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Temporal dynamics of shorebird assemblages in Valinokkam Lagoon, Southeast India: A new wintering site along the Central Asian Flyway

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Abstract Anthropogenic activities are global threats to natural coastal wetlands that are crucial for shorebirds. Man-made wetlands such as salt extraction ponds provide alternate sites for feeding and roosting. Valinokkam Lagoon, a salt extraction site on the southeast coast of India, has emerged as a critical wintering and over-summering site along the Central Asian Flyway. A five-year study (2019 to 2024) documented 32 shorebird species, which include eight Near Threatened, two Vulnerable, two Endangered, and a single regional endemic Hanuman Plover, unassessed (IUCN). 87.5% of the species were winter visitors and four were breeding residents. Eleven species of over-summering shorebirds were documented, highlighting consistent resources in the lagoon throughout the year. Temporal abundance patterns peaked in 2023–2024, with the highest total monthly abundance in January 2023. Little Stint, Siberian Sand Plover, Curlew Sandpiper, and Kentish Plover were the dominant species. The highest species richness and diversity were in 2021–2022, and lowest in 2023–2024. This is the first pivotal study from this unprotected lagoon, which acts as a substitute for natural wetlands. This study further contributes to the estimation of global population trends, and hence this site requires further conservation action plans both regionally and internationally, as 72% of the species recorded here show a declining global trend.

Keywords: artificial lagoon, over-summering, saltpans, unprotected wetland, wetland

Összefoglalás Az emberi tevékenységek globális mértékben veszélyeztetik a természetes tengerparti vizes élőhelyeket, melyek a partimadarak számára kulcsfontosságúak. A mesterséges vizes élőhelyek viszont, mint például a sólepárló tavak, alternatív élőhelyeket kínálnak ezen fajok számára mind táplálkozásra, mind pihenésre. A Valinokkam-lagúna, amely egy sólepárló terület India délkeleti partvidékén, a Közép-Ázsiai Madárvonulási Útvonal egyik kritikusan fontos telelő- és átnyaraló élőhelyeként ismert. A jelen, öt évet átölelő (2019–2024) tanulmány 32 partimadár-faj jelenlétét dokumentálta, melyek közül az IUCN besorolása szerint nyolc faj Mérsékelten Fenyegetett, kettő Sebezhető, kettő Veszélyeztetett, valamint egy besorolatlan faj – a korábban a széki lile egy alfajaként ismert, de újra faji rangra emelt *Charadrius seebohmi* – regionális endemizmusként ismert a területen. A vizsgált fajok 87,5% téli vendég, négy faj állandó és fészkelő volt. A vizsgálat során 11 átnyaraló partimadár-fajt azonosítottak, ami jelzi, hogy a lagúna táplálékforrásai folyamatosan rendelkezésre állnak. Az abundanciák időbeli csúcsa 2023–2024-ben volt megfigyelhető, amin belül a legmagasabb abundancia-értéket 2023 januárjában rögzítették. A vizsgálat domináns fajai az apró partfutó, a tibeti lile, a sarlós partfutó és a széki lile voltak. A legmagasabb fajgazdagsági és fajdiverzitási értékeket 2021–2022-ben, míg a legalacsonyabbakat 2023–2024-ben detektálták. Ez az első jelentős tanulmány ebből a nem védett lagúnából, amely természetes élőhelyeket helyettesít. Emellett ez a vizsgálati terület hozzájárul globális szinten a partimadár-állományok fenntartásához, így a lagúna további, regionális és nemzetközi szintű természetvédelmi beavatkozást igényel, mivel az itt megfigyelt fajok 72%-a csökkenő állomány-adatokat mutat világszerte.

Kulcsszavak: mesterséges lagúna, átnyaralás, sólepárlók, nem védett terület, vizes élőhely

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Introduction

Waterbird populations experience a global decline (Hansen *et al*. 2015, Wang *et al*. 2017, Rashiba *et al*. 2022), and 50% of waterbird populations in Asia have declined (Haq *et al*. 2018, Mundkur *et al*. 2023). Birdlife International (2022) estimated that 8% of migratory bird species in the Central Asian Flyway (CAF) are globally threatened and 6% are Near Threatened in the IUCN Red List. Coastal wetlands, among the most threatened ecosystems worldwide (Newton *et al*. 2018, Rodrigues-Filho *et al*. 2023), act as critical habitats for both migratory and resident waterbird species, especially shorebirds (Masero *et al*. 2000, Colwell 2010). The species diversity and population abundance of birds are considered as bio-indicators of environmental change in wetlands (Zhang *et al*. 2020) due to their long lifespan and migratory behaviors (Piatt *et al*. 2007, Parson *et al*. 2008).

Shorebird populations are sensitive to habitat changes (Rogers *et al*. 2006, Méndez *et al*. 2018), and their survival and population fluctuations are intricately linked to land use changes (Rogers *et al*. 2006) and human disturbance (Koleček *et al*. 2021), both in their breeding grounds and wintering habitats (Jourdan *et al*. 2021, Comber *et al*. 2023). Hence, artificial wetlands such as aquaculture ponds and coastal saltpans (Warnock & Takekawa 1995, Li *et al*. 2013, Rogers *et al*. 2015), are increasingly recognized for their role in providing alternative feeding and roosting areas for waterbirds (Perez-Hurtado & Hortas 1991, Green *et al*. 2015, Byju *et al*. 2023a), although they cannot replace natural wetlands completely (Choi *et al.* 2014, Sebastián-González & Green 2016). The ecological value of these artificial or restored wetland habitats are widely recognized (Elphick 2000, Czech & Parsons 2002, Pandiyan *et al*. 2021), as the loss of the stopover sites or wintering sites is one of the major reasons for migratory birds' population decline globally (Wen *et al*. 2016, Liao *et al*. 2017).

Saline habitats such as coastal saltpans provide critical support to migratory shorebirds due to their high productivity and suitable water depths (Aarif *et al*. 2024), which create ideal feeding and roosting conditions (Britton & Johnson 1987). Saltpans are utilized by shorebirds across diverse geographic regions, including Africa, North America, Europe, the Mediterranean, Asia and Australia (Lei *et al*. 2018). In India, the country's diverse coastlines support rich shorebird diversity and abundance, which are associated with important habitats like sandy beaches, mangroves, intertidal zones, saltpans, lagoons and mudflats (Joshi *et al*. 2020, Sangha 2021, Rashiba *et al*. 2022).

