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Seasonal variation in wetlands influence the dynamics of waterbird communities in Dungarpur district, Rajasthan, India

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Abstract Human activities have rendered freshwater ecosystems among the most endangered in the globe, yet these ecosystems provide critical habitats for a variety of waterbird species. Semi-arid landscapes, characterized by variable climatic conditions and water availability, present unique challenges to these ecosystems. In our study, we investigated how wetland size and seasonal variations in a semi-arid climate influence waterbird populations, distribution, and habitat preferences. Using an *a-priori* field design, we surveyed areas with varying wetland extents across different seasons in the Dungarpur district, Rajasthan, western India. Between March 2021 and January 2022, we recorded 69 waterbird species belonging to 9 orders, including 10 species of global conservation concern. We found that both bird species diversity and richness were significantly higher in areas with high wetland extent. Interestingly, seasonal changes did not significantly affect waterbird diversity and richness. However, encounter rates were higher in winter than summer and monsoon seasons. The encounter rates of different feeding guilds varied across wetland classes, except for omnivores, which showed significant seasonal variation. Overall, our findings indicate that wetland extent is a major driver of waterbird population and distribution. Therefore, we strongly recommend the protection of extensive wetland areas to enhance waterbird conservation in the study area.

Keywords: bird conservation, wetlands, bird diversity, Mewar region, Aravalli region

Összefoglalás Az emberi tevékenységek következtében az édesvízi ökoszisztémák a világ legveszélyeztetettebb ökológiai rendszerei közé sorolódnak annak ellenére, hogy ezek a rendszerek a vízimadarak széles taxonómiai skálájának nyújtanak kritikusan fontos élőhelyeket. A félsivatagos tájak, amelyeket változatos klimatikus feltételek és vízellátottság jellemez, ezen ökoszisztémák számára különleges kihívásokat jelentenek. Jelen vizsgálatunkban azt elemeztük, hogy a vizes élőhelyek kiterjedése és a félsivatagos klíma szezonális változása hogyan befolyásolja a vízimadár-populációkat, ezek elterjedését és élőhelyválasztását. Előre meghatározott (a priori) terepi kísérleti elrendezést alkalmazva, változatos kiterjedésű vizesélőhely-rendszereket mértünk fel különböző évszakokban a nyugat-indiai Rajasthan Dungapur tartományban. 2021 márciusa és 2022 januárja között 9 madárrend 69 vízimadár-fajáról gyűjtöttünk adatokat, melyek közül 10 faj globális szinten veszélyeztetett. Eredményeink alapján a madarak fajdiverzitása és -gazdagsága szignifikánsan magasabb volt a nagy vizesélőhely-arányt mutató területeken. Érdekes módon a szezonális változások nem befolyásolták jelentősen a vízimadarak diverzitását és fajgazdagságát. Ezzel szemben viszont a megfigyelési arányok magasabbak voltak télen, mint nyáron vagy a monszun ideje alatt. Az eltérő táplálkozási guildek megfigyelési arányai változtak a vizesélőhely típusa szerint, a mindenevők kivételével, melyek szignifikáns szezonális változást mutattak. Összességében eredményeink rámutatnak, hogy a vizesélőhelyek a vízimadarak állománynagyságainak és elterjedésének fő meghatározó tényezői. Így nyomatékosan ajánljuk a kiterjedt vizesélőhely-rendszerek védelmét, ami a vizsgált területen erősítheti a vízimadarak védelmét.

Kulcsszavak: madárvédelem, vizes élőhelyek, madár diverzitás, Mewar régió, Aravalli régió

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Introduction

Freshwater ecosystems are vital for maintaining ecological balance and supporting biodiversity by providing essential habitats for numerous species. However, these ecosystems are among the most endangered ones globally due to a range of human activities and environmental changes, including overexploitation, habitat degradation, agricultural conversion, wetland drainage, urban development, the spread of invasive species, and industrial and agricultural runoff (Craig *et al*. 2017, Reid *et al*. 2019). Over the past century, more than half of the world's wetlands have either disappeared or been severely degraded, with approximately 35% being destroyed since 1970 (Ramsar Convention on Wetlands 2018). This widespread loss exerted devastating effects on wetland-dependent species, particularly waterbirds, which rely heavily on these ecosystems for their survival. Currently, 38% of the world's waterbird populations are in decline, largely due to the degradation and loss of wetlands (Kirby *et al*. 2008).

Wetlands in tropical and subtropical Asia are deeply intertwined with the socio-cultural relations and are often actively managed, as seen in paddy fields and aquaculture ponds (Gopal 2013). Precipitation variability and seasonal changes are key factors influencing these ecosystems, affecting hydrological patterns, wetland extent, and the provision of ecological services (Bassi *et al*. 2014). A significant ratio of the human population living near wetlands depends heavily on them for agriculture and livelihoods (Blake *et al*. 2004). In recent decades, these wetlands have attracted global attention due to their critical role in supporting diverse wildlife (Kumar & Sharma 2019, Chatterjee & Bhattacharyya 2021, Rawal *et al*. 2021). Many wetland ecosystems, such as Keoladeo National Park, a Ramsar site, are renowned for their high avian biodiversity. Chatterjee and Bhattacharyya (2021) highlighted that 11 mammal species dependent on Indian wetlands are under significant threat. Rawal *et al*. (2021) recently emphasized the importance of ponds as vital remnant ecosystems for bird diversity in Delhi, India's capital, one of the world's most densely populated megacities. They found that bird abundance in city ponds increases with pond size and greater shoreline heterogeneity.

Semi-arid tropics and sub-tropics are characterized by distinct climatic conditions and often experience high human population densities (Huang *et al*. 2016, Marcotullio *et al*. 2021). Over the past 60 years, semi-arid regions have seen the most significant expansion of dry areas globally (Huang *et al*. 2016). These areas are marked by pronounced seasonal changes and variability in precipitation, creating unique habitats. Nonetheless, recent changes in their land cover pose survival challenges for both wildlife and human populations. The availability of water fluctuates over time, impacting ecological services and wildlife habitats in these regions. Most wetlands in semi-arid areas are agricultural wetlands, which are used for a variety of purposes, including agriculture, domestic water supply, cattle grazing, and the harvesting of wetland products such as fish, reed and silt (Gopal 2005, Sundar & Kittur 2013). Despite these diverse uses, recent studies have increasingly recognized these wetlands as critical habitats for biodiversity conservation (Verhoeven & Setter 2010). However, much of the wetland research to date has focused on individual and large wetland sites, with a limited application of landscape-level approaches, particularly in India (Foote *et al*. 1996, Ladhar 2002, Sundar *et al*. 2015, Ramachandran *et al*. 2017, Kumar & Sharma 2019, Rawal *et al*. 2021).

