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Original Research

Long-term Population Dynamics of Large Wading Birds in Gulf of Mannar Lagoons: Potential Influence of Changing Landscapes with Expanding Agriculture

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Abstract

Large wading birds are key indicators of wetland ecosystem health and productivity. Despite supporting significant populations, lagoon systems along the coast of the Gulf of Mannar Biosphere Reserve have received limited studies. The present study analyses long-term (1985-2024) discontinuous population trends (1985-1989, 2005-2007, 2018-2019, 2021-2024) of large wading birds recorded in coastal lagoons at Pillaimadam, Valinokkam, and Dhanushkodi. Bird count data obtained from monthly systematic field surveys were compiled; seasonal peak count per year was taken, and principal coordinates analysis (PCoA), Mann–Kendall test, and beta diversity partitioning were employed to assess community assemblage and temporal changes. A total of 15 large wading species belonging to three families were recorded, where egrets constituted the dominant guild. Species richness and diversity substantially increased after 2018. Beta diversity indicated moderate temporal dissimilarity, driven primarily by nestedness, while turnover contributed to a lesser extent. A substantial change in community composition and dominance from Little Egret in earlier years (1985-88 and 2005-07) to Intermediate Egret in the recent period (2018-2024) was recorded. The recent period has also recorded several new species: Black-headed Ibis, Glossy Ibis, Painted Stork and Asian Openbill. Over the last few decades, the observed increase in cultivated land area in Ramanathapuram may have influenced resource availability, thereby altering species composition relative to the earlier study period, but causality remains untested. These findings highlight the ecological importance of lagoon-agriculture mosaics and the need for integrated conservation strategies.

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Statement of Sustainability: This study provides a long-term assessment of large wading bird populations in the lagoon regions and the associated agricultural area of the Gulf of Mannar. The findings highlight the ecological importance of lagoons and adjacent agroecosystems as significant foraging and roosting habitats. The study helps in further understanding of wetland-dependent bird communities as indicators of wetland health, which can help wetland conservation, guide sustainable agricultural practices, and inform regionally relevant conservation planning.

1. Introduction

Wetlands support diverse assemblages of waterbirds. Each species differs in its use of habitats and resources. Globally, wetlands are degraded due to increasing anthropogenic pressure corresponding with changes in climate, altered nutrient cycles, hydrological alterations and changes in the community structure of aquatic species (Sievers et al., 2018), including waterbirds (Ma et al., 2010; Woodrey et al., 2012). Coastal lagoons are also no exception to anthropogenic pressures like pollution, land clearing for economic development and conversion to aquaculture ponds, etc. (Kennish & Paerl, 2010). Lagoonal habitats are critical for several resident and migratory waterbird species that use them for roosting, nesting, stopover or foraging sites (Sandilyan and Kathiresan, 2015; Byju et al., 2024a). The availability and quality of foraging habitats strongly influence breeding success and population dynamics, particularly during energy-demanding breeding and migration periods (Kingsford et al., 2017; Byju et al., 2025a). Habitat selection, therefore, plays a critical role in determining the distribution and abundance of waterbirds across wetland ecosystems.

Large wading birds are often significant functional components of the wetlands. Herons, egrets, storks, ibises and spoonbills are among the most widespread and ecologically significant groups of large waders, occurring across a wide range of aquatic habitats, including coastal lagoons and human-modified landscapes (Weseloh and Green, 2018). They play an important ecological role in coastal wetlands as upper trophic level consumers and indicators of ecosystem condition (Aarif et al., 2025). The natural wetlands and waterlogged agricultural fields mosaic is emerging as an alternative foraging habitat for large wading birds in India. The inundated paddy fields provide suitable prey species, macroinvertebrates, small fish, and larval amphibians (Byju et al., 2024b; 2025b).

The coastal wetlands of the Gulf of Mannar (GoM) represent one of the most productive ecosystems in Ramanathapuram, Tamil Nadu, comprising lagoons, mudflats and mangroves that support diverse waterbird communities. Large wading birds are recorded in these lagoons, mangroves and islands of GoM (Byju et al., 2023a; 2023b; 2023c; 2024a; 2025c). Although several studies have documented waterbirds in the region, most are restricted to coastal birds. Long-term population assessments and habitat use by large wading birds of the region remain limited. Hence, understanding long-term trends is essential for evaluating ecological changes and developing conservation strategies.