The present study investigates the potential of Valinokkam Lagoon as a critical wintering site for shorebirds and its significance as an internationally important wetland within CAF. India, the third largest salt producer globally, has substantial saltpan areas, with Tamil Nadu ranking as the second largest salt-producing state in the country, after Gujarat. Approximately 12,000 hectares (ha) of land in Tamil Nadu are under salt extraction (Pandiyan *et al*. 2014, Tamil Nadu Salt Corporation 2018). Traditional saltpans in the state play a pivotal role in sustaining overwintering shorebird populations (Sandilyan 2017). However, despite existing studies, the identification of critical shorebird habitats, stopover sites, key seasons and ecosystems along India's coast remains incomplete (Rao *et al*. 2022).

Shorebird populations in natural coastal lagoons are in decline; while saltpans in the Gulf of Mannar (GoM), continue to support over-summering winter migrants (Byju *et al*. 2024). Studies in the region have provided insights into shorebird populations on the Valinokkam avifauna (Byju *et al*. 2023a), 21 islands of GoM (Byju *et al*. 2023b) and Karangadu mangroves (Byju *et al*. 2023c). However, significant knowledge gaps persist regarding the ecological role of anthropogenic wetlands in supporting shorebird populations in this region. This study aims to address these gaps by assessing the abundance and diversity of shorebirds in Valinokkam Lagoon, with a particular focus on temporal variations. We evaluated shorebird population trends and seasonal dynamics to determine the potential of Valinokkam Lagoon as a vital wintering site within the CAF. Our objectives include: 1) to assess the abundance and species diversity of shorebirds during the winters in five migratory seasons; 2) to analyze temporal trends in shorebird populations and identify peak periods of shorebird activity; 3) to evaluate the ecological significance of the site as a critical wintering habitat within the CAF, and 4) to provide baseline data for formulating effective conservative measures to protect shorebird population and their habitats.

Material and Methods

Study area

Valinokkam Lagoon (9.1661° N, 78.6141° E) is a man-made coastal lagoon situated in the Kadaladi Taluk, Ramanathapuram District, Tamil Nadu, on the southeast coast of India *(Figure1)*. This lagoon extends over 10.12 km, encompassing an area of 1,145.84 ha. The lagoon, on one side, is surrounded by saltpans, which constitute around 1,197.34 ha, operated by the State-owned Salt Corporation. Seawater is pumped into these reservoirs for salt production. Over time, the evaporation process has led to the formation of expansive mudflats within the reservoir pond, which now serve as vital habitats for waterbirds, especially shorebirds that prefer these mudflats rather than the actual salt evaporation ponds. Although fishing activities and prawn culture occur intermittently, these activities are limited to periods when water levels are sufficient, supporting the local communities with livelihood opportunities.

Data collection

Shorebird surveys were conducted monthly once over five migratory seasons, spanning from June 2019 to May 2024 between 06.00 to 10.00 and 15.00 to 18.00 hours. Bird abundance was estimated using the block count and direct visual count methods (Howes & Bakewell 1989, Bibby *et al*. 2000). Block counts were used for large flocks of birds, either by distance or by how dense they are. This method involves estimating 'blocks' of birds within a flock

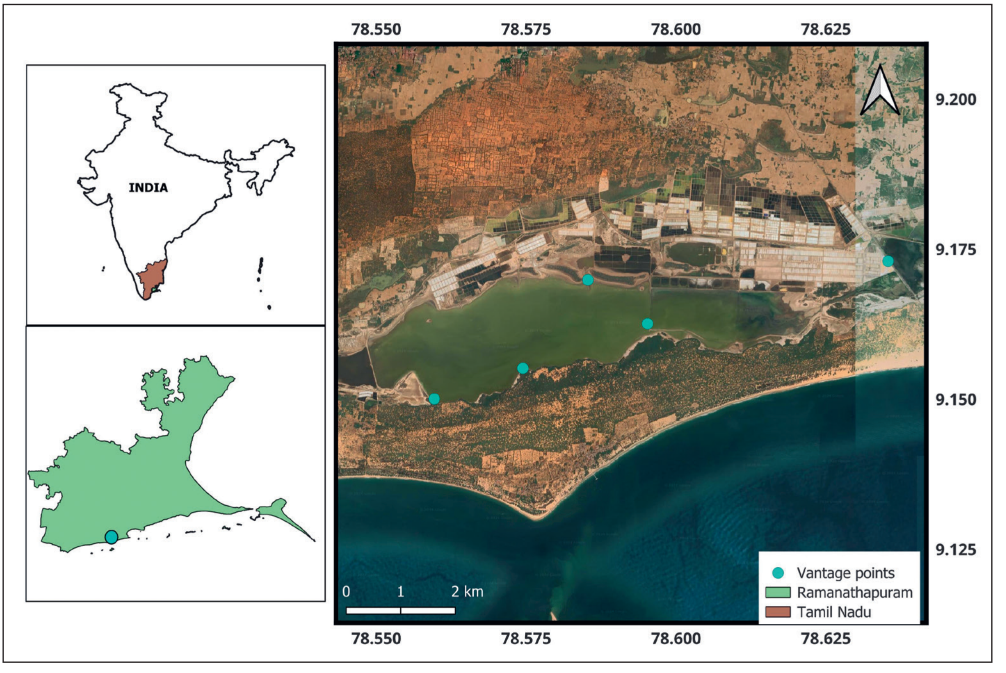

Figure 1. Map of the study area showing the vantage points and adjacent saltpans in Valinokkam Lagoon

1. ábra A vizsgálati terület térképe a megfigyelési pontokkal és szomszédos sólepárlókkal a Valinokkam-lagúnában

depending on the overall flock size. The 'block' is used to measure the remainder of the flock from our previous experiences in the field monitoring for more than a decade. Five scanning points, ranging from 600–1,500 meters apart, were selected based on year-round water availability and shorebird congregation dynamics *(Figure 1)*. Observations were carried out using Nikon binoculars (10×50) and Vanguard spotting scope (14×70) and birds were photographed for identification with a Canon 100–400 mm lens. Field guides (Grimmett *et al*. 2011*,* Hayman *et al*. 2011) were employed to aid species identification. To minimize disturbance to birds, a five-minute acclimatization period was observed upon arrival at each scanning point before commencing counts. As Valinokkam is a man-made lagoon, no tidal variations were observed during the study. Smaller groups of shorebirds were counted directly, while larger congregations were estimated with assistance from two or three teams for accuracy.