Effective wetland management requires a fundamental understanding of ecosystem processes, species interactions, and life history strategies (Gray *et al*. 2013). Williamson *et al*. (2013) observed that many threatened inland-breeding waterbirds are concentrated in Asia, yet studies on these species remain limited. To address this gap, we conducted our study with an *a-priori* study design, stratifying the landscape based on wetland extent in the semi-arid region of Dungarpur, the southernmost district of Rajasthan, western India. Our goal was to examine the effects of two key drivers – seasonal changes and wetland extent – on waterbird populations. This area, interspersed with the Aravalli Mountain range, provides a unique habitat for study. Our broad objectives were: (1) to document waterbird diversity in the Dungarpur district, (2) to assess the impact of seasonal changes and wetland extent on waterbird diversity, richness and abundance as well as (3) to evaluate waterbird habitat use within the study area. Given that waterbirds primarily depend on wetlands, we hypothesized that waterbird biodiversity, richness, and density would be higher in areas with greater wetland extent, with waterbirds predominantly utilizing wetland habitats. Additionally, considering the study area's significance as a habitat for winter migratory bird species (Sharma & Tehsin 1994), we anticipated higher waterbird diversity and richness during the winter season. In Dungarpur, natural wetlands typically fill during the monsoon season and are subsequently used for agriculture throughout the rest of the year. Most wetlands dry out between the end of winter and the onset of summer, and larger wetlands that retain water during these dry periods (with temperatures reaching ~45 °C) attract waterbirds (Sundar 2006, Asawra *et al*. 2022). Therefore, we expected that areas with larger wetlands would support a greater density or encounter rate of waterbirds during the summer. Finally, we predicted that waterbirds would be encountered more frequently in wetland habitats compared to other habitat types.

Material and Methods

Study area

Our study was conducted in the Dungarpur district (23°00'–24°01' N, 73°22'–74°24' E, covering 3,770 km^2), located in the southernmost region of Rajasthan state, western India *(Figure 1)*. The district has a human population of 1,388,552, with approximately 70% belonging to tribal communities who primarily rely on agriculture and animal husbandry for their livelihoods (Census of India 2011, Asawra *et al*. 2022). A network of streams traverses the district, eventually discharging into the two major rivers, the Som and the Mahi. The Som Kamla reservoir on the Som River and the Kadana Dam on the Mahi River play crucial roles in mitigating the area's arid climate. Most natural wetlands in the district fill up during the monsoon season and are utilized for various purposes, including irrigation. These wetlands typically dry up by the end of winter, leaving only the larger wetlands with some water throughout the hot summer months (Asawra *et al*. 2022). The region experiences three distinct seasons based on temperature and precipitation: summer (March-June), monsoon (July–October), and winter (November–February). Temperatures range from a minimum of ~5 °C in winter to a maximum of ~45 °C in summer. The area received 877.6 mm of rainfall in 2020 (Monsoon Report Rajasthan 2020). Dungarpur is located in the humid southern plains agro-climatic zone. Agriculture in the district includes both rain-fed and irrigated crops (Rao & Singh 2018). Most farmers practice mixed farming, which includes crops, fruit orchards, vegetables, dairy, and poultry (Asawra *et al*. 2022). Common crops during the Kharif season include maize *(Zea mays)*, paddy *(Oryza sativa)*, and sorghum (*Sorghum* sp.), while wheat (*Triticum* spp.) and small millets are grown in the Rabi season. Cotton (*Gossypium* spp.) and sugarcane *(Saccharum officinarum)* are also commercially cultivated across the district. Previous studies in this region have shown that it supports a healthy population of several threatened waterbird species (Sharma & Tehsin 1994, Koli *et al*. 2013, Asawra *et al*. 2022).

Study design

The study area was initially divided into 5×5 km grids, resulting in 128 squares *(Figure 1)*. We then estimated the Normalized Difference Water Index (NDWI) (McFeeters 1996) for the entire Dungarpur district using the green (Band 3) and near-infrared (Band 8) bands from Sentinel-2 satellite imagery (spatial resolution 10 m) downloaded from https://scihub.copernicus.eu. NDWI was calculated for the first two months of each season – summer, monsoon, and winter – to capture seasonal variation. To represent each season, we averaged the NDWI values for March–April 2021 for summer, July–August 2021 for monsoon, and November–December 2021 for winter. Subsequently, we manually classified the NDWI scores to identify surface water presence. Using the "Tabulate Area" feature in ArcMap (Version 10.8), we calculated the proportion of each 5×5 km grid square covered by water during each season. The wetland area within each grid square ranged from 0.002 to 7.73 km^2, with over 73% of the squares containing less than 1 km^2 of wetlands. We categorized the squares into three classes based on the availability of wetland extent: low (<0.1 km^2), medium (0.1–0.3 km^2), and high (>0.3 km^2). Due to limited manpower and funding, we randomly selected five squares from each category for sampling during the first season (summer) and repeated the sampling in the subsequent seasons, resulting in a total of 15 grid squares *(Figure 1)*. Before sampling, we ensured that the selected grids consistently represented the same wetland extent classes across all seasons.

