

Waterbird Diversity in Seven Villus (Natural Lakes) in Wilpattu National Park, Sri Lanka

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Article Details: Received: 2025-11-30 | Accepted: 2026-05-05 | Available online: 2026-09-30

<https://doi.org/10.15414/afz.2026.29.03.280-289>



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Wilpattu National Park (WNP), located in Sri Lanka's dry avifaunal zone along the Central Asian Flyway, serves as a vital habitat for resident and migratory waterbirds. This study provides the first assessment of waterbird assemblages in WNP, recording abundance across seven selected villus over six months using binocular surveys at randomly chosen points. A total of 46 species comprising 4,324 individual birds were documented. Diversity varied among sites, with the highest Shannon diversity at Site A ($H' = 3.070$) and the lowest at Site F ($H' = 1.330$); Pielou's evenness ranged from 0.399 to 0.879, with Site G highest. Although Shannon diversity generally increased with species richness, Site F deviated from this trend. Hierarchical clustering indicated notable ecological heterogeneity among wetlands, while CCA results, though not statistically significant, revealed distinct ordination patterns. Environmental correlations showed dead tree cover negatively affected species richness ($r = -0.276$), whereas salinity had a positive relationship ($r = 0.276$). Six nationally threatened species and one rare migrant kingfisher were recorded. Despite this, overall richness was lower than in other northern wetlands, underscoring the importance of ecological research to identify factors limiting waterbird diversity in WNP.

Keywords: Biodiversity, Dry avifaunal region, Natural lake, Richness, Waterbird, Willpattu National Park

1 Introduction

Wilpattu National Park (WNP) is located between the geo-coordinates 8° 26' N, 80° 00' E and is one of the oldest National Parks in Sri Lanka. Being the largest national park in Sri Lanka, together with its unique location makes it a significant forest ecosystem and a historically significant landmass (Weerakoon & Goonatilleke, 2007). The park takes its name due to the presence of several natural lakes or "villus" with fresh (hardwater or softwater), saline water, and brackish water (Weerakoon & Goonatilleke, 2007). WNP supports several water bodies known as "villu's" (also referred to as vila, wetland, lake, etc.). Villus are characterized by saucer-shaped, water-filled depressions or lakes surrounded by grasslands and forests. Grasslands are found just above the high-water line. Villus of Wilpattu are surrounded by a tree belt (forest patch) sometimes called a watershed of the villu.

Rainwater gets collected in the shallow depressions and groundwater percolates through the bottom limestone substratum. Hence, villus near the sea has brackish water, and those that are away from the sea (more inland) have freshwater. Conversely, some villus in the central part of the park also have brackish water, such as Kokkari Villa and Lunu Villa (Rajapaksha et al., 2024). WNP is significant for the conservation of biodiversity since it forms a protected area complex (~1,300 km²) that comes under the jurisdiction of the Department of Wildlife Conservation (DWC) (Samarasinghe et al., 2022). WNP represents a potential habitat for the long-term survival of many wildlife species, including Sri Lankan leopard (*Panthera pardus kotia*), Sri Lankan sloth bear (*Melursus ursinus inornatus*), Sri Lankan elephant (*Elephas maximus maximus*), and many avifaunal species. WNP represents a wide array of ecosystems and habitats that

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can be broadly categorized into terrestrial and aquatic habitats. Having over 50 fresh and brackish water natural lakes (villus) in the park makes it a critical stopover for the migrant waterbirds. Consequently, WNP was declared a wetland of world importance by the Ramsar Convention in 2013 (Köpke, 2021).

Wetlands are important ecosystems that support many waterbird species (Kotagama & Bambaradeniya, 2006). They are considered biodiversity hotspots that provide critical stopovers for resident and migrant waterbirds (Thanusanth et al., 2019). Waterbirds are defined as bird species that are ecologically dependent on wetlands (Wetlands International, 2010). Wetlands support a diverse array of microhabitats for feeding, nesting, resting, and roosting for resident and migrant waterbirds (Hattori & Mae, 2001). Therefore, the status of waterbirds is an important criterion of the ecological health and productivity of a particular wetland (Wei et al., 2009). A total of around 463 bird species have been recorded from Sri Lanka, including 35 endemic species, 68 endemic subspecies, and 24 globally threatened species (Kotagama & Ratnavira, 2017; Ceylon Bird Club, 2022). Among the recorded bird species, 242 are breeding residents, and the rest are regular migrants, and vagrants (Ceylon Bird Club, 2022).