Shorebird status classification

The residential status of shorebirds was determined as either Resident (R) or Winter Visitor (WV), based on their temporal and distribution patterns (Grimmett *et al*. 2011). Resident species are the ones that are present throughout the year in the study area and may breed locally. Winter Visitors are those observed during winter months (September to April).

These species undertake long-distance migrations from their breeding grounds in temperate or arctic regions to wintering grounds in the Indian subcontinent, including the study area. The global conservation status was categorized following the International Union for Conservation of Nature (IUCN) Red List classifications, including Least Concern (LC), Near Threatened (NT), Vulnerable (VU) and Endangered (EN) (IUCN 2024). Population sizes and global trends for each species were referenced from Birdlife International (2024). Shorebird species listed under the Convention on the Conservation of Migratory Species of Wild Animals (CMS) were referred from CMS (2024) data. The study also considered the Conservation of Migratory Waterbirds and their Habitats-CAF, which promotes international cooperation for the conservation of migratory birds and their habitats under CMS Appendix II. Additionally, we integrated priorities outlined by the Arctic Migratory Birds Initiative (AMBI), which emphasizes the conservation of migratory shorebird species that traverse flyways from the Arctic to other regions (Arctic Council 2024). This multi-layered approach gives a comprehensive assessment of the conservation status of shorebirds observed at Valinokkam Lagoon.

Data analysis

Shorebird species diversity was quantified using the Shannon–Wiener index (Shannon & Wiener 1949), and the Menhinick index, which gives a relative estimation of species richness, accounting for varying sample sizes (Menhinick 1964). Higher values indicate high diversity and richness for both indices, respectively. Pielou's index was employed to evaluate species evenness across different years (Pielou 1975), which ranges from 0 (highly uneven) to 1 (even). The Berger–Parker index, ranging from 0 (no dominance) to 1 (complete dominance), was assessed whether one or few shorebird species dominated the lagoon during the study period (Berger & Parker 1970). Given the non-normal distribution of the species abundance data (as confirmed by the Shapiro–Wilk test, $p < 0.05$) the Kruskal–Wallis test, a non-parametric method, was performed to examine whether there is a statistically significant difference in the shorebird species abundances among five years (Kruskal & Wallis 1952).

To further investigate species composition, similarity percentage analysis (SIMPER) was performed, quantifying the percentage contribution of each bird species to temporal variations. Individual rarefaction curves were generated for each dataset to accurately compare species richness across years. This method enables standardized comparisons of species richness across samples of varying sizes, ensuring that observed differences in species richness reflect ecological patterns rather than sampling discrepancies (Gotelli & Colwell 2001). Seasonal trend decomposition using LOESS (STL) (LOESS – Locally Estimated Scatterplot Smoothing), a non-parametric regression method, was performed to visualize the non-linear patterns and variabilities in the time series of five study years. STL method filters the temporal data into components like the actual data, overall long-term trend, seasonal patterns, and remainders (Cleveland *et al*. 1990). The trend component represents the long-term direction of the data. It does not reflect the short-term fluctuations. The seasonal component shows the recurring, regular temporal patterns in the data, capturing the monthly fluctuations. The remainder component represents the amount of noise or outliers in the data, after the calculations of the trend and seasonal components. It represents the random variations or the data points, which deviate from the expected trend, and are not explained by the trend or seasonal components.

All statistical analyses and graphical representations were done using PAST version 4.17 (Hammer *et al*. 2001) and R 4.4.1 (R Core Team 2023).

Results

Shorebird species composition

A comprehensive five-year survey conducted in Valinokkam Lagoon recorded a total of 32 shorebird species from the order Charadriiformes, represented by four families: Scolopacidae (n = 21), Charadriidae (n = 8), Burhinidae (n = 2) and Recurvirostridae (n=1). As per the IUCN Red List (2024), 25% (n=8) of the shorebird species observed in the lagoon are categorized as Near Threatened. These include Bar-tailed Godwit *(Limosa lapponica)*, Black-tailed Godwit *(L. limosa)*, Eurasian Curlew *(Numenius arquata)*, Dunlin *(Calidris alpina)*, Ruddy Turnstone *(Arenaria interpres)*, Red-necked Stint *(C. ruficollis)* from the family Scolopacidae, Beach Stone-curlew *(Esacus magnirostris)* and Great Stone-curlew *(E. recurvirostris)* from Burhinidae. Two species, the Curlew Sandpiper *(C. ferruginea)* and Grey Plover *(Pluvialis squatarola)* were categorized as Vulnerable, while Great Knot *(C. tenuirostris)* and Siberian Sand Plover *(Anarhynchus mongolus)* were classified as Endangered. Notably, Hanuman Plover *(A. seebohmi)* is Not Assessed. The remaining 59.3% (n=19) of the species were classified as Least Concern. Notably, 87.5% (n=28) of the species recorded at Valinokkam Lagoon are listed under Appendix II of CMS (2024) *(Table 1)*.

Winter visitors constituted 87.5% (n=28) of the total shorebird species documented. Resident species accounted for 12.5% (n=4), of which three species – Great Stone-curlew, Black-winged Stilt *(Himantopus himantopus)* and Hanuman Plover – were confirmed breeding within the lagoon. Global population trends indicated that 72% of the shorebird species recorded have declined (Birdlife International 2024), while global population size remained unknown for 62.5% *(Table 1)*.