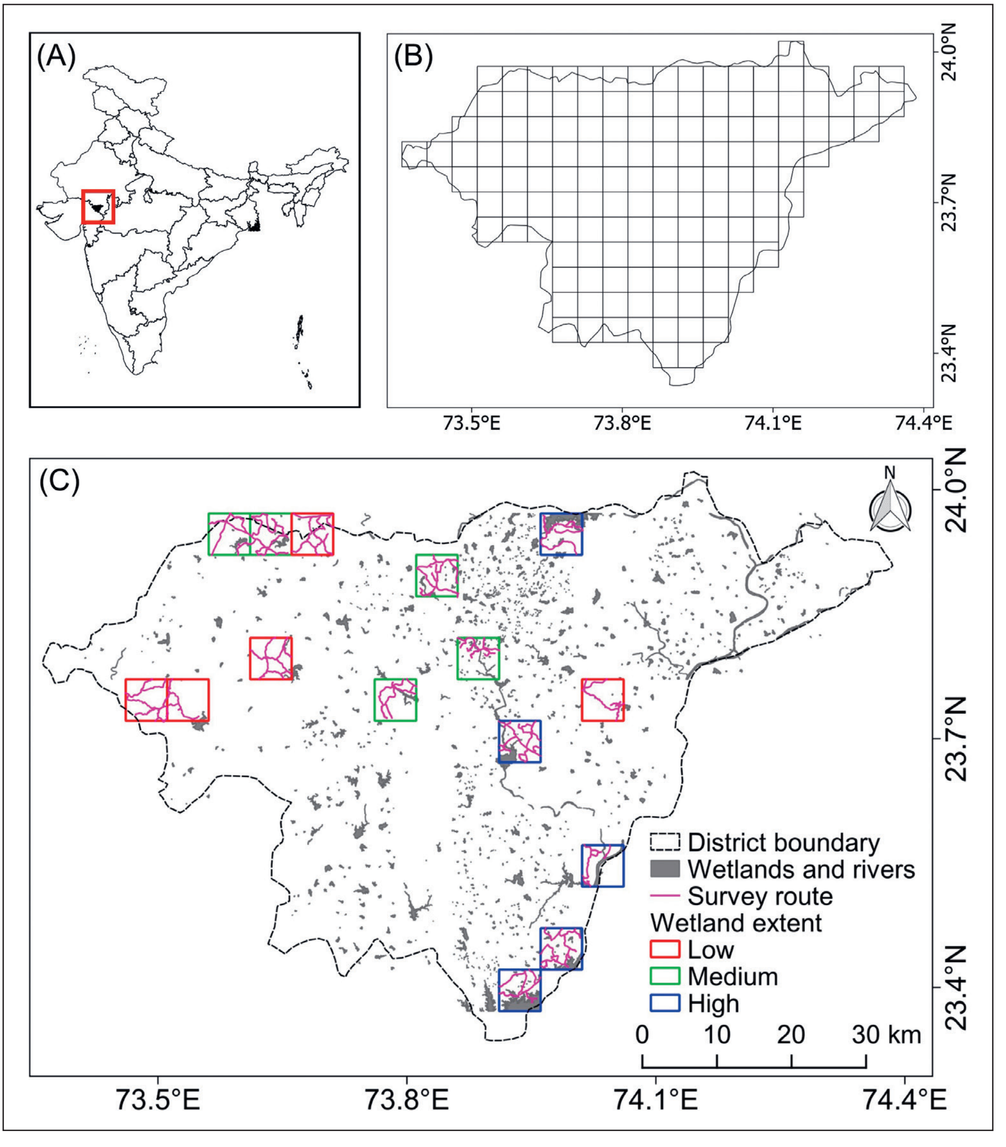

Figure 1. Study area i.e. Dungarpur district, located southern Rajasthan, India (A). The district was divided into 5 × 5 km squares (B), and 15 squares with varied wetland extents (low, medium, and high) were chosen randomly to count waterbirds (C). The sampling effort (roads travelled) in each square is also shown

1. ábra A nyugat-indiai Rajasthan Dungarpur tartományában elhelyezkedő vizsgálati terület (A). A területet 5 × 5 km kvadrátra osztottuk (B), melyek közül 15, változatos vizesélőhely-kiterjedéssel jellemzett (alacsony, közepes, magas) kvadrátot véletlenszerűen választottunk ki a vízimadarak felméréséhez (C). A felmérés ráfordítását (megtett útvonal) is feltüntettük az ábrán

Field method

Field surveys were conducted across 15 selected grid squares in random order between March 2021 and January 2022 to cover all three seasons, using motorbikes driven at a speed of ~20 km/hr. Wetland areas outside the district boundaries were not included in the survey. The survey routes and the distance covered were recorded using the smartphone application LOCUS map (Ver. 4.25.1). For large wetlands near road networks that could not be fully observed from a vantage point, we conducted on-foot surveys to count all waterbirds present, and the walking distance was also included in the survey track. Each grid square was surveyed once per season, and waterbirds observed within approximately 200 meters on either side of transects were recorded. Given our primary objective of assessing the impact of wetland extent and seasonal changes on waterbird diversity, richness, and abundance, the sampling methodology was kept consistent across these factors. For instance, the field surveys were carried out by the same two observers (KS and AM) following nearly identical routes throughout all seasons to minimize potential biases, such as observer bias and variations in visibility.

Waterbird sightings were categorized according to habitat types: agriculture (land with standing or growing crops), wetlands (both in water and on wet soil adjacent to wetlands), open areas (uncultivated land), and other categories (including garbage sites, drainage lines, grasslands, and roadsides). Bird species were identified and classified by their feeding guilds (carnivore, herbivore, insectivore, piscivore, omnivore, molluscivore) and migratory status (resident vs. migratory) based on Rasmussen and Anderton (2005), Ali and Ripley (2007), and Grimmett *et al*. (2011). Bird nomenclature followed Clements *et al*. (2023), and the global conservation status of species was obtained from BirdLife International (2024).

Statistical analysis

Given the slightly unequal distribution of road transects across the grids, waterbird abundance was estimated per grid based on the encounter rate (waterbirds counted/transect length in km). To understand the habitat utilization by waterbirds, we used the raw number of birds (abundance), as estimating encounter rates at the habitat level was difficult. Waterbird diversity was assessed using various metrics, including Shannon–Wiener index (for species diversity) and species richness. The Shannon–Wiener index and Simpson's index was calculated using PAST software (Version 3.15) (Hammer *et al*. 2001). To evaluate the adequacy of our seasonal sampling and compare species richness across seasons, we employed sample-size-based rarefaction curves using the 'ggiNEXT' function in the R package 'iNEXT' (Chao *et al*. 2014). We used species richness (Hill number $q = 0$) to thoroughly assess our sampling coverage across different subnetworks. This approach allowed us to determine whether observed differences between subnetworks were more likely due to sampling effectiveness rather than biological processes. Hill numbers are valuable statistic for measuring species diversity, assessing sampling coverage, and comparing datasets (Chao *et al*. 2014, Roswell *et al*. 2021). We used the

Chao 1 index of species richness and the 'ChaoRichness' function from the same package to estimate the number of undiscovered species throughout our investigation (Colwell &Coddington 1994).