The Indian subcontinent, including Sri Lanka, provides wintering stopovers for most of the migrant waterbirds that come through the Central Asian Flyway (CAF) (Kannan & Pandiyan, 2012; Aarif et al., 2020). Importantly, wetlands in Sri Lanka become the last destination for most of the waterbirds flying southward through the CAF (Warakagoda & Sirivardana, 2006). Fresh and brackish waterbodies of different sizes in WNP provide vital habitats for waterbirds. Its location in the northern part of Sri Lanka makes it further significant in bird conservation. WNP's diverse habitats provide essentials for migrant bird species. Hence, studying WNP's waterbird diversity is of utmost importance for the conservation of waterbirds in Sri Lanka. A handful of avifaunal studies have been undertaken in northern Sri Lanka (Kishoran et al., 2017; Wijesundara et al., 2017; Kandasamy et al., 2019; Aloysius et al., 2023; Jayarathna & Wijesundara, 2024), and most of the areas are understudied in terms of waterbirds. WNP, for instance, is one such place where limited bird-related studies are conducted. Only one study can be found in the literature that studied avian diversity in WNP (Weerakoon & Goonatilleke, 2007). Therefore, the diversity of waterbirds in seven natural water bodies has been studied in this survey. The objectives of this study were to:

1. find out the composition and diversity of waterbirds;
2. determine whether habitat characteristics cause species richness and diversity of waterbirds in seven natural lakes;

3. examine whether the diversity and richness of waterbirds in WNP differs between waterbird hotspots in the north Sri Lanka, such as Jaffna, Kilinochchi, Mullaitivu Lagoons, and Mannar, etc.

2 Material and Methods

2.1 Study Area

WNP is about 1,317 km² in size and located in the north-western part of Sri Lanka, while it lies within the north-central and western provinces (Eisenberg & Lockhart, 1972). The park is bordered by the Indian Ocean on its western boundary, Moderagam Aru on the North, and Kala Oya on the South (Eisenberg & Lockhart, 1972; Reuter et al., 2020). The mean annual temperature averages 27 °C, characterized by long dry periods from August to mid-October (Sandamali et al., 2018), and the average rainfall is about 1,000 mm received from late October to January (Eisenberg & Lockhart, 1972; Sandamali et al., 2018). The park has several types of vegetation, including littoral vegetation with salt grass, low scrub adjacent to the beach, and low-stature monsoon scrublands transitioning into monsoonal forests with tall emergent trees (Figure 1). WNP is popular for its charismatic megafauna such as the Sri Lankan leopard, the Sri Lankan sloth bear, the Sri Lankan elephant, Asian wild water buffalo (*Bubalus arnee*), spotted deer (*Axis axis*), sambar deer (*Rusa unicolor*), barking deer (*Muntiacus muntjak malabaricus*), jungle cat (*Felis chaus*), and golden jackal (*Canis aureus naria*).

2.2 Sampling

Field visits and data collection of the present study were conducted for six months from February to April and June to August in 2024, covering both winter migrant and non-migrant seasons. Sampling was done twice a month for each location. Seven selected villus, including Borupan Villa (A), Thimbiri Vila (B), Kumbuk Vila (C), Mahapatassa (D), Kudapatassa (E), Kokkari Vila (F), and Nelum Vila (G) (Figure 1). The existing vehicle tracks close to and around the villus were used to collect bird abundance data. Each villu was visited using a vehicle and the vehicle stopped at randomly selected locations close to the lakes for collecting data. Then the abundance of all waterbirds present at the perimeter and close to the lake was recorded. As each lake was located more than 1 km away from the other, the bias of double-counting was minimal. Each sampling location was visited randomly on selected two days during each month and the data were collected from 0600 h to 1,800 h. The same amount of time was spent in each location and the birds were observed using a Nikon Aculon 10 × 42 binoculars. The birds were identified to the species level using Warakagoda et al. (2012). Photographs were taken whenever possible