Community dynamics and diversity indices

Alpha diversity indices were analyzed to better understand the community dynamics of shorebirds in the study site over five years. Pielou's evenness index revealed a relatively uneven distribution of shorebird species across the years. The highest evenness was observed during the 2021–2022 migratory season (0.26), while the lowest was recorded in 2023–2024 (0.19). These findings were supported by the Berger–Parker dominance index, which indicated a slight dominance of a few species in 2023–2024 (0.38) compared to 2021–2022, which exhibited the lowest dominance (0.28). Despite the unevenness, there was no complete dominance by any single species in any of the five years. Menhinick's index highlighted

Table 1. Checklist of shorebirds in Valinokkam Lagoon with IUCN, migration and global population statuses

1. táblázat A Valinokkam-lagúna partimadár-fajainak listája, IUCN-besorolásokkal és globális állomány-státuszokkal

Common name	Scientific name	Migration status	IUCN status	Global population (BirdLife International)	Global population trend (BirdLife International)	CMS (Appendix II) species
Scolopacidae						
Whimbrel	*Numenius phaeopus*	*WV*	*LC*	1,800,000–2,650,000	Decreasing	✓
Eurasian Curlew	*Numenius arquata*	*WV*	*NT*	Unknown	Decreasing	✓
Bar-tailed Godwit	*Limosa lapponica*	*WV*	*NT*	Unknown	Decreasing	✓
Black-tailed Godwit	*Limosa limosa*	*WV*	*NT*	Unknown	Decreasing	✓
Terek Sandpiper	*Xenus cinereus*	*WV*	*LC*	Unknown	Decreasing	✓
Common Sandpiper	*Actitis hypoleucos*	*WV*	*LC*	Unknown	Decreasing	✓
Marsh Sandpiper	*Tringa stagnatilis*	*WV*	*LC*	Unknown	Decreasing	✓
Green Sandpiper	*Tringa ochropus*	*WV*	*LC*	Unknown	Increasing	✓
Wood Sandpiper	*Tringa glareola*	*WV*	*LC*	Unknown	Stable	✓
Common Greenshank	*Tringa nebularia*	*WV*	*LC*	Unknown	Stable	✓
Common Redshank	*Tringa totanus*	*WV*	*LC*	Unknown	Unknown	✓
Curlew Sandpiper	*Calidris ferruginea*	*WV*	*VU*	420,000–960,000	Decreasing	✓
Red-necked Stint	*Calidris ruficollis*	*WV*	*NT*	Unknown	Decreasing	✓
Dunlin	*Calidris alpina*	*WV*	*NT*	3,000,000–7,000,000	Decreasing	✓
Temminck's Stint	*Calidris temminckii*	*WV*	*LC*	110,000–850,000	Decreasing	✓
Little Stint	*Calidris minuta*	*WV*	*LC*	1,000,000–1,100,000	Increasing	✓
Great Knot	*Calidris tenuirostris*	*WV*	*EN*	Unknown	Decreasing	✓
Sanderling	*Calidris alba*	*WV*	*LC*	900,000–1,200,000	Unknown	✓
Ruff	*Calidris pugnax*	*WV*	*LC*	Unknown	Decreasing	✓
Ruddy Turnstone	*Arenaria interpres*	*WV*	*NT*	750,000–1,750,000	Decreasing	✓
Red-necked Phalarope	*Phalaropus lobatus*	*WV*	*LC*	Unknown	Decreasing	✓
Charadriidae						
Grey Plover	*Pluvialis squatarola*	*WV*	*VU*	1,000,000–2,500,000	Decreasing	✓

Common name	Scientific name	Migration status	IUCN status	Global population (BirdLife International)	Global population trend (BirdLife International)	CMS (Appendix II) species
Pacific Golden Plover	*Pluvialis fulva*	*WV*	*LC*	Unknown	Decreasing	—
Common Ringed Plover	*Charadrius hiaticula*	*WV*	*LC*	Unknown	Decreasing	✓
Greater Sand Plover	*Anarhynchus leschenaultii*	*WV*	*LC*	100,000-225,000	Decreasing	✓
Little Ringed Plover	*Thinornis dubius*	*WV*	*LC*	Unknown	Stable	✓
Siberian Sand Plover	*Anarhynchus mongolus*	*WV*	*EN*	18,000–50,000	Decreasing	✓
Hanuman Plover	*Anarhynchus seebohmi*	*R*	*NE*	Unknown	Not assessed	—
Kentish Plover	*Anarhynchus alexandrinus*	*WV*	*LC*	100,000–499,999	Decreasing	✓
Burhinidae						
Great Stone-curlew	*Esasus recurvirostris*	*R*	*NT*	Unknown	Decreasing	—
Beach Stone-curlew	*Esacus magnirostris*	*R*	*NT*	4000	Decreasing	—
Recurvirostridae						
Black-winged Stilt	*Himantopus himantopus*	*R*	*LC*	Unknown	Increasing	✓

IUCN status: LC- Least Concern, NT- Near Threatened, VU- Vulnerable, EN- Endangered, NE- Not Evaluated| Migration status: R-Resident, WV- Winter Visitor| CMS status- ✓ listed in CMS appendix II, — not listed in CMS appendix II.

Table 2. Abundance of shorebirds and biodiversity indices across five years
2. táblázat A partimadarak abundanciája és diverzitási indexei a vizsgált öt évben

	2019–2020	2020–2021	2021–2022	2022–2023	2023–2024
Pielou's Evenness index	0.2300	0.2443	0.2645	0.1913	0.2029
Shannon–Wiener index	1.8260	1.8490	2.0370	1.7470	1.8390
Menhinick index	0.5425	0.5542	0.7003	0.5030	0.4393
Berger–Parker index	0.3295	0.3671	0.2893	0.3404	0.3852

variations in species richness, with the highest value recorded in 2021–2022 (0.7) and the lowest in 2023–2024 (0.4). Intermediate richness values were observed during 2019–2020, 2020–2021 and 2022–2023, with minimal fluctuations (0.5). The Shannon–Wiener index exhibited significant inter-annual variability in shorebird diversity. The highest diversity was recorded in 2021–2022 (2.0), while the lowest was observed in 2022–2023 (1.7). Other years demonstrated relatively stable diversity, with values clustering around the rest of the years (1.8) *(Table 2)*.

Temporal patterns and trends

Across the five study years, total shorebird abundance was highest in 2023–2024 (n=59,750), followed by 2022–2023 (n=42,687), while the lowest abundance was recorded in 2021–2022 (n=20,572) *(Figure 2)*. Familywise, Scolopacidae species including Little Stint *(C. minuta)*, Curlew Sandpiper and Common Redshank *(Tringa totanus)* were most abundant across all years. In the Charadriidae family, Kentish Plover *(A. alexandrinus)*, Siberian Sand Plover and Greater Sand Plover *(A. leschenaultii)* were predominant *(Figure 3)*. 26 species were recorded consistently in all the years. Of the remaining six species, Dunlin was recorded only in 2021–2022, Red-necked Stint, Red-necked Phalarope *(Phalaropus lobatus)* and Black-tailed Godwit in 2022–2023 and 2023–2024. Wood Sandpiper *(T. glareola)* was recorded only in 2021–2022 and 2023–2024, and Sanderling *(C. alba)* was absent in 2020–2021 but recorded in other years.