We employed Permutational Multivariate Analysis of Variance (PERMANOVA; a non-parametric test) to compare species diversity (Shannon–Wiener index and Simpson's index), species richness, and encounter rates across different wetland classes and seasons. In this analysis, we tested two-way interactions between wetland extent and seasons to determine whether variations in species diversity, species richness, and encounter rates were attributable solely to wetland extent, seasons, or their interaction. This analysis was conducted in R using the 'lmPerm' package (Ver. 2.1.0) and the 'aovp' function (Wheeler & Torchiano 2016). Additionally, due to small sample size, Fisher's Exact Test was utilized in R to evaluate whether the distribution and abundance of waterbirds varied across different habitat categories, wetland extent classes, and seasons.

Results

Waterbird diversity, richness and composition

A total of 1,436.1 km was surveyed in search of waterbirds (565.7 km covered in summer, 437.4 km in the monsoon, and 433 km in winter). During the study period, we recorded 69 waterbird species across 9 orders and 19 families *(Table 1)*. According to Chao 1 index, we observed the highest proportion 84.50% (n = 60) of the potential total species richness in winter (mean Chao = 63.99±5.29 SE), followed by summer with 70.42% (n = 50; mean Chao = 61.12±1.76 SE), and monsoon with 60.53% (n = 43; mean Chao = 63.99±5.29 SE) *(Figure 2)*. Of the total species recorded, 39 were resident and 30 were migratory. In terms of feeding guilds, 28 species were carnivores, 14 were omnivores, 10 were herbivores, 10 were piscivores, 6 were insectivores, and a single species was a molluscivore. According to BirdLife International, most species (n = 59) were classified as Least Concern, with 6 species being Near Threatened and 4 being Vulnerable *(Table 1)*.

Species diversity (Shannon–Wiener index and Simpson's index) varied significantly across different wetland classes ($P < 0.0001$) but did not differ significantly between seasons ($P = 0.55$) *(Figure 3)*. Grids with a high extent of wetlands exhibited significantly greater species richness ($P < 0.0001$). There was no significant interactive effect of seasons and wetland extent on either species diversity ($P = 1.0$) or species richness ($P = 0.91$) *(Figure 3)*.

Encounter rate

The overall encounter rate of waterbirds per grid was 7.95 (±7.03 SD; range: 0.05–29.62). Winter had the highest encounter rate (10.48±9.08 SD; range: 0.66–28.17), followed by summer (7.23±7.64 SD; range: 0.15–29.62) and monsoon (6.14±3.96 SD; range: 0.05–14.04). Encounter rates were significantly higher during winter ($P = 0.03$) and in grids with a high extent of wetlands ($P < 0.0001$). The interaction between wetland extent and seasonal

Table 1. A checklist of waterbirds and their number of individuals recorded in different seasons in Dungarpur district, Rajasthan, India from March 2021 and January 2022 along with their taxonomic order, IUCN and local status, and feeding guild

1. táblázat A 2021 március és 2022 január között a nyugat-indiai Rajasthan Dungarpur tartományában különböző évszakokban megfigyelt madárfajok egyedszáma, taxonómiai helyzete, IUCN-besorolása, helyi státusza és táplálkozási guildje

Order	Family	Common name	Scientific name	Number of individuals			IUCN status	Local status	Feeding guild
				Summer	Monsoon	Winter			
Anseriformes	Anatidae	Bar-headed Goose	*Anser indicus*	0	0	18	LC	M	Herbivore
		Common Pochard	*Aythya ferina*	0	0	21	VU	M	Herbivore
		Tufted Duck	*Aythya fuligula*	0	0	10	LC	M	Omnivore
		Eurasian Wigeon	*Mareca penelope*	0	0	238	LC	M	Herbivore
		Gadwall	*Mareca strepera*	0	0	140	LC	M	Herbivore
		Garganey	*Spatula querquedula*	132	0	19	LC	M	Carnivore
		Graylag Goose	*Anser anser*	0	0	27	LC	M	Herbivore
		Eurasian Teal	*Anas crecca*	0	0	69	LC	M	Herbivore
		Indian Spot-billed Duck	*Anas poecilorhyncha*	234	14	78	LC	R	Herbivore
		Northern Pintail	*Anas acuta*	0	12	92	LC	M	Omnivore
		Knob-billed Duck	*Sarkidiornis melanotos*	10	0	17	LC	R	Herbivore
		Lesser Whistling-duck	*Dendrocygna javanica*	241	84	188	LC	R	Herbivore
		Northern Shoveler	*Spatula clypeata*	0	0	47	LC	M	Omnivore
		Ruddy Shelduck	*Tadorna ferruginea*	65	0	18	LC	M	Omnivore
Gruiformes	Rallidae	Eurasian Coot	*Fulica atra*	2	18	1109	LC	R	Omnivore
		Eurasian Moorhen	*Gallinula chloropus*	20	4	0	LC	R	Omnivore
		Gray-headed Swamphen	*Porphyrio poliocephalus*	6	0	0	LC	R	Herbivore
		White-breasted Waterhen	*Amaurornis phoenicurus*	20	16	16	LC	R	Omnivore
	Gruidae	Common Crane	*Grus grus*	0	0	1	LC	M	Omnivore
		Sarus Crane	*Antigone antigone*	4	0	0	VU	R	Omnivore
Charadriiformes	Burhinidae	Great Thick-knee	*Esacus recurvirostris*	13	5	0	LC	R	Carnivore