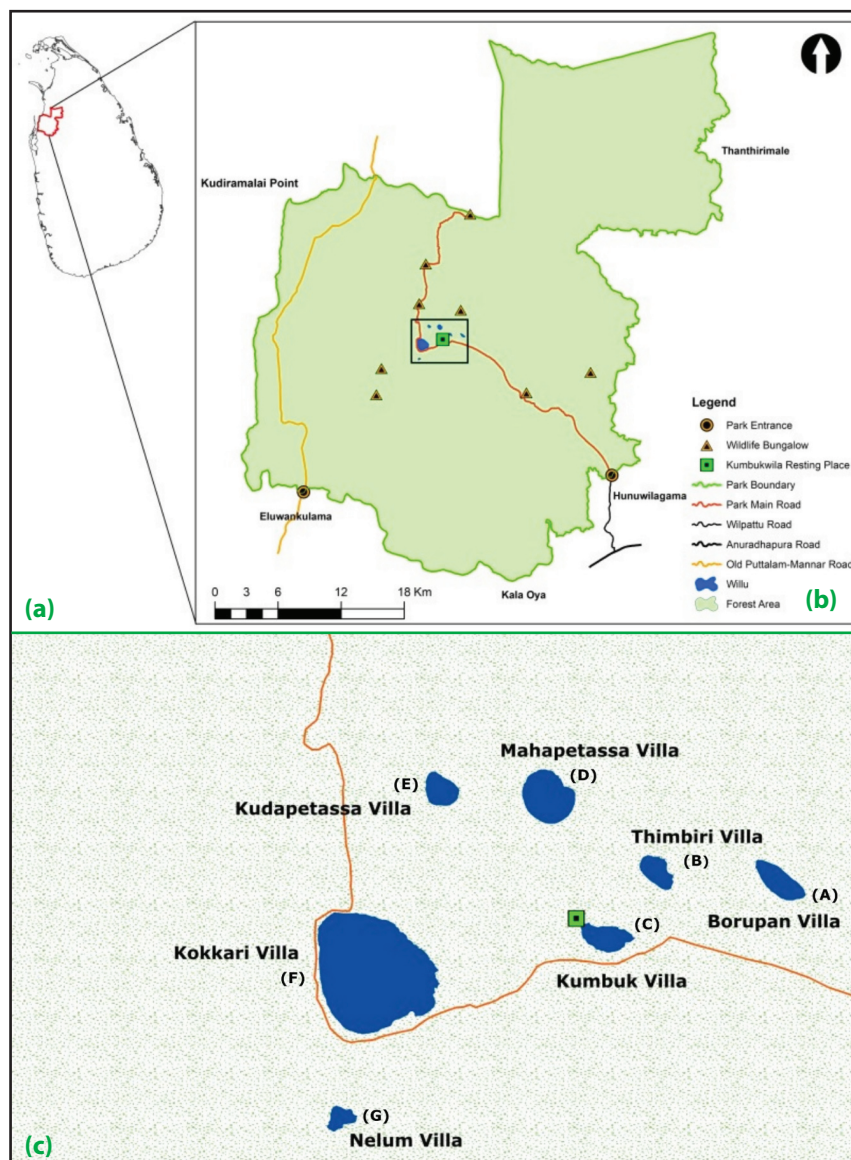


Figure 1 The Map of Wilpattu National Park (WNP) showing the seven studied villas
(a) location of WNP in Sri Lanka map; (b) WNP and its prominent features;
(c) seven studied locations within WNP

using a digital camera (Nikon P900) for later identification.

Measuring environmental variables
environmental variables were incorporated alongside species data to provide an ecological context for the study. The variables included living tree cover, dead tree cover, reed cover, open grass cover, lake size, perimeter, salinity, and seasonality. Collectively, these site-level metrics were used to interpret species distribution patterns in relation to habitat structure and hydrological

conditions. Living tree cover, dead tree cover, and lake size were quantified using the Visual Plot Characterization method described by Duhl et al. (2012). High-resolution Google Earth® imagery (2024) of WNP was used to visually assess and extract these estimates. Measurements were obtained using the built-in tools in Google Earth®, where the ruler function was employed to measure linear dimensions, and the polygon tool was used to calculate area (m²). Imagery was viewed at an aerial resolution

of approximately 50–100 m above ground level to ensure accuracy in delineating polygons representing lake boundaries, living tree cover, and dead tree cover.

Species diversity across the seven sites was measured using the Shannon diversity index, calculated in R (version 4.4.0) with the vegan package (function diversity(), index = "shannon").

The Shannon index was computed using the formula:

$$H' = -\sum (p_i \times \ln(p_i))$$

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where: p_i – the proportion of individuals belonging to the i^{th} species; $\ln$ – denotes the natural logarithm; $\sum$ – indicates summation across all species

Calculations were based on an abundance matrix containing total counts of each species recorded per site. Environmental drivers such as salinity, vegetation cover, and lake size were examined through correlation analyses and generalized linear models (GLMs) to identify key factors influencing species diversity. Habitat heterogeneity among sites was further assessed using hierarchical clustering with Bray-Curtis or Euclidean distance measures to group sites with similar habitat characteristics.

For community-level analysis, Canonical Correspondence Analysis (CCA) was conducted using the vegan package in R to explore relationships between species composition and environmental variables. Additionally, regression models were employed to assess associations between species richness and habitat metrics (e.g., living tree cover, dead tree cover, reed cover, open grass cover, lake size, perimeter, salinity, and seasonality), allowing the identification of significant predictors of species richness.

3 Results and Discussion

3.1 Diversity Analysis of Waterbird Communities

A total of 46 waterbird species were recorded across seven wetland sites in WNP, with 4,324 individual

sightings counted. The highest species richness was recorded in site G (46), followed by sites A (38), B (34), and C (33), respectively (Table 1).

Table 1 Species composition of waterbird recorded in seven villus (presence (+), absence (-))