In this context, the present study analyses long-term observations of large wading birds recorded from lagoon habitats along the GoM coast over four decades. The objectives of this study are to a) Document species composition of large wading birds in the selected lagoons, b) Assess relative abundance and dominance patterns, c) Compare historical and recent population trends and d) Highlight the conservation significance of lagoon habitats and explore potential associations with landscape change.

2. Materials and Methods

2.1. Study area

The study was conducted in the coastal lagoons of the GoM, Tamil Nadu, India. The lagoons included Pillaimadam, Valinokkam and Dhanushkodi (Figure 1). These lagoons are shallow coastal wetlands influenced by tidal fluctuations and seasonal freshwater inflow and are characterized by mudflats, sandbars and patches of mangroves that provide suitable foraging habitats for waterbirds. Valinokkam is a man-made lagoon with no tidal influence. These habitats support diverse fish, crustaceans and molluscs, which form important prey for large wading birds. The GoM region experiences a tropical climate with temperatures ranging between 24°C and 35°C. Rainfall is mainly received during the northeast monsoon between October and December.

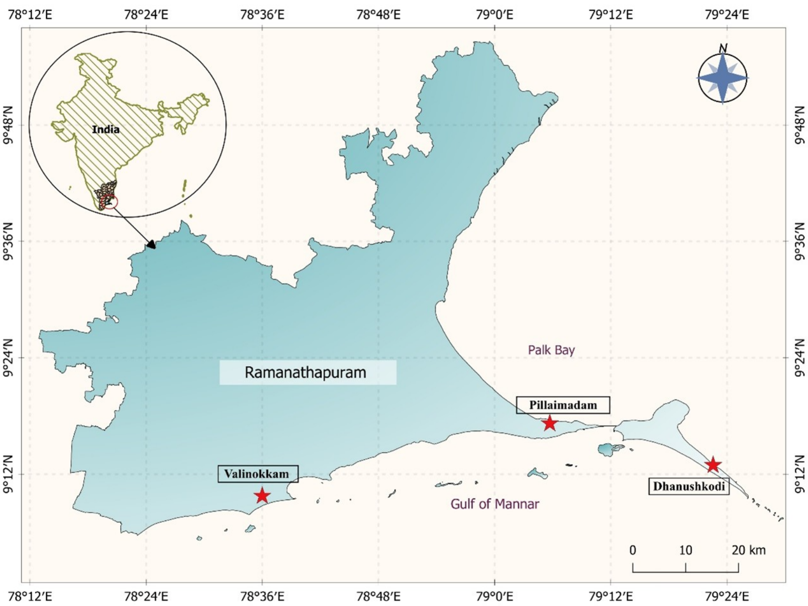

Figure 1. Map showing the lagoons of Ramanathapuram within the Gulf of Mannar region.

2.2. Bird Surveys and Data Compilation

Large wading bird data from the 1985–1988 survey period were sourced from Balachandran (1990). Subsequent surveys from 2005–2007 (Daniel et al., 2007) were conducted from September to August, covering low tides similar to the earlier period. Recent surveys were carried out during 2018–2019 and 2021–2024 from June to May. To ensure comparability across time periods with differing survey durations and intensities, all datasets were standardised to a monthly resolution, and only months with comparable survey coverage were retained for analysis. Surveys across all periods broadly encompassed the same seasonal window, spanning the northeast monsoon (October–December) to summer (April–June), thereby minimizing seasonal bias in bird occurrence. Field surveys were conducted using the direct visual count method (Bibby et al., 2000), during peak activity periods (06.00 and 10.00 hours) and (16.00 to 18.00 hours), depending on tidal influence. Although exact sampling effort (e.g., number of visits per month) varied among study periods, survey protocols, timing, and habitat coverage were broadly consistent, allowing for relative comparisons of bird assemblages. To further reduce bias arising from unequal effort, we:(i) restricted analyses to presence–absence and peak count metrics, which are less sensitive to variation in sampling frequency, and (ii) avoided direct comparison of absolute abundance across periods without standardization. Valinokkam, a non-tidal site identified as a wintering site post 2018, was included in analyses pertaining to recent datasets to avoid inflation of long-term trends. Based on bird congregation patterns, we selected vantage points on each site - eleven at Dhanushkodi, five at Valinokkam and four at Pillaimadam. A five-minute acclimatization period at each point was given for birds to minimize disturbance. Nikon binoculars (10×50), Vanguard spotting scope (14×70) and Canon telephoto lens (100-400 mm or 600 mm) were used for the field observations. Species were identified from the author's field experience, along with standard field guides (Grimmett et al., 2011).

