, Hossain & Aditya 2016).

Conservation concern was reflected in the presence of six species from the IUCN-declining categories (vulnerable, endangered, near threatened) in PL, whereas only one such species was recorded in HL. Furthermore, a significant fraction of the species recorded showed globally declining trends (PL: 32.93%; HL: 26.67%). The consistent presence of declining species such as Ferruginous Duck, Common Pochard, and River Lapwing underscores the importance of PL as a critical refuge for waterbirds in the lower Gangetic delta (Chakraborty *et al.* 2021). Notably, Lesser Whistling Duck remained the most abundant species in PL despite its globally declining trend, while the Cattle Egret dominated HL.

The diversity indices further reinforce the ecological distinctiveness between the two lakes. PL, with its semi-open and semi-lotic character, exhibited higher Shannon diversity (H′), Simpson's index (D), and Richness (RI) values compared to HL. These patterns reflect fundamental hydrological contrasts: PL maintains periodic connectivity with the main river channel, which ensures flushing, nutrient turnover, and oxygen renewal, thereby sustaining dynamic conditions. In contrast, HL, a closed-lentic system, receives inflow mainly during monsoon floods and remains stagnant for much of the year. Such restricted hydrology promotes hypoxia, accumulation of toxic compounds like ammonia and hydrogen sulphide, and loss of sensitive benthic invertebrates (Obolewski 2011, Obolewski *et al.* 2015). Such bottom-up constraints cascade through the food web. In PL, nutrient-rich sediments, dynamic water movement, and diverse macrophyte cover (*Eichhornia* sp., *Ipomoea* sp., *Hydrilla* sp., *Ceratophyllum* sp.) sustain invertebrate prey, thereby supporting more diverse and functionally rich bird assemblages (Obolewski *et al.* 2015, Hossain & Aditya 2016, Kiros *et al.* 2018, Saha *et al.* 2020). In HL, reduced macrophyte heterogeneity and depauperate prey base restrict avifaunal diversity. Seasonal fluctuations were evident in both lakes, with species richness declining during the pre-monsoon and peaking post-monsoon, whereas evenness (J′) exhibited the opposite pattern. Comparable inverse richness–evenness dynamics have also been reported by Sandal *et al.* (2024), likely driven by the influx and dominance of migratory flocks in the post-monsoon period.

Multivariate analyses corroborated these ecological contrasts. PERMANOVA confirmed significant segregation of avian communities between PL and HL, with differences driven by habitat features, disturbance regimes, and productivity gradients. Although a common seasonal influence shaped clustering patterns in both lakes, subtle dissimilarities in similarity values suggest localized hydro-environmental variations. Indicator species analysis highlighted the predominance of waders in PL, which typically utilize the land–water interface zones. In this lake, such interface habitats become particularly prominent during the dry months, when parts of the lake are seasonally exposed and subsequently used for agricultural activities. These dynamic habitat conditions likely create a mosaic of foraging opportunities that attract and support wader species (Bancroft *et al.* 2002).

The foregoing narration clearly demonstrates that PL supports higher species richness, greater functional diversity, a larger proportion of migratory species, and more conservation-concern taxa than HL. This reinforces the ecological significance of PL as a critical wetland habitat in the lower Gangetic delta that demands strengthened conservation and management strategies. Conversely, the comparatively degraded ecological condition of HL highlights the urgent need for habitat restoration and sustainable interventions to enhance its capacity to support diverse bird assemblages.

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