	Common name	Family	Scientific name	A	B	C	D	E	F	G	NCS
1	Common Kingfisher	Alcedinidae	<i>Alcedo atthis</i>	+	+	+	+	-	+	+	LC
2	Stork-billed Kingfisher	Alcedinidae	<i>Pelargopsis capensis</i>	+	-	+	-	-	-	+	LC
3	Black-capped Kingfisher	Alcedinidae	<i>Halcyon pileata</i>	-	-	+	-	-	+	+	CR
4	White-throated Kingfisher	Alcedinidae	<i>Halcyon smyrnensis</i>	+	+	+	+	+	+	+	LC
5	Black-backed Dwarf Kingfisher	Alcedinidae	<i>Ceyx erithaca</i>	-	+	-	-	-	-	+	NT
6	Lesser Whistling Duck	Anatidae	<i>Dendrocygna javanica</i>	+	+	-	-	+	-	+	LC
7	Oriental Darter	Anhingidae	<i>Anhinga melanogaster</i>	+	+	+	+	+	+	+	LC
8	Great Egret	Ardeidae	<i>Ardea alba</i>	+	+	+	+	+	+	+	LC
9	Little Egret	Ardeidae	<i>Egretta garzetta</i>	+	+	+	+	+	+	+	LC
10	Intermediate Egret	Ardeidae	<i>Ardea intermedia</i>	+	+	+	+	+	+	+	LC
11	Cattle Egret	Ardeidae	<i>Bubulcus ibis</i>	+	+	+	+	+	+	+	LC
12	Indian Pond Heron	Ardeidae	<i>Ardeola grayii</i>	+	+	+	+	+	+	+	LC
13	Purple Heron	Ardeidae	<i>Ardea purpurea</i>	+	+	+	+	+	-	+	LC
14	Grey Heron	Ardeidae	<i>Ardea cinerea</i>	+	+	+	+	+	+	+	LC
15	Black-crowned Night Heron	Ardeidae	<i>Nycticorax nycticorax</i>	+	-	+	-	-	-	+	LC
16	Striated Heron	Ardeidae	<i>Butorides striata</i>	+	-	-	-	-	-	+	LC
17	Great stone-curlew	Burhinidae	<i>Esacus recurvirostris</i>	+	+	+	+	+	+	+	LC
18	Indian Stone Curlew	Burhinidae	<i>Burhinus indicus</i>	+	-	-	-	-	-	+	LC
19	Red-wattled Lapwing	Charadriidae	<i>Vanellus indicus</i>	+	+	+	+	+	+	+	LC
20	Little-ringed Plover	Charadriidae	<i>Charadrius dubius</i>	+	+	-	+	+	+	+	EN
21	Lesser Sand Plover	Charadriidae	<i>Charadrius mongolus</i>	+	+	+	+	+	+	+	LC
22	Pacific Golden Plover	Charadriidae	<i>Pluvialis fulva</i>	+	+	+	+	+	+	+	LC
23	Kentish Plover	Charadriidae	<i>Charadrius alexandrinus</i>	+	+	+	+	-	+	+	EN
24	Painted Stork	Ciconiidae	<i>Mycteria leucocephala</i>	+	+	+	-	-	-	+	LC
25	Asian Openbill	Ciconiidae	<i>Anastomus oscitans</i>	+	-	-	-	-	-	+	LC
26	Lesser Adjutant Stork	Ciconiidae	<i>Leptoptilos javanicus</i>	-	+	-	+	-	-	+	VU
27	Wooly-necked Stork	Ciconiidae	<i>Ciconia episcopus</i>	+	+	-	-	-	-	+	LC
28	Whiskered Tern	Laridae	<i>Chlidonias hybrida</i>	+	+	+	+	+	+	+	LC
29	Gull-billed Tern	Laridae	<i>Gelochelidon nilotica</i>	+	+	+	+	-	-	+	CR
30	Little Turn	Laridae	<i>Sternula albifrons</i>		-	-	-	-	-	+	VU
31	Spot-billed Pelican	Pelecanidae	<i>Pelecanus philippensis</i>		-	+	-	-	+	+	LC
32	Black-headed Ibis	Pelecaniformes	<i>Threskiornis melanocephalus</i>	+	+	+	+	+	+	+	LC
33	Little Cormorant	Phalacrocoracidae	<i>Microcarbo niger</i>	+	+	+	+	+	+	+	LC
34	Indian Cormorant	Phalacrocoracidae	<i>Phalacrocorax fuscicollis</i>	+	-	-	-	-	+	+	LC
35	Little Grebe	Podicipedidae	<i>Tachybaptus ruficollis</i>	+	+	+	+	+	+	+	LC
36	White-breasted Waterhen	Rallidae	<i>Amaurornis phoenicurus</i>	+	-	-	-	-	-	+	LC
37	Black-winged Stilt	Recurvirostridae	<i>Himantopus himantopus</i>	+	+	+	+	+	+	+	LC
38	Common Sandpiper	Scolopacidae	<i>Actitis hypoleucos</i>	+	+	+	+	+	+	+	LC
39	Green Sandpiper	Scolopacidae	<i>Tringa ochropus</i>	+	+	+	+	-	+	+	LC

Table 1 Species composition of waterbird recorded in seven villus (presence (+), absence (-)).

	Common name	Family	Scientific name	A	B	C	D	E	F	G	NCS
40	March Sandpiper	Scolopacidae	<i>Tringa stagnatilis</i>	+	+	+	+	-	+	+	LC
41	Black-tailed Godwit	Scolopacidae	<i>Limosa limosa</i>	+	+	+	+	-	+	+	LC
42	Common Greenshank	Scolopacidae	<i>Tringa nebularia</i>	+	+	+	+	+	-	+	LC
43	Common Redshank	Scolopacidae	<i>Tringa totanus</i>	+	+	+	+	-	-	+	LC
44	Pin-tailed Snipe	Scolopacidae	<i>Gallinago stenura</i>	+	-	+	+	+	-	+	LC
45	Wood Sandpiper	Scolopacidae	<i>Tringa glareola</i>	+	+	-	-	+	+	+	LC
46	Eurasian Spoonbill	Threskiornithidae	<i>Platalea leucorodia</i>	+	-	-	-	-	-	+	LC
Total				38	34	33	30	24	28	46	

NCS – National Conservation Status follows The National Red List 2021 – Conservation status of the birds of Sri Lanka (2021)