Monthly abundance data showed that January 2023 had the highest total abundance (n=14,038), followed by January 2024 (n=11,220) *(Figure 4)*. The five most abundant and threatened species one-time peak monthly counts from the lagoon include Little Stint (n=6,520), Kentish Plover (n=2,400) and Greater Sand Plover (n=1,930) were observed in January 2023. The highest annual abundance of the Endangered Siberian Sand Plover was recorded in 2022–2023, with a peak monthly count in September 2022 (n=3,300), abundant from January to March in all study years. Number of Curlew Sandpiper was highest in 2023–2024, with a peak count in September 2023 (n=2,800) *(Figure 5)*.

Among the threatened species, the Endangered Great Knot was recorded at its highest abundance (n=10) in February 2022, followed by March 2023 (n=8), and was absent in 2019–2020 and 2020–2021. The Vulnerable Grey Plover was most abundant in 2022–2023,

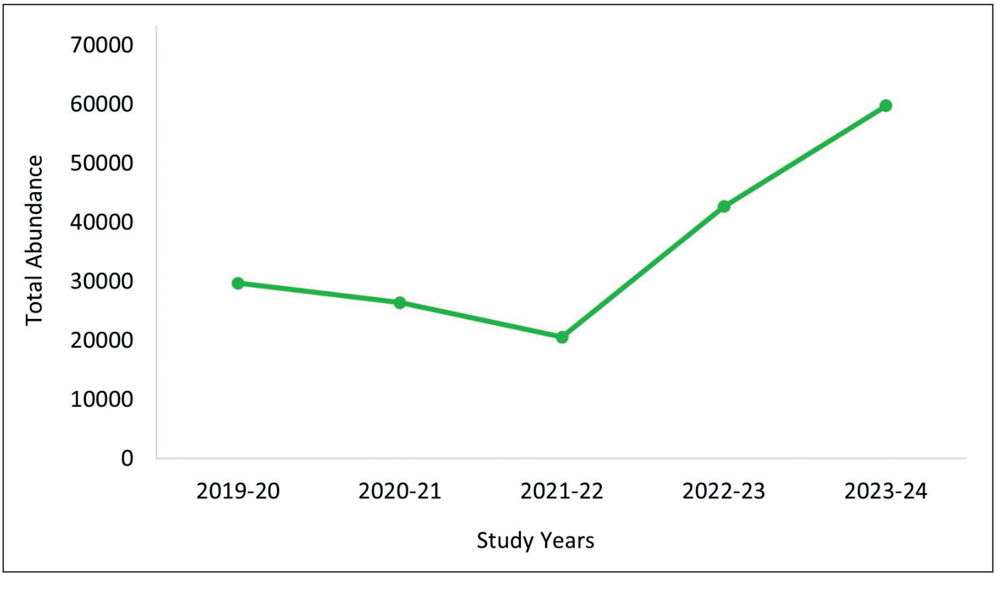

Figure 2. Total abundance of shorebirds in each year
2. ábra A partimadarak teljes évenkénti abundanciája

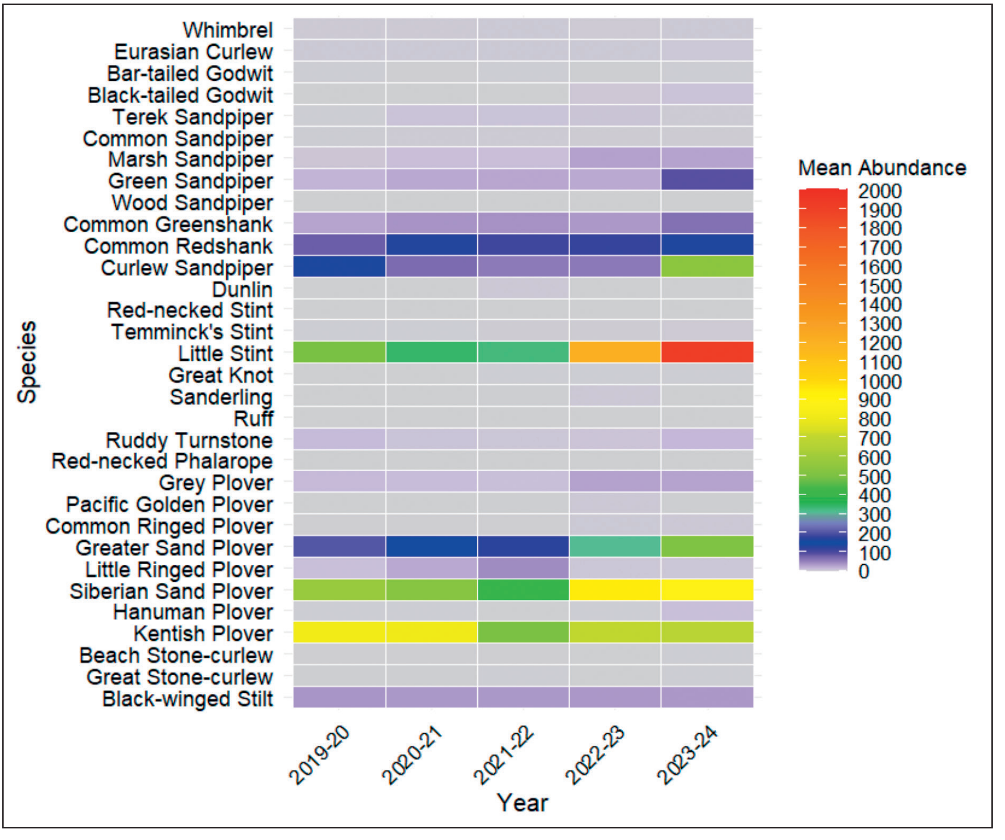

Figure 3. Mean abundance of shorebird species across five years
3. ábra A partimadár-fajok átlagos abundanciája, az ötéves adatsort feldolgozva

followed by 2023–2024, with a peak count in January 2023 (n=62). The Near Threatened Dunlin was observed only in April 2022 (n=60). One or two individuals of Beach Stone-curlew were recorded annually. Great Stone-curlew highest record was in April 2022 (n=8), and one or two individuals were recorded consistently across all years. Bar-tailed Godwit was present each year, peaking in January 2023 (n=10). Black-tailed Godwit was recorded from September to March in 2022–2023 and 2023–2024, with the highest count in November 2022 (n=40). Red-necked Stint was recorded only in December 2022 (n=4) and September 2023 (n=2). Ruddy Turnstone was recorded in all the years, with its peak count in August 2023 (n=60). Eurasian Curlew abundance increased in September across all years, with the highest count in September 2022 and November 2020 (n=12) *(Figure 6)*.