2.3. Data Analysis

To account for inconsistencies in sampling effort across time periods, analyses were designed using effort-independent or minimally effort-sensitive metrics. Monthly abundance patterns were assessed using relative abundance (proportional contribution of each species per month) rather than raw counts, thereby reducing bias due to unequal sampling intensity. Species richness was calculated as the total number of species recorded per year. Species diversity was assessed using the **S**hannon–Wiener diversity index (Shannon and Weaver, 1949), applied to standardised monthly data.

To ensure comparability across datasets (1985-1988, 2005-07, 2018-19 and 2021-24), the maximum count for each species was considered the annual peak abundance, as it was a robust metric and less sensitive to differences in sampling frequency and commonly used in long-term waterbird monitoring studies (Wetland International, 2018). Temporal variation in species composition was quantified using the Sørensen beta diversity (βSOR), an assessment protocol following Baselga (2010), and separated into components representing species replacement (turnover; βSIM) and species gain or loss (nestedness; βSNE). These were calculated using the *betapart* package in R (Baselga and Orme, 2012). These analyses were based on presence–absence data to minimize sampling bias.

Patterns of community composition were examined using Principal Coordinates Analysis (PCoA) based on the Bray–Curtis dissimilarity matrix. Ordination was performed using classical multidimensional scaling (cmdscale) (Gower, 1966). To reduce effort-related bias, abundance data were square-root transformed and standardized prior to analysis, and results were interpreted cautiously in the context of varying sampling intensity. Further, temporal trends in species-specific peak abundance were assessed using the Mann–Kendall test (Mann, 1945; Kendall, 1975), a non-parametric method robust to irregular sampling intervals. Kendall's tau (τ) was used to quantify trend direction and strength, and significance was assessed at $\alpha = 0.05$.

2.4. Limitations

Visual counts may introduce detectability bias due to observer variability and habitat complexity. Rare species were excluded from statistical analyses to avoid distortion, but are discussed qualitatively.

3. Results and Discussion

3.1. Species Composition

A total of 15 species of large wading birds were recorded from the lagoons of GoM, belonging to three families: Ardeidae: Grey Heron (*Ardea cinerea*), Indian Pond Heron (*Ardeola grayii*), Green-backed Heron (*Butorides striata*) (earlier known as Striated Heron), Cattle Egret (*Bubulcus ibis*), Great Egret (*Ardea alba*), Intermediate Egret (*Ardea intermedia*), Little Egret (*Egretta garzetta*) and Western Reef Egret (*Egretta gularis*), Purple Heron (*Ardea purpurea*), Black-crowned Night Heron (*Nycticorax nycticorax*); Threskiornithidae: Black-headed Ibis (*Threskiornis melanocephalus*), Glossy Ibis (*Plegadis falcinellus*), Eurasian Spoonbill (*Platalea leucorodia*); Ciconiidae: Asian Openbill (*Anastomus oscitans*) and Painted Stork (*Mycteria leucocephala*). All the species are Residents except Western Reef Egret, which is a Local migrant to the region. All species are Least Concern in the IUCN Redlist (IUCN, 2026). Among these, two species, Purple Heron and Black-crowned Night Heron, were stragglers, recorded only one or two individuals in single months in 2018-19 and 2022-23, respectively, and hence, excluded from further statistical analysis. However, their presence is ecologically important and indicates occasional habitat use.

Species richness was relatively lower during earlier years (1985–1988) with seven species and intermediate years (2005–2007) with six species and a marked increase in recent years (2018–2024), reaching 11–13 species. Shannon diversity (H′) followed a similar pattern. Early years exhibited moderate diversity (H′ = 1.23–1.39), whereas 2005–06 showed a decline (H′ = 0.66), with a recovery in 2006–07 (H′ = 1.22) but remained lower than recent values (H′ = 1.80–2.07). Total beta diversity across years was moderate (βSOR = 0.50), where nestedness (βSNE = 0.471) contributed more to overall dissimilarity than turnover (βSIM = 0.028).