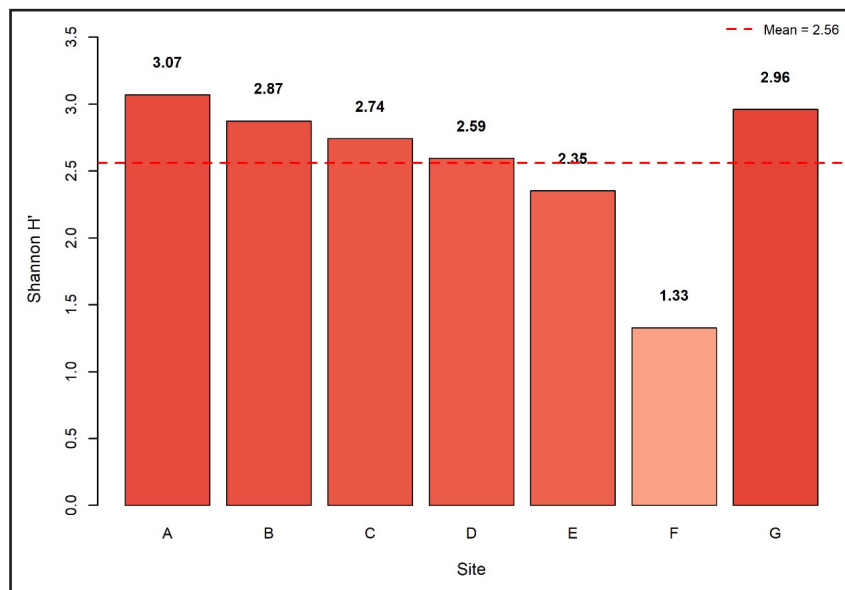


Figure 2 Variation in Shannon diversity index (H') among study sites, illustrating differences in overall species diversity across the sampled locations

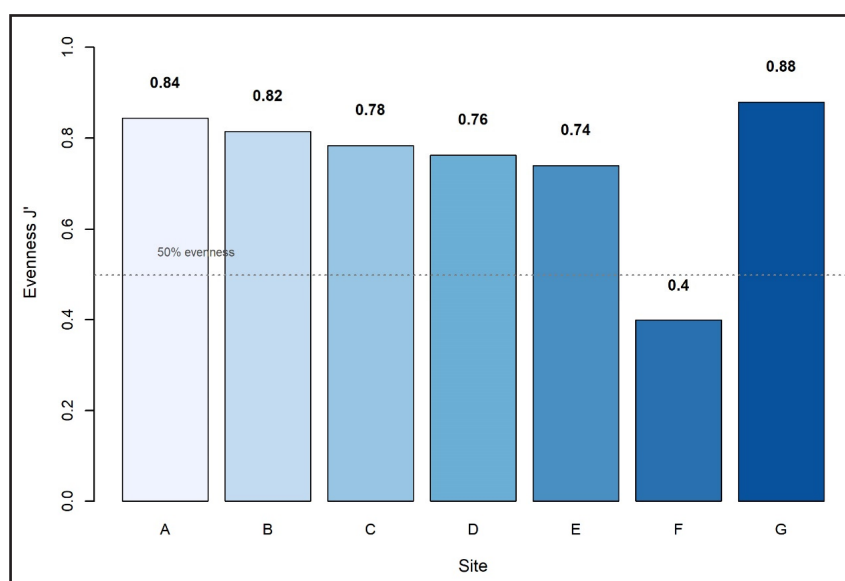


Figure 3 Variation in Pielou's evenness index (J') among study sites, reflecting differences in the uniformity of species abundances independent of species richness

Shannon diversity indices (H') varied substantially among sites, ranging from 1.330 at Site F to 3.070 at Site A (Figure 2). The mean Shannon diversity across all sites was $2.56 (\pm 0.58 \text{ SD})$. Site A exhibited the highest diversity ($H' = 3.070$), followed by Site G ($H' = 2.960$) and Site B ($H' = 2.875$), while Site F displayed markedly lower diversity ($H' = 1.330$), indicating strong species dominance. The Shannon diversity values indicated a clear negative relationship between diversity and salinity, with site F exhibiting the highest salinity levels. Other environmental factors, such as lake size, perimeter, and dead tree cover, also showed strong negative correlations with species diversity. Although site F was the largest among all sites, it had the lowest diversity index. The dead tree cover mainly supported a limited number of bird species, such as cormorants, kingfishers, and some egrets and herons.