Order	Family	Common name	Scientific name	Number of individuals			IUCN status	Local status	Feeding guild
				Summer	Monsoon	Winter			
	Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*	102	196	186	LC	R	Insectivore
	Charadriidae	Little Ringed Plover	*Charadrius dubius*	11	18	1	LC	M	Carnivore
		Red-wattled Lapwing	*Vanellus indicus*	571	615	212	LC	R	Insectivore
		Yellow-wattled Lapwing	*Vanellus malabaricus*	1	14	3	LC	R	Carnivore
	Rostratulidae	Greater Painted-snipe	*Rostratula benghalensis*	10	0	0	LC	R	Omnivore
	Jacanidae	Bronze-winged Jacana	*Metopidius indicus*	20	4	16	LC	R	Omnivore
		Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	0	1	4	LC	R	Carnivore
	Scolopacidae	Black-tailed Godwit	*Limosa limosa*	132	3	20	NT	M	Carnivore
		Common Redshank	*Tringa totanus*	8	3	0	LC	M	Carnivore
		Green Sandpiper	*Tringa ochropus*	1	16	29	LC	M	Carnivore
		Wood Sandpiper	*Tringa glareola*	95	41	74	LC	M	Omnivore
		Common Snipe	*Gallinago gallinago*	0	0	2	LC	M	Omnivore
		Wood Snipe	*Gallinago nemoricola*	0	0	3	VU	M	Carnivore
		Little Stint	*Calidris minuta*	0	0	3	LC	M	Carnivore
		Ruff	*Calidris pugnax*	0	0	39	LC	M	Omnivore
	Glareolidae	Small Pratincole	*Glareola lactea*	0	0	62	LC	R	Insectivore
	Laridae	Common Sandpiper	*Actitis hypoleucos*	42	8	0	LC	M	Carnivore
		Gull-billed Tern	*Gelochelidon nilotica*	2	0	0	LC	M	Carnivore
		Pallas's Gull	*Ichthyaetus ichthyaetus*	3	0	7	LC	M	Carnivore
		River Tern	*Sterna aurantia*	200	31	55	VU	R	Piscivore
		Whiskered Tern	*Chlidonias hybrida*	0	0	9	LC	M	Carnivore
Podicipediformes	Podicipedidae	Great Crested Grebe	*Podiceps cristatus*	0	0	3	LC	M	Carnivore
		Little Grebe	*Tachybaptus ruficollis*	111	28	56	LC	R	Carnivore
Ciconiiformes	Ciconiidae	Asian Openbill	*Anastomus oscitans*	123	29	127	LC	R	Molluscivore

Order	Family	Common name	Scientific name	Number of individuals			IUCN status	Local status	Feeding guild
				Summer	Monsoon	Winter			
		Black-necked Stork	*Ephippiorhynchus asiaticus*	3	2	3	NT	R	Piscivore
		Painted Stork	*Mycteria leucocephala*	52	31	22	NT	R	Piscivore
		Woolly-necked Stork	*Ciconia episcopus*	10	10	7	NT	R	Carnivore
Suliformes	Anhingidae	Oriental Darter	*Anhinga melanogaster*	0	1	1	NT	M	Piscivore
	Phalacrocoracidae	Great Cormorant	*Phalacrocorax carbo*	24	5	0	LC	M	Piscivore
		Indian Cormorant	*Phalacrocorax fuscicollis*	97	37	16	LC	R	Piscivore
		Little Cormorant	*Microcarbo niger*	178	173	264	LC	R	Piscivore
Pelecaniformes	Threskiornithidae	Black-headed Ibis	*Threskiornis melanocephalus*	105	76	102	NT	R	Carnivore
		Eurasian Spoonbill	*Platalea leucorodia*	57	7	0	LC	R	Piscivore
		Glossy Ibis	*Plegadis falcinellus*	72	48	366	LC	R	Carnivore
		Red-naped Ibis	*Pseudibis papillosa*	171	202	53	LC	R	Carnivore
	Ardeidae	Cattle Egret	*Bubulcus ibis*	671	613	641	LC	R	Insectivore
		Great Egret	*Ardea alba*	47	52	37	LC	R	Carnivore
		Grey Heron	*Ardea cinerea*	9	9	6	LC	R	Piscivore
		Intermediate Egret	*Ardea intermedia*	29	22	5	LC	R	Carnivore
		Purple Heron	*Ardea purpurea*	11	2	4	LC	R	Carnivore
		Indian Pond Heron	*Ardeola grayii*	68	27	26	LC	R	Carnivore
		Little Egret	*Egretta garzetta*	159	284	130	LC	R	Carnivore
Coraciiformes	Alcedinidae	Common Kingfisher	*Alcedo atthis*	2	0	4	LC	R	Carnivore
		Pied Kingfisher	*Ceryle rudis*	2	5	3	LC	R	Piscivore
		White-throated Kingfisher	*Halcyon smyrnensis*	10	1	13	LC	R	Carnivore
Passeriformes	Motacillidae	White-browed Wagtail	*Motacilla maderaspatensis*	5	0	2	LC	R	Insectivore
		Western Yellow Wagtail	*Motacilla flava*	15	9	1	LC	M	Insectivore
		White Wagtail	*Motacilla alba*	1	7	0	LC	M	Carnivore