Assessing the monthly abundance of large wading birds showed a moderate difference among months from 2018-19 to 2023-24. Peak abundance was during November–January (2005–06: n = 546–755; 2021–22: n = 506–602) and also during March–April (2022–23: n = 771–952; 2023–24: n = 532–781). Maximum abundance was recorded in April 2022–23 (n = 952), while the lowest values occurred in June–August of earlier years (2006–07: n = 52–102) (Figure 2).

The pattern of increase in species richness and diversity from the 1980s to recent years is consistent with several wetland systems undergoing rapid alterations, where new species supplement existing assemblages (Carvalho et al., 2013). The results showed that total beta diversity was moderate and largely driven by nestedness rather than turnover, suggesting that temporal changes in the assemblage were characterized more by species additions while replacement contributed to a lesser extent. In other words, the assemblage remained largely similar, but some species were occasionally absent or newly recorded, probably owing to multiple factors such as changing macro and micro-habitats, seasonality or human disturbances (Ekwemuka et al., 2025). The monthly abundance patterns from 2018 to 2024 appear to coincide with the agricultural cultivation season in the region (August to January and April-May, depending on the crop type) (Ramanathapuram District Profile, 2026).

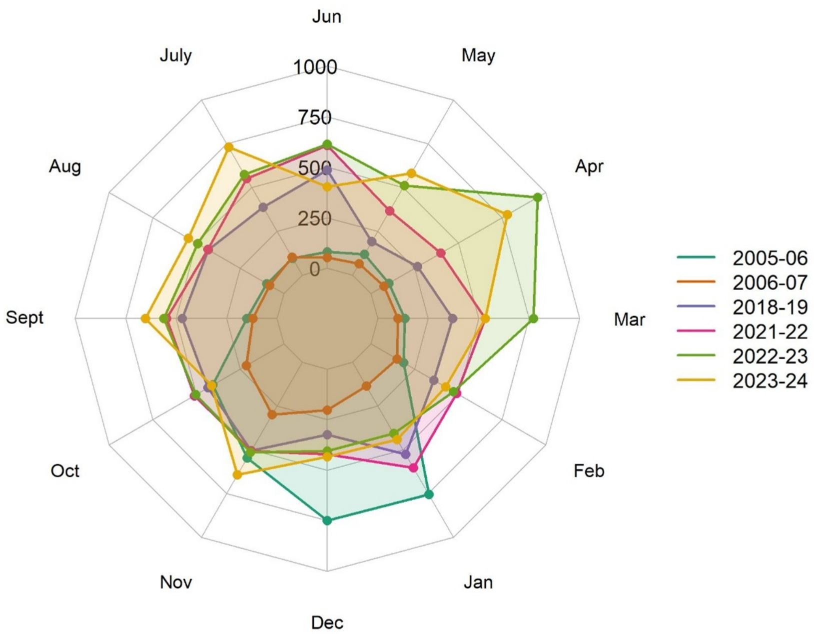

Figure 2. Monthly abundance of the total large wading waterbirds from 2005-06 to 2023-24.

3.2. Community Structure

Seasonal peak counts of large wading birds revealed clear shifts in the community structure and dominance patterns. During the early period (1985–88), the assemblage was strongly dominated by Little Egret, with peak seasonal counts ranging from 440 to 800 individuals, followed by Cattle Egret (n = 261 to 350) and Indian Pond Heron (n = 114 to 178) (Figure 3). During 2005–06 and 2006–07, Little Egret dominated the assemblage (670 and 112 individuals with a relative abundance of 78.1% and 48.9%, respectively), although it showed a marked decline in later years. During this period (2005-07), it was followed by Cattle Egret (100–140 individuals; 13.5–35.5%) and Indian Pond Heron (18–34 individuals; 6.4–8.6%), whereas Intermediate Egret remained relatively scarce (10–16 individuals, <5%). From 2018–2019 onwards, there was a remarkable shift in the distribution, with Intermediate Egret becoming the most abundant species, contributing 45.8% in 2018–19, 44.5% in 2021–22, 37.4% in 2022–23, and 40.3% in 2023–24. During the same period, Little Egret declined to 86 individuals by 2023–24, with relative abundance ranging from 12.3–14.5% (2018-19 to 2023-24). Great Egret was a major component from 2018–2019 onwards, contributing from 11.8% to 13.6% (2018–19 to 2023–24). The results showed that, across all study periods in GoM, egrets dominated the overall community of large waders. There was a marked shift in dominance from Little Egret to Intermediate Egret, which showed a species or group-specific ecological shift in the region. Few species absent in earlier years reappeared from 2018–19 onwards, although the relative abundance was not significant, including Asian Openbill (0.03–1.01%), Black-headed Ibis (0.21–1.11%), Eurasian Spoonbill (0.42–1.15%), Painted Stork (0.80–2.76%), and Glossy Ibis (0–0.72%). Western Reef Egret and Green-backed Heron remained consistently rare across all years ($\leq$0.87%) (Figures 3 and 4).