SIMPER analysis identified four species as primary contributors (80.9%) to the temporal dissimilarity in shorebird communities, based on the Bray–Curtis similarity index across the study period. Little Stint accounted for 41.9% of the dissimilarity, followed by Siberian Sand Plover (17.08%), Curlew Sandpiper (11.76%) and Kentish Plover (10.17%), indicating their dominant influence on community dynamics at Valinokkam Lagoon. The remaining 28 species contributed only 19.1% to the temporal variation *(Table 3)*. STL decomposition

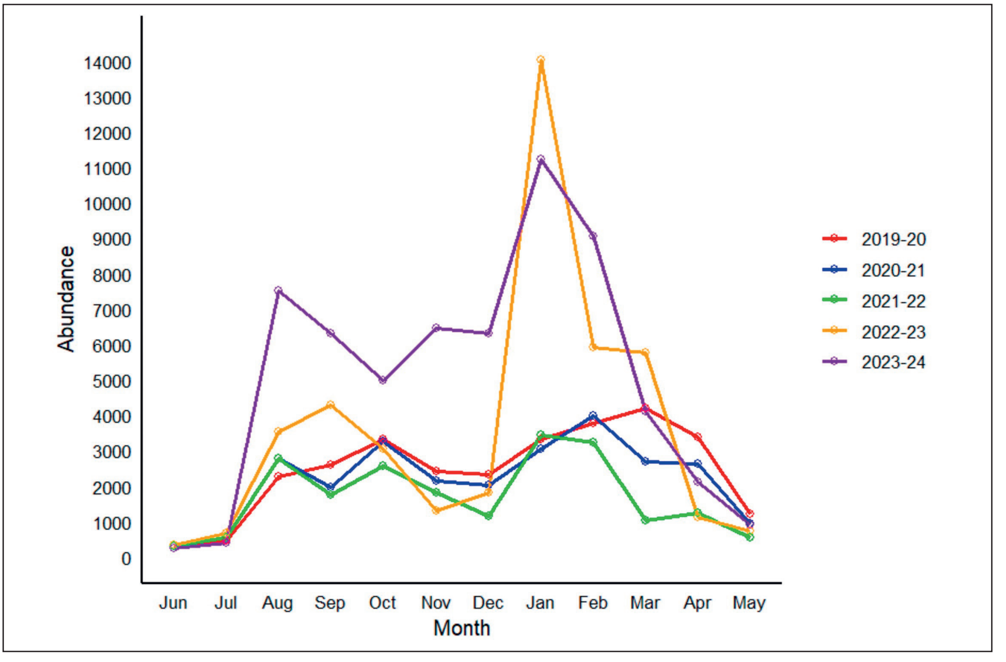

Figure 4. Total monthly abundance of shorebirds across five study years
4. ábra A partimadarak teljes havi abundanciája az öt vizsgálati év alatt

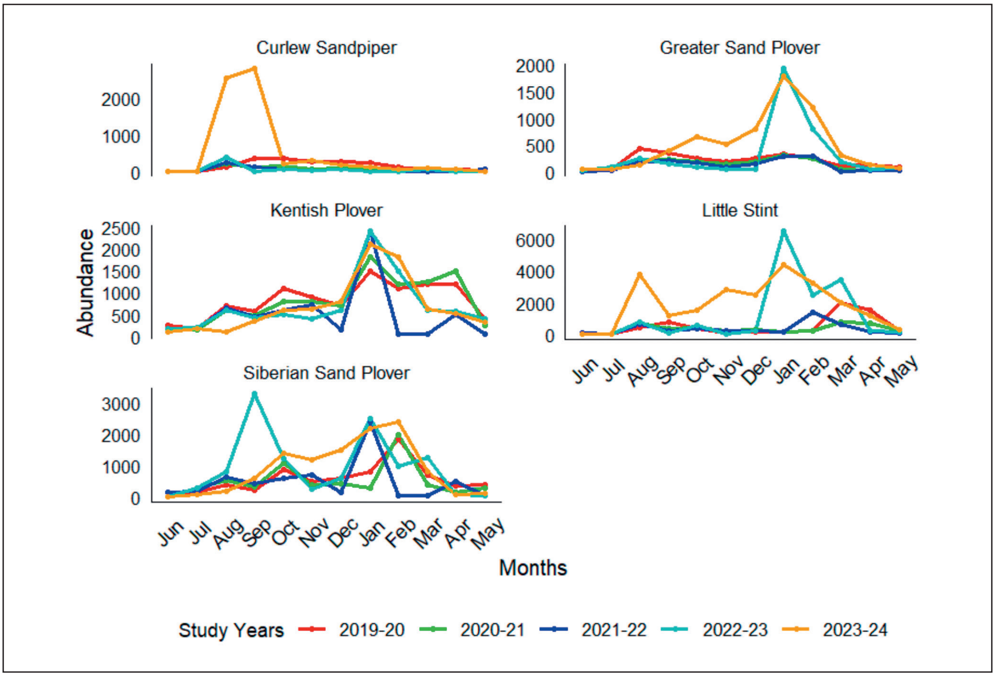

Figure 5. Monthly abundance of the five most abundant shorebird species
5. ábra Az öt leggyakoribb partimadár-faj havi abundancia-értékei

Figure 6. Monthly abundance of the 10 threatened shorebird species
6. ábra A 10 legveszélyeztetettebb partimadár-faj havi abundancia-értékei

confirmed the temporal trends in shorebird abundance. The data plot illustrated patterns in the actual data with abundance fluctuating between 2,000 and 14,000 individuals, with a notable peak reaching approximately 14,038 individuals in 2022–2023. The trend component revealed a substantial increase during 2022–2024, rising from approximately 3,500 to 5,000 individuals, representing a positive trend of approximately 1,500 individuals over this period with a typical monthly rise of around 622 individuals. Outliers and fluctuations were also high in these two years, as indicated in the remainder plot, with deviations ranging from -2,000 to +6,000 individuals, including a pronounced positive anomaly of approximately 6,000 individuals in 2022–2023. The standard deviation of the remainder component was 1,492.0, indicating outliers. The seasonal component displayed a regular repeating pattern with a consistent amplitude of approximately 6,476.6 individuals, with peaks occurring in August annually *(Figure 7)*.