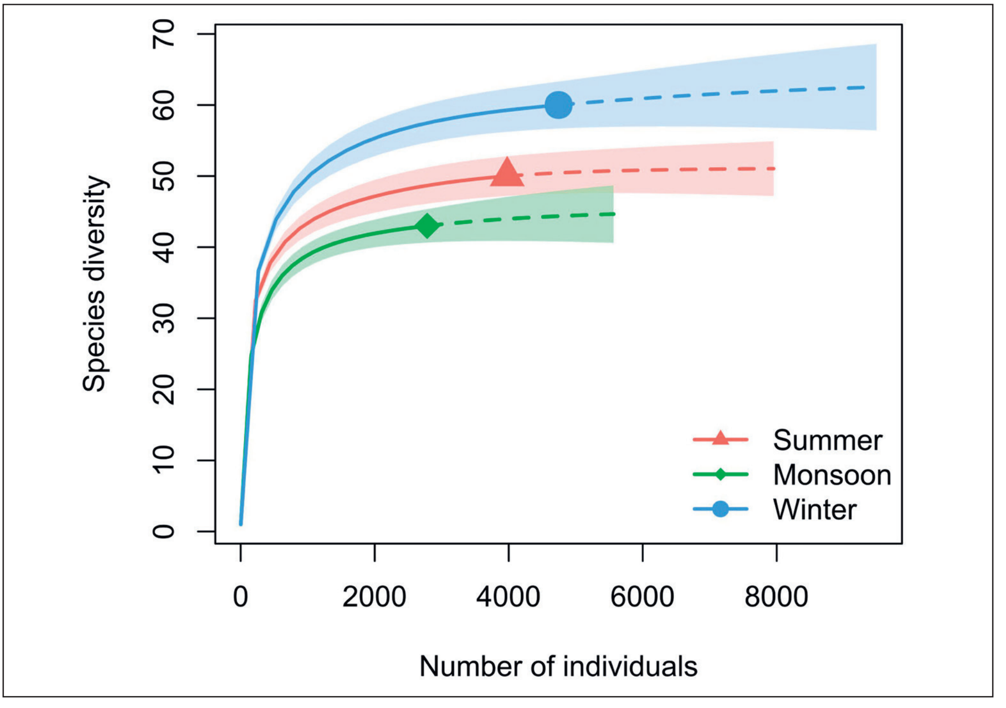

Figure 2. Waterbird species' diversity (estimated by Hill numbers, q = 0 species richness) varies by seasons (summer, monsoon and winter). The shaded area depicted 95% confidence interval, whereas dotted line depicted extrapolation

2. ábra A vízimadarak fajgazdagsága (Hill-számokkal becsülve, q = 0), mely az évszakok szerint változott (nyár, monszun és tél). Az árnyékolt terület a 95%-os konfidenciaintervallumokat, míg a szaggatott vonal az extrapolált értékeket mutatja

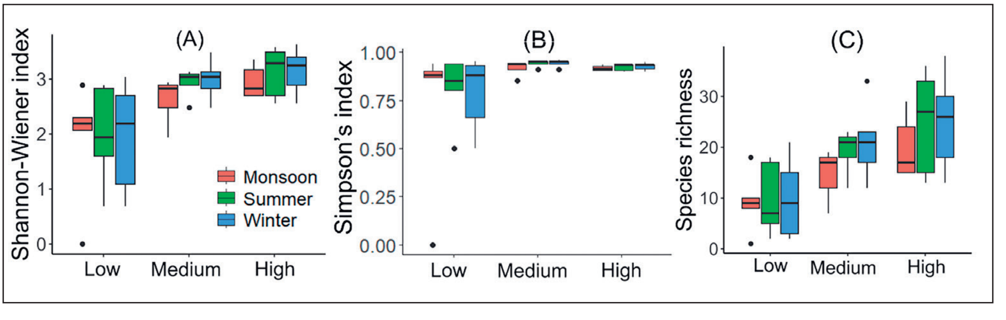

Figure 3. Shannon–Wiener index (A), Simpson's index (B) and species richness (C) per grid recorded across different wetland extent classes in Dungarpur district, southern Rajasthan, India from March 2021 to January 2022.

3. ábra A 2021 márciusa és 2022 januárja között különböző vizesélőhely-típusokban, a nyugat-indiai Rajasthan Dungarpur tartományában megfigyelt madárfajok gridenként mért Shannon–Wiener-indexe (A), Simpson-indexe (B) és fajgazdagsága (C)

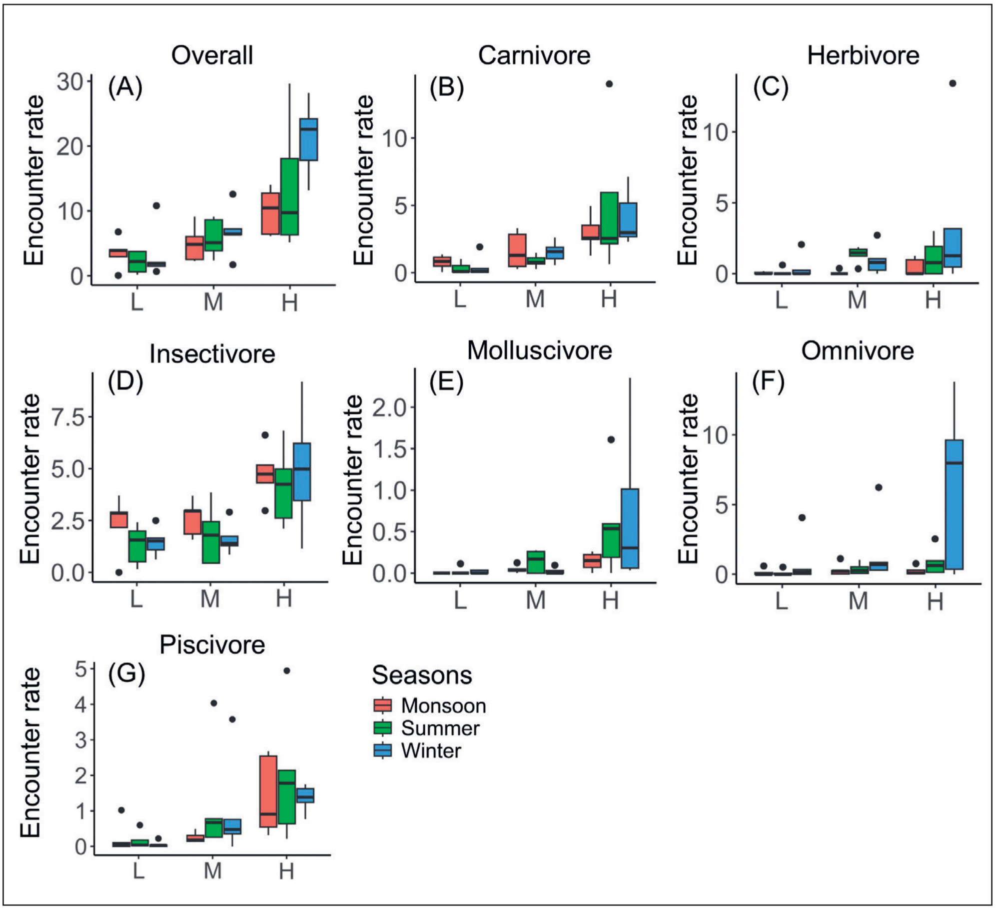

Figure 4. Seasonal encounter rates (waterbird seen per km in individual grids) of waterbird recorded across different wetland extent classes (L-low, M-Medium, H-high) in Dungarpur district, Rajasthan, India recorded from March 2021 and January 2022.