The absence of these species prior to 2018-19 and followed by their subsequent establishment is the key record prior to 2018, which points to increased diversification of community structure and a recent improvement or expansion of suitable foraging habitats, including increased agricultural expansion. The occasional records of Purple Heron and Black-crowned Night Heron also indicate a changing habitat, supporting species with specific preferences for roosting and feeding (Kularatne et al., 2021; Byju et al., 2024c). Such spatial shifts in large wading bird assemblages are commonly associated with changes in habitat structure and foraging opportunities (Ma et al., 2010), particularly water depth (Elphick, 2000) and prey accessibility (Tojo, 1996; Choi et al., 2007) that favoured larger egret species and large-bodied waders such as storks and ibises. This link is directly related to changes in monsoon and the extent of agriculture, which further requires intense research to fully understand the changes. While some variation in sampling effort exists among survey periods, the consistent seasonal coverage and use of effort-independent metrics likely reduce its influence on the overall trends reported.

The clustering of recent years (2018–24) in PCoA indicates increased community similarity driven by the dominance of Intermediate Egret, Great Egret and the presence of Black-headed Ibis and Glossy Ibis, whereas earlier years of 1985-88 were mostly associated with Little Egret. Cattle Egret, Green-backed Heron, and Indian Pond Heron show no specific associations, being nearly at the origin (Figure 5).

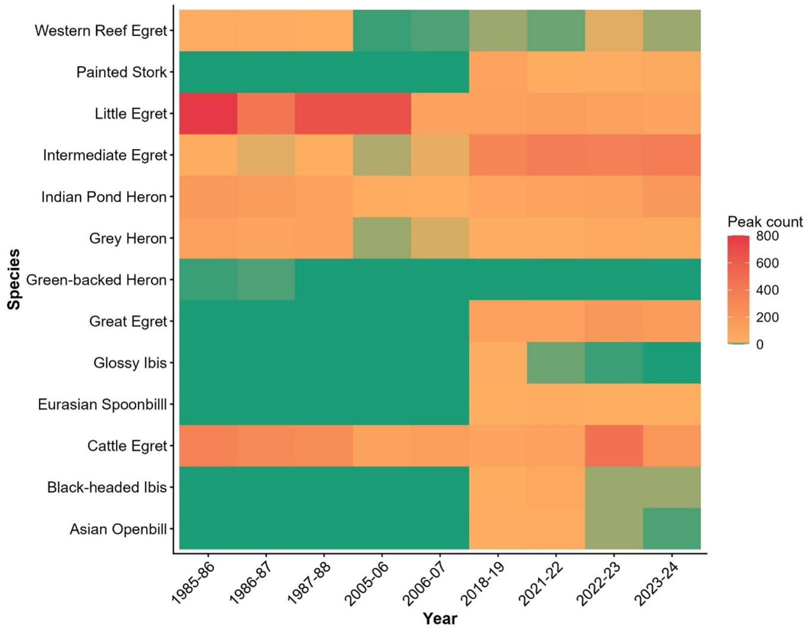

Figure 3. Annual seasonal peak counts of large wading waterbirds across all study years.