Pielou's evenness index (J'), which measures the equitability of species abundances independent of richness, ranged from 0.399 to 0.879 across sites (Figure 3). Site G demonstrated the highest evenness ($J' = 0.879$), suggesting a less balanced community structure. In contrast, Site F showed the lowest evenness ($J' = 0.399$), indicating that a few species dominated the assemblage despite the presence of 28 species. Sites A, B, and C maintained high evenness

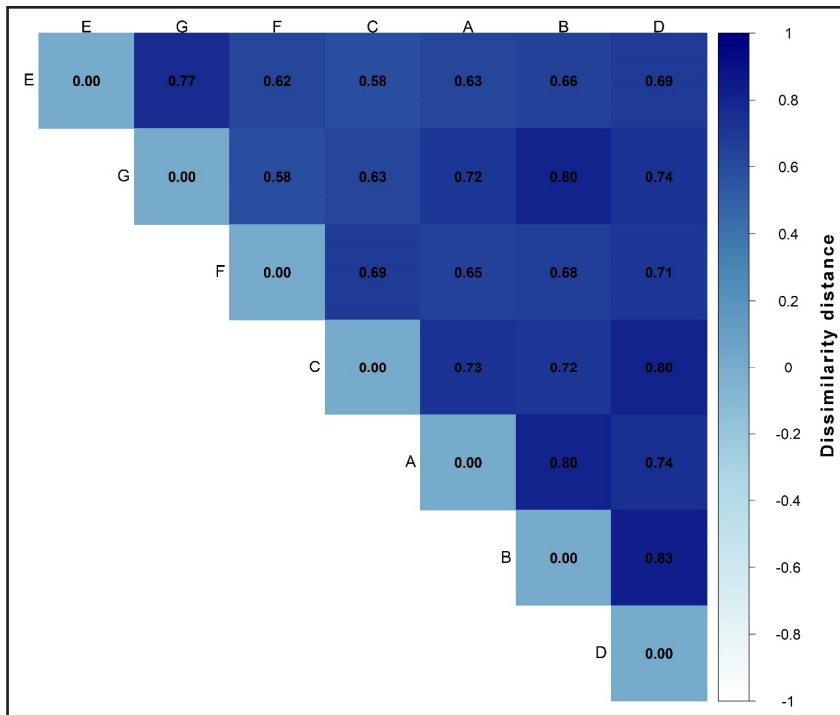


Figure 4 Pairwise environmental dissimilarity matrix of the seven study sites (A–G), based on standardized environmental variables. Values in cells indicate dissimilarity distances between sites; darker shading denotes greater environmental difference

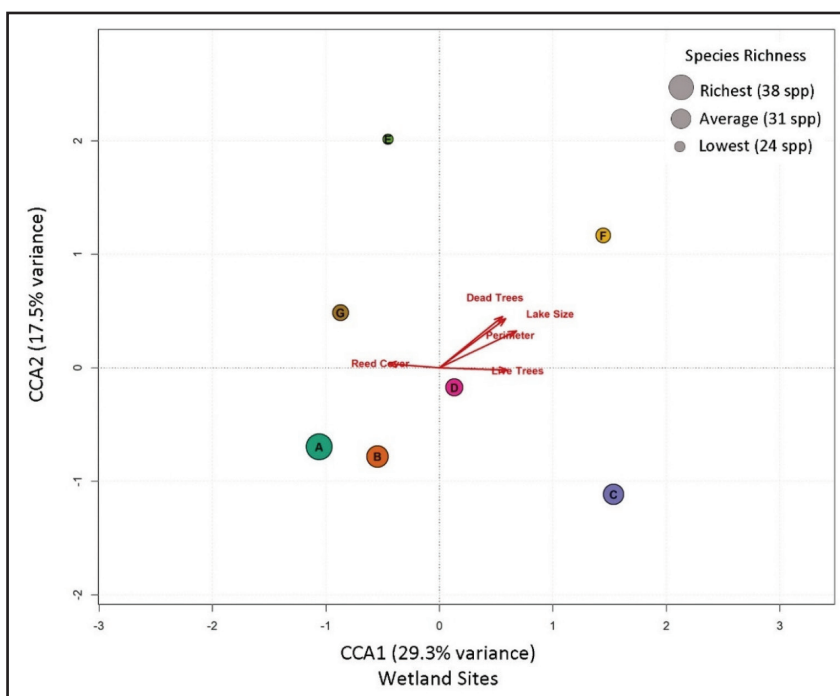


Figure 5 Canonical correspondence analysis (CCA) biplot of the seven study sites (A–G) in relation to environmental variables. Arrows indicate the direction and relative strength of environmental gradients (living tree cover, dead tree cover, reed cover, lake size and perimeter); symbol size is proportional to waterbird species richness at each site. Percentages on the axes show the variance explained by CCA1 and CCA2

values ($J' > 0.78$), suggesting well-balanced communities.

High salinity, limited food availability, or other ecological constraints may be suppressing bird diversity at site F. Overall, both species richness and diversity of waterbirds in all seven sites are lower compared to well-known waterbird habitats such as Mannar, Jaffna, Kilinochchi, and Sarasalai (Kishoran et al., 2017; Wijesundara et al., 2017; Kandasamy et al., 2019; Aloysius et al., 2023; Jayarathna & Wijesundara, 2024). The factors limiting waterbird use of villus within WNP require further investigation through future studies.

3.2 Habitat Heterogeneity & Species-Environment Relationships

Hierarchical clustering of sites based on environmental similarity revealed three distinct habitat groups (Figure 4), reflecting the heterogeneous nature of Wilpattu's wetland landscape. This environmental stratification provided a robust framework for examining species-habitat relationships across contrasting wetland types.