4. ábra A 2021 márciusa és 2022 januárja között különböző vizesélőhely-típusokban, a nyugat-indiai Rajasthan Dungarpur tartományában felvett, évszakonkénti megfigyelési ráták (az egyes gridekben megfigyelt vízimadár-egyedek száma) vizesélőhely-típusok szerint (L-alacsony, M-közepes, H-magas)

changes did not have a significant effect ($P = 0.31$). Significant differences in encounter rates between wetland extent classes were observed for carnivore ($P < 0.0001$), insectivore ($P < 0.0001$), piscivore ($P < 0.0001$), and molluscivore ($P < 0.001$) feeding guilds, whereas only omnivores showed a significant seasonal difference ($P < 0.01$) *(Figure 4)*.

Habitat selection

Most waterbird sightings (total n = 395) occurred in wetlands (n = 185; 46.84%), followed by agriculture (n = 175; 44.30%), other habitats (n = 21; 5.32%), and open areas (n = 14; 3.54%). Overall, waterbird sightings across various habitat categories differed significantly

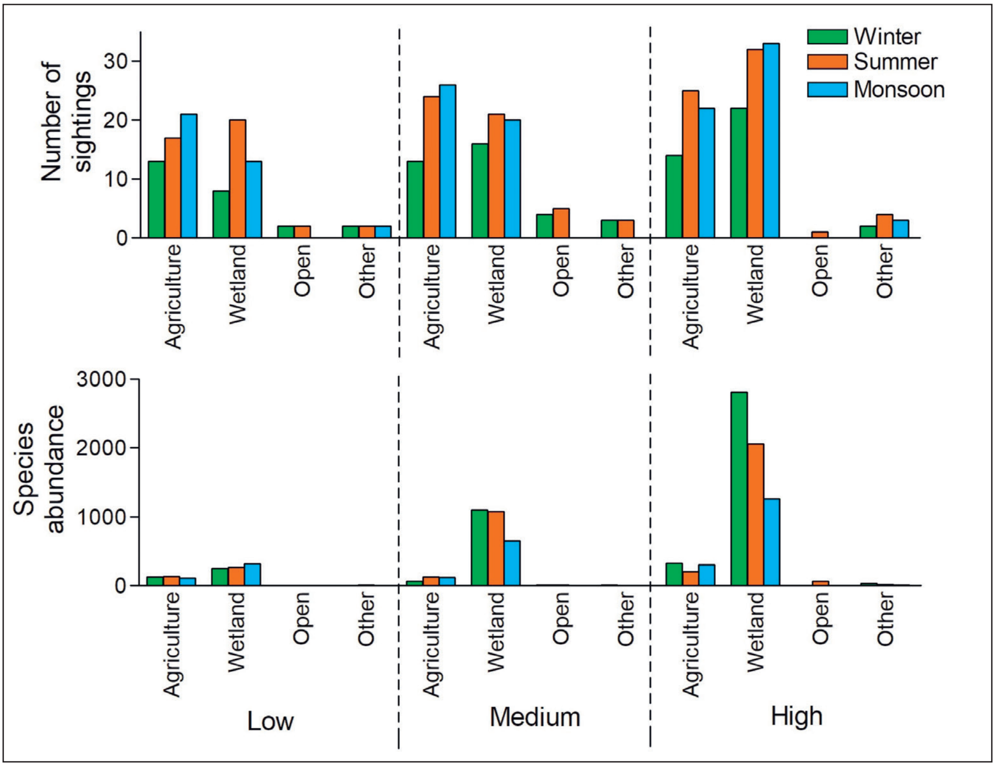

Figure 5. Sightings and species abundances of waterbirds were recorded in different habitats seasons in three wetland extent classes in Dungarpur district, Rajasthan, India, between March 2021 and January 2022.

5. ábra A 2021 március és 2022 január között különböző vizesélőhely-típusokban, a nyugat-indiai Rajasthan Dungarpur tartományában megfigyelt vízimadár-fajok abundanciája

between seasons (P = 0.04), but no significant variation was observed across different wetland extent classes (low: P = 0.472; medium: P = 0.063; high: P = 0.992). Wetland habitats consistently supported higher bird abundance compared to other habitats throughout all seasons (monsoon: P = 0.002; winter: P = 0.0004; summer: P = 0.0004) *(Figure 5)*.

Discussion

Waterbird diversity, richness and composition

Our study represents one of the first systematic investigations in western India employing an *a-priori* study design to assess waterbird diversity, composition, and density. We documented 69 waterbird species, with populations varying across seasons and wetland classes. The study area supports several species of global conservation significance, including six Near Threatened species: Black-tailed Godwit *(Limosa limosa)*, Black-necked Stork *(Ephippiorhynchus asiaticus)*, Painted Stork *(Mycteria leucocephala)*, Woolly-necked Stork

(Ciconia episcopus), Black-headed Ibis *(Threskiornis melanocephalus)*, and Oriental Darter *(Anhinga melanogaster)*, as well as four Vulnerable species: Common Pochard *(Aythya ferina)*, River Tern *(Sterna aurantia)*, Wood Snipe *(Gallinago nemoricola)*, and Sarus Crane *(Antigone antigone)*. Of these, six species were resident in our study area, highlighting its importance for future conservation efforts. The presence of Black-tailed Godwits throughout all three seasons suggests their resident nature in the area, while Common Pochards and Wood Snipes were only observed during winter. Previous studies have reported a healthy population of Painted Storks, Black-headed Ibises, and Sarus Cranes (Vyas 2002, Koli *et al*. 2013, Chaudhury & Koli 2018, Koli *et al*. 2019). Additionally, nesting of Painted Storks, Black-headed Ibises, Oriental Darters, and Black-necked Storks has been documented in Dungarpur district (Koli *et al*. 2019).

Our findings indicate that species diversity and richness were higher in grids with a high extent of wetlands, with no significant interaction between wetland extent and seasonal changes. This underscores the importance of wetlands for waterbirds. We observed nearly equal numbers of resident (n = 39) and migratory species (n = 30), with no seasonal variation in species diversity or richness, suggesting that waterbird species have landscape preferences that remain consistent throughout the year.