The long-term changes observed in the large wading bird assemblage reflect broader ecological processes that have reshaped wetland communities in South Asia. The ecological drivers likely include hydrological changes, prey base shifts, salinity and temperature changes and anthropogenic pressures such as agriculture and urban expansion, which shape the waterbird assemblages across Asia (Fasola et al., 2010; Xie et al., 2019; Li et al., 2019). The characteristics of individual lagoon habitats might also play a significant role. Valinokkam lagoon, being a salt pan surrounded by agricultural fields and with a stable water level due to seawater pumping throughout the year, supported higher abundances of Grey Herons, Great Egrets, Painted Storks, and other large wading birds (Byju et al., 2023a). In contrast, Dhanushkodi lagoon supported relatively higher abundances of egrets, particularly Intermediate Egret and Little Egret, suggesting that this site offers more suitable shallow-water wetland conditions preferred by these species (Byju et al., 2024a). In Pillaimadam, egrets were commonly recorded, Western Reef Egret, and all ibises are rare or seasonal. Such spatial differentiation suggests species composition in this region is primarily structured by local wetland conditions and surrounding land use, with larger wading birds more likely to exploit landscape-scale resource mosaics (Ma et al., 2010).

3.3. Overall Population Trend

Among the 13 species analysed, the Mann–Kendall test indicated statistically significant trends in four species. Eurasian Spoonbill (τ = 0.63, p = 0.037), Great Egret (τ = 0.72, p = 0.016), and Intermediate Egret (τ = 0.56, p = 0.048) showed significant increasing trends, whereas Little Egret exhibited a significant declining trend (τ = −0.70, p = 0.012). All remaining species lacked statistically significant trends ($p > 0.05$). Species such as Grey Heron, Cattle Egret, and Western Reef Egret showed weak negative trends (τ ranging from −0.17 to −0.31) with no significance, while Asian Openbill, Black-headed Ibis, Glossy Ibis, and Painted Stork showed positive but non-significant trends. Indian Pond Heron showed no trend (τ = 0.00, p = 1.00), indicating stable abundance over time (Figure 6).

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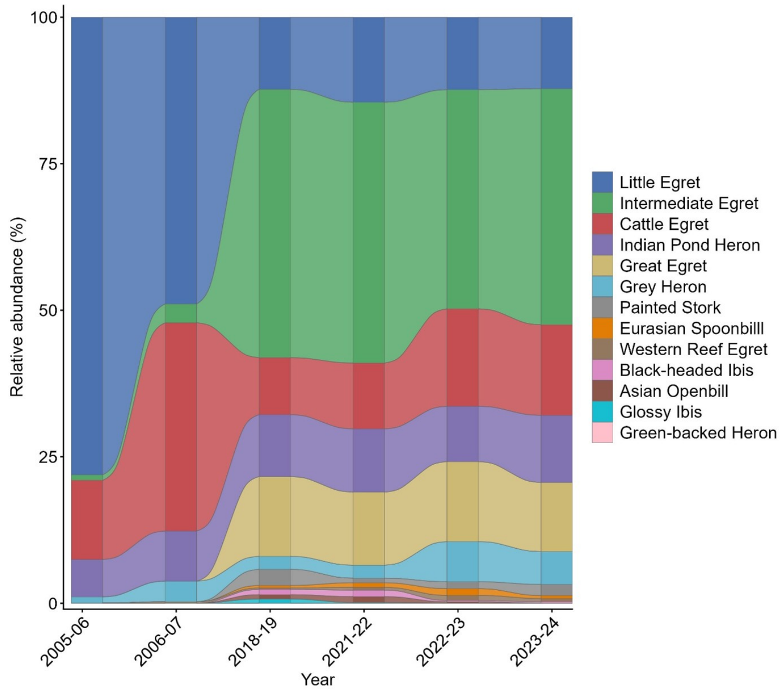

Figure 4. Relative Abundance (%) of large wading birds from 2005-06 to 2023-24 based on monthly abundance.