Wetland ecosystems with heterogeneous habitats can support more waterbird diversity (Simons et al., 2000), a principle strongly supported by our finding that perimeter complexity was the strongest individual predictor of community variation (21.2% variance explained). This relationship aligns with the habitat heterogeneity hypothesis, which predicts that structurally complex habitats provide more niche opportunities for specialist species (Ericson et al., 2003). Previous studies in the Prairie Pothole Region of North America have similarly demonstrated that wetland heterogeneity promotes both species richness and abundance of waterbirds, though species-specific responses vary considerably (Steen et al., 2016).

Table 2 Environmental data in seven selected sites in Wilpattu National Park

Site	Living tree cover (ha)	Dead tree cover (ha)	Reed cover (ha)	Open grass cover (ha)	Lake size (ha)	Perimeter (m)	Water quality	Seasonality
A	0.31	0.00	1.18	1.34	9.13	1297.23	freshwater	seasonal
B	0.00	0.00	2.39	0.45	6.64	1208.77	freshwater	seasonal
C	2.56	0.00	0.66	2.54	9.41	1731.45	freshwater	seasonal
D	0.12	0.00	0.00	3.40	18.71	1604.43	freshwater	seasonal
E	0.07	0.00	0.46	0.00	7.34	1026.85	freshwater	seasonal
F	1.93	4.52	0.00	2.52	97.33	4032.23	brackish	permanent
G	2.24	0.00	2.87	2.83	7.11	1490.02	fresh water	seasonal

Canonical Correspondence Analysis (CCA) of the presence-absence matrix revealed clear environmental structuring of waterbird assemblages along two primary gradients (Figure 5). The first canonical axis (explaining 42% of constrained variance) primarily reflected wetland size and perimeter complexity, while the second axis (31% of constrained variance) was associated with vegetation structure variables.

Despite clear ordination patterns, the overall CCA model was not statistically significant ($F = 0.63$, $p = 0.961$). This result reflects the challenge of detecting significant community-environment relationships with limited spatial replication ($n = 7$), a common constraint in landscape-scale waterbird studies where suitable wetlands are naturally sparse.

3.3 Species Richness-Habitat Relationships

Species richness showed moderate correlations with several environmental variables, providing insights into diversity drivers (Figure 6). Dead trees exhibited the strongest negative relationship with species richness ($r = -0.276$), suggesting that sites with tree mortality may support reduced waterbird diversity (Table 2). Dead trees often indicate hydrological stress, nutrient imbalances, or salinity increases in wetland systems (Kozłowski, 1997). Climate-altered wetlands with increasing salinity and reduced freshwater availability create water stress for waterbirds, potentially explaining the reduced diversity in sites with extensive tree mortality. This relationship has significant implications for wetland management in tropical dry forests, where hydrological changes