11 shorebird species were found to be over-summering in Valinokkam Lagoon from June 15 to July 31 (Byju *et al*. 2024). These included Grey Plover, Greater Sand Plover, Siberian Sand Plover, Whimbrel *(N. phaeopus)*, Eurasian Curlew, Common Greenshank *(T. nebularia),* Common Redshank, Curlew Sandpiper, Little Stint, Ruddy Turnstone and Kentish Plover, with Siberian Sand Plover being the most abundant over-summering species.

Species accumulation patterns analyzed using individual rarefaction curves indicated a continuous rise without reaching a plateau, indicating the possibility of documenting more species, particularly in 2019–2020 and 2021–2022. The highest species richness was recorded in 2022–2023 and 2023–2024, and the lowest in 2020–2021 *(Figure 8)*. Despite these temporal trends, the Kruskal–Wallis test results revealed no statistically significant difference in shorebird abundances across the five study years ($p = 0.66$, $Chi^2 = 2.392$).

Table 3. SIMPER analysis of shorebird species
3. táblázat A partimadár-fajok SIMPER-elemzése

Taxon	Contribution %
Little Stint	41.900
Siberian Sand Plover	17.080
Curlew Sandpiper	11.760
Kentish Plover	10.170
Greater Sand Plover	9.727
Common Redshank	1.544
Green Sandpiper	1.435
Wood Sandpiper	1.258
Little Ringed Plover	1.195
Common Greenshank	0.819
Marsh Sandpiper	0.673
Grey Plover	0.584
Ruddy Turnstone	0.288
Terek Sandpiper	0.251
Black-tailed Godwit	0.250
Hanuman Plover	0.212
Dunlin	0.141
Common Ringed Plover	0.129
Pacific Golden Plover	0.117
Sanderling	0.115
Black-winged Stilt	0.073
Temminck's Stint	0.047
Great Knot	0.042
Eurasian Curlew	0.038
Bar-tailed Godwit	0.035
Great Stone-curlew	0.034
Beach Stone-curlew	0.031
Common Sandpiper	0.028
Red-necked Stint	0.009
Red-necked Phalarope	0.006
Ruff	0.006

Discussion

This five-year study provides critical insights into the temporal patterns and community dynamics of shorebirds in Valinokkam Lagoon, underscoring its ecological importance as a wintering and breeding site for species, including those classified as threatened by the IUCN Red List (2024). We documented fluctuations in species richness, abundance, and community composition, highlighting both consistent seasonal trends and inter-annual variations. Monthly monitoring and counts aimed to identify the important periods during which the site is used by shorebirds, like the months with the maximum count or species diversity and to record the regular changes in the site usage as this is a first attempt on this important wintering site. Below, we discuss the significance of these findings in the context of shorebird conservation and potential drivers of observed patterns.

Shorebird composition and community dynamics

Valinokkam Lagoon supported 32 shorebird species, including eight Near Threatened and four globally threatened species, reaffirming the critical role of the habitat. As 72% of the recorded species show declining global population trends (Birdlife International 2024), sustained monitoring and protection of this habitat is vital for their survival. The high proportion (87.5%) of migratory species among the documented shorebirds aligns with earlier findings (Razak & Rahman 2020, Byju *et al*. 2023e, Shree & Malathi 2024),

Figure 7. Seasonal Trend decomposition plot using LOESS (STL) across five years
7. ábra Az öt évet felölelő partimadár-adatok Szezonális Trend-dekompozíciós ábrája LOESS (STL) alkalmazásával

emphasizing the importance of this coastal lagoon as a stopover and wintering site along CAF. The over-summering of 11 species in the lagoon highlights the year-round ecological value with the availability of prey and suitable environmental conditions for the shorebirds in Valinokkam Lagoon.

SIMPER analysis further elucidated the dominant influence of four species (Little Stint, Siberian Sand Plover, Curlew Sandpiper and Kentish Plover) on community dynamics, contributing over 80% to temporal dissimilarity. Their predominance suggests that the ecological health of Valinokkam Lagoon is closely tied to the habitat preferences of these key and common species in coastal wetlands of the CAF and are known to be highly responsive to changes in habitat conditions (Ma *et al*. 2013). This makes them useful bioindicators for monitoring ecosystem changes (Barter 2002, MacKinnon *et al*. 2012).

The relatively uneven species distribution and the dominance index also substantiated the SIMPER results. The year 2023–2024 marked the highest total abundance contributed mainly by the four most abundant species, yet the lowest values of species evenness, richness and diversity, whereas the year 2021–2022 had the lowest abundance yet slightly

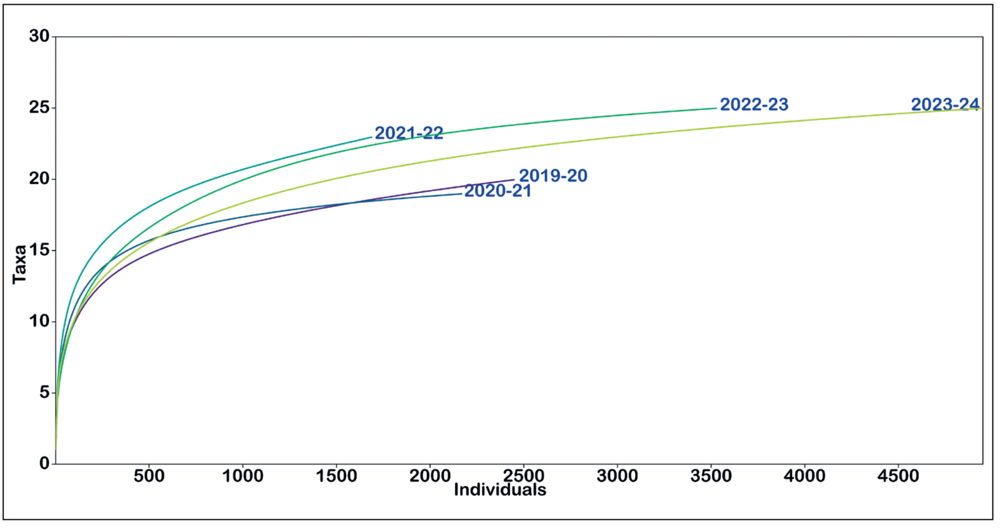

Figure 8. Individual rarefaction curves across five years
8. ábra Évenkénti ritkítási görbék az öt éves vizsgálati adatsorokra