Encounter rate

Contrary to our expectations, the highest encounter rate of waterbirds was observed during winter rather than summer, particularly in grids with extensive wetland coverage. This is likely due to the influx of winter migratory birds into the larger wetland areas of our study region. The encounter rate was lowest during the monsoon, likely because the widespread availability of water throughout the district may have encouraged local movements of waterbirds away from our sampled grids or from areas with high wetland coverage to nearby locations. The summer season, which is the breeding period for many waterbirds in our study area, likely promotes the aggregation of waterbirds at nesting sites (Chaudhury & Koli 2018, Mehta *et al*. 2024), which may explain the reduced encounter rates during this time.

In our study, birds in the carnivore, insectivore, piscivore, and molluscivore feeding guilds showed a preference for areas with extensive wetlands, likely due to the high availability of water and their specific feeding requirements. The molluscivore category, represented by a single species – the Asian Openbill *(Anastomus oscitans)* – similarly relies heavily on wetlands for food. Previous studies have shown that certain waterbird species select roosting and nesting sites near wetlands to facilitate breeding and chick rearing (Chaudhury & Koli 2018, Koli *et al*. 2019), which could be another reason for their preference for these high-wetland areas. In contrary, omnivorous species, which can exploit a variety of food resources and habitats such as agricultural fields, fallow lands, urban drainage lines, and garbage sites (Chaudhury & Koli 2018, Ameta *et al*. 2022, 2024, Asawra *et al*. 2022,), do not rely solely on wetlands. This could explain why encounter rates of omnivores did not vary significantly across different wetland extent classes. However, seasonal differences in omnivore encounter rates may be related to local movements or the influx of migratory omnivorous species such as the Northern Pintail *(Anas acuta)*, Northern Shoveler *(Spatula clypeata)*, Ruddy Shelduck *(Tadorna ferruginea)*, Tufted Duck *(Aythya fuligula)*, and Wood Sandpiper *(Tringa glareola) (Table 1)*.

Habitat selection

Our study identified wetlands as the primary habitat for waterbirds in the Dungarpur district; however, agricultural areas also play a significant role, accounting for 44.3% of sightings. Habitat use by waterbirds varied significantly with the seasons but did not differ across wetland classes. Water availability in the region is primarily determined by seasonal rainfall, mainly during the monsoon, with most wetlands drying out between the end of winter and the onset of summer *(pers. obs.)*. Dungarpur is among the least developed districts, with 93% of the human population residing in rural areas and relying on domestic livestock and agriculture, which covers about 34% of the district's geographical area (Rao & Singh 2018). This extensive agricultural landscape is likely to provide important habitat for waterbirds. In recent decades, agricultural lands in various parts of India have been recognized as vital natural habitats for several waterbird species (Czech & Parsons 2002, Sundar 2006, 2011, Sundar *et al*. 2015, Ameta *et al*. 2022), and our findings align with these observations. Seasonal shifts in agricultural practices are likely the primary drivers of changes in habitat use by waterbirds in our study area. Agriculture is practiced at several of our study sites, including the beds of wetlands once they dry out. Wetland water is often used for crop irrigation, accelerating the drying process. In such mixed conditions, waterbirds frequently venture into agricultural areas to feed on planting seeds, rodents, and insects *(pers. obs.)*. Sundar and Kittur (2013) noted that the conservation of waterbirds in the agricultural landscapes of northern India cannot rely solely on a few large wetlands. Habitat use by waterbirds varies also by species (Sundar 2006); for example, the abundance of Woolly-necked Storks, Asian Openbills, and Sarus Cranes increases in areas with more wetlands, while Cattle Egrets *(Bubulcus ibis)* decline (Sundar 2011, Sundar & Kittur 2012, Kittur & Sundar 2021). Ameta *et al*. (2022) and Asawra *et al*. (2022) identified fallow agricultural fields (fields with no standing crops) as key foraging habitats for Red-naped Ibis in southern Rajasthan. Conversely, Sundar and Kittur (2013) identified the highest known bird species richness in South Asia within the agricultural landscape of northern India, despite the intense human pressure on wetlands. Waterbird habitat selection is also influenced by the availability of that habitat (Kittur & Sundar 2021, Ameta *et al*. 2022), which was not accounted for in our study. Consequently, habitat utilization by waterbirds appears to be more complex than our basic structured study in the semi-arid region of southern Rajasthan could fully explain due to the small sample size. Further research is needed to explore the intricate dynamics of waterbird-agriculture interactions in our study area, which is both intriguing and complex. Studies on landscapes with different crop types are lacking, and additional research will help determine which crops in agricultural areas attract or deter specific waterbird species.

A few limitations of this work bear addressing. Previous research highlights that the presence and abundance of waterbird species are influenced by various habitat characteristics, including water quality, soil texture, water depth, aquatic vegetation, shoreline heterogeneity, food availability, and the presence of islands (Kumar *et al*. 2007, Rawal *et al*. 2021, Mukherjee *et al*. 2022). However, our study focused exclusively on two environmental variables: wetland extent and seasonal changes. Besides to that, our study design stratified areas solely based on wetland extent, without accounting for other available habitat types that waterbirds use, such as agriculture and open land. Additionally, the selected few sampling grids were geographically adjacent, which may have introduced spatial bias. Lastly, few variations in survey route lengths due to landscape changes occasionally occurred, potentially influencing the accuracy of our observations.

Conclusions

Our study provides the first preliminary assessment of waterbird diversity, richness, and abundance in the semi-arid landscape of Dungarpur district, western India. Our findings indicate that wetlands are the primary habitat for waterbirds in the area, with agricultural lands serving as the second most important feeding habitat. Notably, we did not observe substantial seasonal effects on habitat use. Habitat preferences among waterbirds varied according to their feeding guilds. The presence of globally significant species underscores the conservation relevance of our study area. We recommend prioritizing the protection of areas with extensive wetlands to safeguard waterbird populations. We also recommend further research to better understand the impact of additional variables on the presence and distribution of waterbirds in Dungarpur district and similar environments in Rajasthan state, India.

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