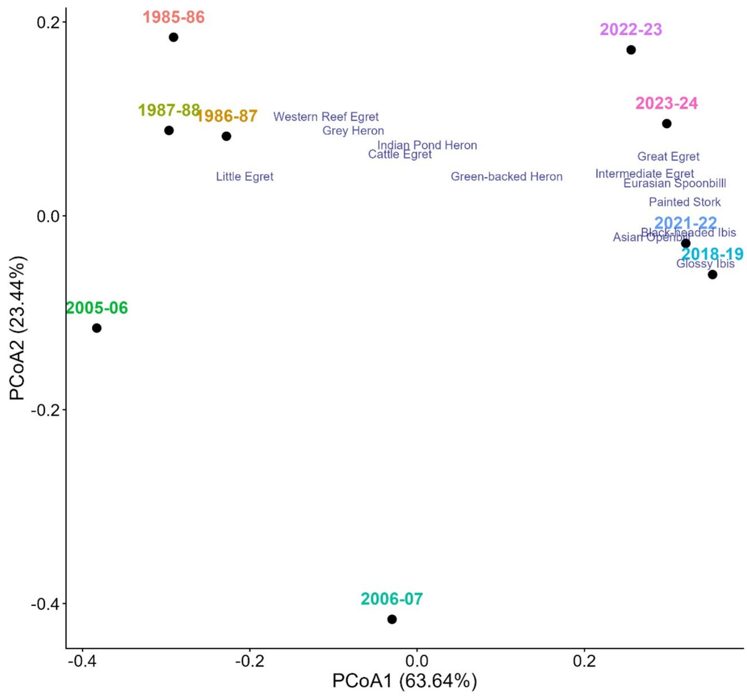

Figure 5. PCoA analysis showing the variation in large wading waterbird composition across all study years.

The non-significant declines observed in Grey Heron, Cattle Egret, and Western Reef Egret may reflect sensitivity to localized habitat degradation or competition with expanding Intermediate Egret populations or local movement to the adjacent suitable habitats. In contrast, the stability of Indian Pond Heron underscores its adaptability to varied wetland conditions, consistent with its generalist foraging ecology (Kushlan and Hancock, 2005).

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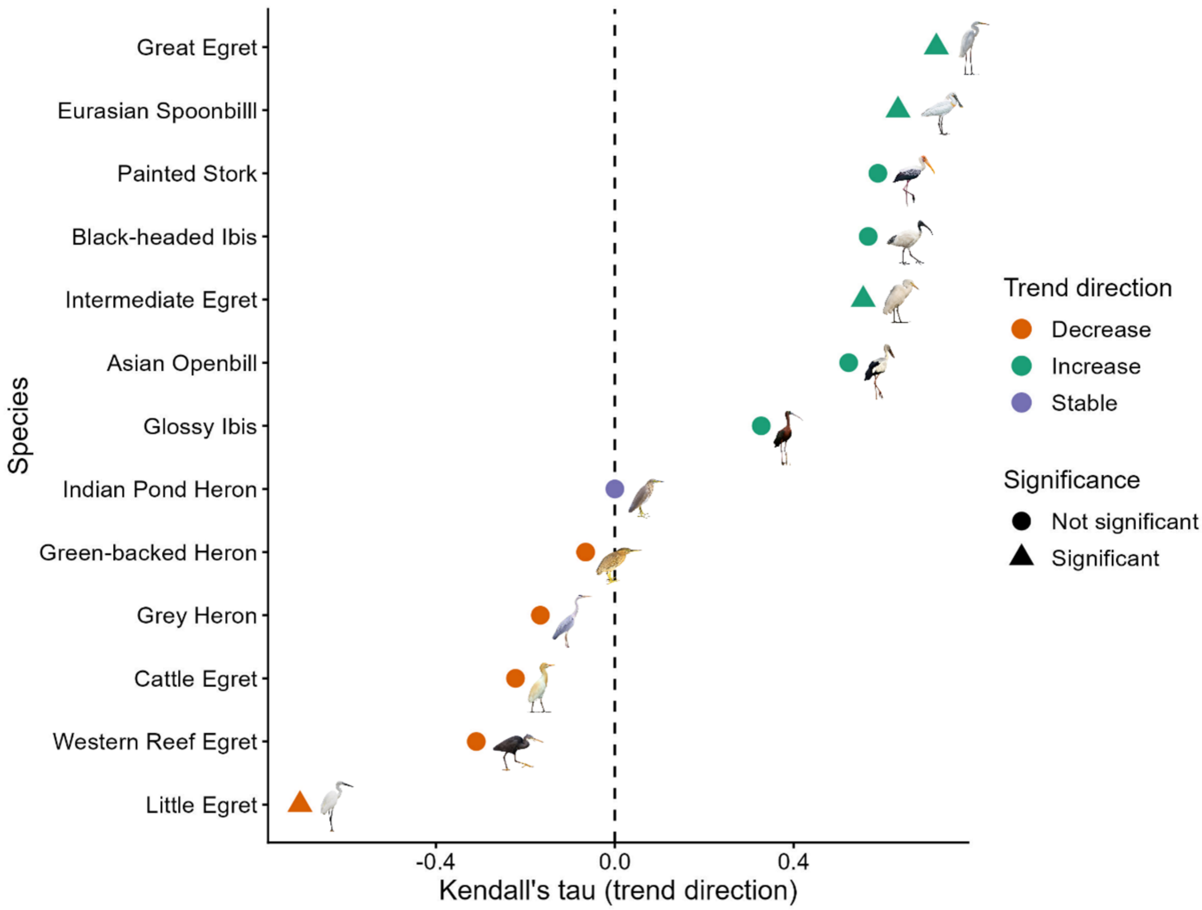