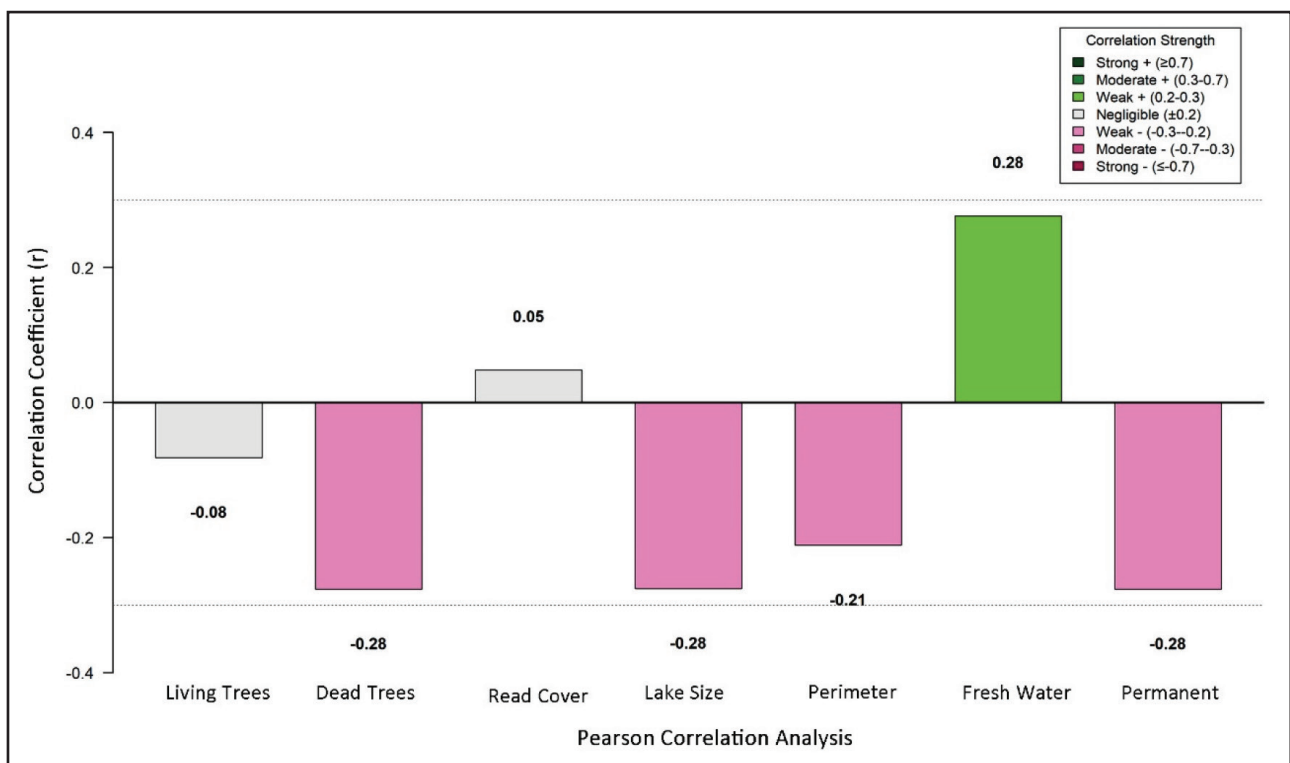


Figure 6 Pearson correlation coefficients (r) between waterbird species richness and environmental variables across the seven study sites. Bar colours indicate correlation strength and direction; dotted lines mark $r = \pm 0.3$

are increasingly common due to climate variability and anthropogenic pressures.

Conversely, freshwater conditions showed a positive association with richness ($r = 0.276$), consistent with the known preference of most waterbird species for low-salinity habitats. Most waterbird species show strong preferences for low-salinity environments due to physiological constraints and food availability (Ma et al., 2010). However, in areas such as Jaffna, a high waterbird diversity may be observed in brackish water lagoons. According to the findings of previous studies, the waterbird diversity is much lower in Wilpattu compared to some lagoon areas in the *Jaffna peninsula*.

3.4 Conservation Implications

Our findings have several important implications for waterbird conservation in the small water bodies (*Villus*) of WNP. First, the high diversity and species richness at Site A over other sites make its potential role as a regional source habitat, suggesting that limiting the visitors to the park should be a conservation priority. Disturbing such important sites could disproportionately impact regional waterbird diversity through cascading effects on sink habitats. Several locally threatened waterbird species were recorded, including Little Ringed Plover (*Charadrius dubius*), Hanuman Plover (*Charadrius seebohmi*), Gull-billed Tern (*Gelochelidon nilotica*), Little Tern (*Sterna albifrons*), and Lesser Adjutant (*Leptoptilos javanicus*) (MOE, 2021). Locally near threatened (NT), and rare Black-backed Dwarf Kingfisher (*Ceyx erithaca*) was recorded during the survey. Further, these lakes are one of the only sites in Sri Lanka that the rare Black-capped Kingfisher (*Halcyon pileata*), visits during the winter migrant season.

Second, the relationship between habitat heterogeneity (perimeter complexity) and community variation emphasizes the importance of maintaining wetland diversity rather than focusing solely on individual site characteristics. Conservation strategies should consider how biodiversity influences ecosystem functioning and the complex habitat preferences of waterbirds (Li et al., 2021). This suggests that wetland management should prioritize maintaining a portfolio of different wetland types rather than attempting to optimize individual sites.

Third, the negative effects of dead trees on species richness highlight the vulnerability of these communities to hydrological stress and habitat degradation. Climate change and water extraction are likely to exacerbate these pressures in tropical dry forests, making adaptive management strategies essential for long-term waterbird conservation (Davidson et al., 2014).

3.5 Future Research Directions

Several research priorities emerge from our findings. First, expanding the spatial scale of analysis to include more sites, as the WNP contains over 50 lakes and landscape-level variables, would help distinguish between local habitat effects and broader landscape processes. Second, incorporating temporal replication would reveal the stability of species-environment relationships and the role of seasonal variation in community assembly. Third, abundance-based analyses could provide more detailed insights into species-specific responses to environmental gradients. Further research should be directed to investigate the factors that contribute to lower species richness compared to other parts of the northern avifaunal region. Integration of habitat management experiments with canonical correspondence analysis could provide valuable insights into the effectiveness of different conservation interventions (Howe et al., 2007; Steen et al., 2016). Such experimental approaches would be particularly valuable for understanding how habitat modifications influence waterbird community structure in *Villus* in WNP.

4 Conclusions

Our study provides important insights into waterbird community ecology in *Villus* of Wilpattu Wetland Ecosystem, demonstrating significant species richness variation among sites and meaningful relationships with habitat characteristics despite non-significant multivariate models. The results emphasize the importance of habitat heterogeneity, freshwater conditions, and maintaining diverse wetland portfolios for waterbird conservation. However, the low species richness compared to regional waterbird habitats needs further investigation. The apparent role of stochastic processes in community assembly highlights the need for landscape-scale conservation approaches that maintain connectivity and habitat diversity rather than focusing solely on individual site optimization. These findings contribute to growing evidence that effective waterbird conservation requires an understanding of both deterministic habitat relationships and stochastic community processes operating across multiple spatial scales.

Acknowledgments

The authors wish to acknowledge the Department of Wildlife Conservation (DWC) of Sri Lanka for giving visitor permits to enter the park. We are also thankful to the safari drivers who safely took us to the national park.

Conflict of Interest

Authors declare no conflict of interest related to this research.

Author Contributions

Shashi Madhushanka: Conceptual framework, data collection & writing; Danushka Weerasekara: data analysis & writing; Kithsiri Ranawana: Supervising & reviewing.

AI and AI-Assisted Technologies use Declaration

We declared that no AI-assisted technologies were used

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