more even community with less dominance, high species diversity and richness. The factors that influence such species distribution dynamics could be the availability of macroinvertebrates, particularly chironomid larvae that are key food items of shorebirds (Sánchez *et al*. 2006, Yasué & Dearden 2009) as their high production depends mainly on salinity and water level in the saltpans (Velasquez 1992, Rehfisch 1994). Some studies noted a positive correlation between the benthic organisms like bivalves, gastropods, salinity and water level in the saltpans to the abundance and diversity of shorebirds (Warnock *et al*. 2002, Rocha 2013, Pandiyan *et al*. 2021), which is especially true in winter where shorebirds density purely depends on prey density (Pandiyan *et al*. 2006, Sultana *et al*. 2024). These factors could be the potential reasons behind Valinokkam presenting higher abundances of smaller shorebirds (plovers and Little Stint) in all the seasons, which needs further investigation on the benthic fauna and micro-environmental variables in the lagoon.

Inter-annual variability and species-specific trends

Our results revealed notable inter-annual variability in shorebird abundance and species richness. The highest total abundance was in 2023–2024 and the lowest in 2021–2022, suggesting potential links to environmental conditions, prey availability and habitat quality. The increase in shorebird abundance in 2023–2024 warrants further investigation into annual climatic variability and its effects on shorebird assemblages. The rarefaction curves suggested that the lagoon may still host additional undocumented species. This pattern aligns with studies showing that wetlands with fluctuating hydrological regimes often support dynamic shorebird communities, where species richness depends on annual climatic conditions (Galbraith *et al*. 2014).

Species-specific trends highlighted the influence of habitat preferences and migratory patterns on species assemblages. For example, the Siberian Sand Plover population peaked in September 2022, with consistent abundance during the January–March period, aligning with its migration schedule and reliance on intertidal habitats (Rogers *et al*. 2020). Black-tailed Godwit was present from October to March 2022–2023 and 2023–2024, peaking in November 2022. These findings align with studies on the east coast of India by Balachandran (2006), that small and medium-sized shorebirds peak in January and long-legged shorebirds like Black-tailed Godwits from November to March. Similarly, the absence of Dunlin in most years except 2021–2022 and the restricted presence of Red-necked Stint during 2022–2023 and 2023–2024 suggest either habitat-specific requirements or stochastic events influencing their occurrence. The lack of significant differences in species abundances between years, as revealed by the Kruskal–Wallis test, further suggests the lagoon's consistent provision of key habitat types, including mudflats, saltpans and grassy areas, which support a diverse range of shorebirds throughout the year, apart from micro-environmental factors.

Seasonal patterns

We observed a clear seasonal peak in shorebird abundance in August, substantiated by monthly abundance analysis. Despite minor variations over time, shorebird abundance generally started increasing in August, peaked in January and February, and reached its lowest in June and July. This is consistent with earlier studies on a few wintering sites on the southeast coast of India (Balachandran 2006, Pandiyan & Asokan 2016, Rao *et al*. 2022). The observed decline in abundance during May–July likely corresponds to the northward migration of shorebirds to breeding grounds, as well as seasonal shifts in habitat conditions, such as reduced prey availability or water levels. The seasonal pattern might be due to the rainfall from the northeast monsoon in the region (October–December). Temporal fluctuations in shorebird abundance could also occur due to localized movements of birds other than the local environmental factors (Townshend 1981, Pienkowski & Evans 1984).

Conservation challenges and recommendations

From our results, it is evident that Valinokkam is a crucial habitat for both winter visitors and the resident shorebirds. Apart from the IUCN assessed threatened species mentioned earlier, five species recorded in Valinokkam such as Whimbrel, Bar-tailed Godwit, Curlew Sandpiper, Dunlin and Great Knot are listed as Central Asian Flyway Priority Species in AMBI (Arctic Council 2024), whereas 28 of the total shorebirds are recorded in Appendix II of CMS, implying the need of an international cooperative framework for the conservation of these birds and their breeding and wintering grounds. The lagoon is also a breeding ground for two near-threatened species (Beach Stone-curlew and Great Stone-curlew) along with the regional endemic shorebird Hanuman Plover (Byju *et al*. 2023d).

The absence of statistically significant differences in shorebird abundances across years does not diminish the ecological significance of the temporal trends observed. Rather, it highlights the inherent variability in shorebird populations, driven by a complex interplay of local and global factors. The careful management of manmade wetlands, such as industrial saltpans, might boost their utility as a foraging site for waterbirds, particularly migrant shorebirds, during their times of high energy demand (Ntiamoa-Baidu *et al*. 2000). Since Valinokkam lagoon is an unprotected area, the threats of encroachment for developmental activities or establishments of extensive prawn culture persist. We have observed children picking up the eggs of Hanuman Plover and stray dogs disturbing the birds. These observations emphasize the need to warrant a protection status for this lagoon.

To ensure the long-term sustainability of Valinokkam Lagoon as a shorebird habitat, we recommend the following:

1. **Strengthening habitat protection**: Designate Valinokkam Lagoon as a protected wetland under the Ramsar Convention and implement site-specific management strategies to mitigate habitat degradation.
2. **Monitoring and research**: Establish a long-term monitoring program to track population trends and habitat changes. Future studies should focus on understanding prey availability, hydrological dynamics, and the impact of climate change on migratory patterns.
3. **Community engagement**: Involve local communities in conservation efforts through awareness programs and sustainable livelihood initiatives, such as eco-tourism and birdwatching activities.
4. **Collaborative networks**: Strengthen collaborations with international flyway initiatives, such as the CAF Partnership, to align conservation actions with global efforts. Shorebird population data of Valinokkam Lagoon can be a significant contribution to the global database upgrade, since the global population size of more than 62% of the shorebird species that are recorded in this site is unknown.

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