Figure 6. Population trends of the large wading waterbirds as shown by the Mann-Kendall test across all study years.

3.4. Potential Association with Increasing Agroecosystems

The increase in cultivated and irrigated land in Ramanathapuram district, especially between 2004 and 2023, is likely associated with observed changes in the bird community shift (Praveena et al., 2024) and in the increased diversity and abundance of large waders, although this can't be firmly established. Future studies integrating spatial land-use datasets and remote sensing analyses are required to quantitatively test this relationship. Other wetlands in the district, associated with agricultural land, were also known to support a higher diversity of waterbirds, particularly species of the family Ardeidae (Byju et al., 2023d; 2024d).

Agricultural fields, especially those with seasonal inundation like paddy fields, function as alternative foraging habitats, supporting high densities of invertebrates, fish, and amphibians that are accessible to large wading birds (Byju et al., 2024b). Feeding habitat preferences differ among large wading species (Sundar, 2006). These species are known to exploit heterogeneous landscapes that combine wetlands with agricultural fields, particularly irrigated systems where shallow water provides increased prey biomass, particularly molluscs and fish (Ntiamoa-Baidu et al., 1998; Byju et al., 2025b). Similarly, Glossy Ibis and Black-headed Ibis also forage in soft, waterlogged substrates and shallow inundated areas in agricultural landscapes (Tourenq et al., 2001). Their low relative abundance (<1.2%) suggests that these populations are still establishing themselves. Larger species like Grey Heron and Great Egret use more natural wetlands, which are deeper; they do not necessarily need shallow water (Fidorra et al., 2016). However, Intermediate Egret and Cattle Egret depend more on agricultural fields (Choi et al., 2007). The Little Egret prefers very shallow edge habitats and exposed substrates. Cattle Egret, being less dependent on aquatic prey and more associated with terrestrial foraging, did not show a comparable shift in dominance, despite a moderate increase.

3.5. Conservation Implications

The diversity of large waders suggests that conservation efforts should prioritize maintaining hydrological integrity and habitat heterogeneity to support both established and colonizing species. The surrounding agricultural fields may provide supplementary foraging habitats for some species, but species that rely on natural wetland conditions, especially shallow water and mudflat habitats, are more adversely affected by wetland degradation and loss. Many coastal wetlands in India and Tamil Nadu are facing the threat of habitat degradation and loss due to unregulated developmental activities. In addition, surrounding agricultural lands are often managed intensively, including the use of pesticides during cultivation. Such practices can have negative effects on waterbirds, particularly during the breeding period (Krishnamurthy et al., 2024), but their specific impacts in the present study area remain unclear and require further investigation.

4. Conclusion

The lagoon systems along the GoM coast not only support diverse and abundant populations of large wading birds but have also undergone community-level transitions. Long-term data reveal important patterns in species composition and abundance, such as a transition from Little Egret dominance to increased prevalence of Intermediate and Great Egrets, along with the recent addition of several large waders, which reflects ongoing ecological changes. Continued, systematic monitoring of these lagoon ecosystems is therefore essential to track future changes, understand underlying drivers, and inform effective conservation and management of coastal wetland biodiversity. We recommend integrating lagoon conservation with sustainable agricultural practices, maintaining bird-friendly farming, advocating for the reduction in pesticide usage for agroecosystem management, and maintaining the seasonal inundation regimes.

Author Contributions

Byju H: Conceptualization, Data curation, Methodology, Supervision, Writing – original draft, Writing – review & editing; Raveendran N: Data curation, Investigation; Maitreyi H: Visualization, Writing – original draft, Writing – review & editing.

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Declarations

Conflicts of Interest: The authors declare no conflict of interest

Institutional/Ethical Approval: Not Applicable

Supplementary Information Availability: Not applicable

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