The avifauna of Ramanathapuram, Tamil Nadu along the Southeast coast of India: waterbird assessments and conservation implications across key sanctuaries and Ramsar sites

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ABSTRACT

Background. Wetlands, globally, face significant threats from human activities, and waterbirds, as key indicators of wetland health, are essential to maintaining ecological balance. Any long-term conservation measures should prioritize coordinated habitat preservation, wetland restoration, and sustainable management practices involving local communities. Monitoring and analyzing waterbird population trends are critical for understanding restoration, conservation, and management practices.

Methods. The present study was carried out in five bird sanctuaries Chitrangudi, Kanjirankulam (Ramsar sites), Therthangal, Sakkarakottai, and Mel-Kel Selvanoor of Tamil Nadu, Southeast coast of India, over one year (April 2022 to March 2023). Monthly surveys using direct and block methods, with additional fortnightly visits during the breeding season, were conducted from vantage points to record species diversity, nesting activity, and conservation threats. Assessments of the residential status, national status (SOIB), and Convention for Migratory species (CMS) status were done along with the alpha and beta biodiversity profiles, principal component analysis, Pearson correlation and other statistical methods performed to assess breeding waterbirds community structure. Threats to the breeding waterbirds were categorised into high, medium, and low impacts based on degree of severity and irreversibility.

Results. The avifaunal checklist revealed a diversity of waterbird species utilizing the sanctuaries for breeding. Notable findings include two Near-Threatened species like, Asian Woolly-necked Stork *Ciconia episcopus,* and Spot-billed Pelican *Pelecanus philippensis,* where Asian Woolly-necked Stork recorded only in Therthangal Bird Sanctuary. Avifauna of each sanctuary with breeding waterbirds in parenthesis is as follows: Chitragundi 122 (13); Mel-Kel Selvanoor 117 (19); Therthangal 96 (23); Sakkarakottai 116 (17) and Kanjirankulam 123 (14). The breeding activity (incubation in nests) was from November to February except for Glossy Ibis and Oriental Darter whose breeding started in December; Spot-billed Duck and Knob-billed Duck breed only during January and February. Among the 131 species recorded from all the sanctuaries, 78% were resident birds; 27% were breeding waterbirds, and 21% were

Winter visitors. The SOIB and CMS statuses underscore the necessity of implementing effective conservation measures to protect breeding habitats amid anthropogenic pressures. Water unavailability and nest tree unavailability in the sanctuaries are found to be the high degree threats to breeding waterbirds than others. This research provides critical baseline data for the forest department's future wetland management plans.

INTRODUCTION

Wetlands serve as crucial waterbird habitats, playing vital roles in feeding and breeding habitats; stop over sites and wintering grounds for migratory birds (*Chapman et al., 2001*; *Piersma & Lindström, 2004*; *Grimmett & Inskipp, 2007*; *Anand et al., 2023*). Any degradation of these habitats leads to a drop in the water table, disruptions in the food chain leading to declines in breeding and migratory waterbird populations (*Urfi, Sen & Megnathan, 2005*), posing detrimental impacts on the environment, ecosystems, and human well-being (*Kumar & Kankaujia, 2014*). Therefore, understanding the composition of bird communities is essential for identifying suitable local landscapes for avifaunal conservation and associated ecosystems (*Kattan & Franco, 2004*). Waterbirds play a crucial role in the nutrient cycles of wetlands, spanning various trophic levels, and act as bio-indicators (*Canterbury et al., 2000*; *Urfi, Sen & Megnathan, 2005*; *Sekercioglu, 2012*). Wetlands are highly productive ecosystems (*Paracuellos, 2006*) and various elements influence the composition of avifauna in wetland ecosystems (*Rajpar & Zakaria, 2010*), encompassing factors like wetland size (*Paracuellos, 2006*), water depth, duration, seasonal fluctuations (*Lagos et al., 2008*), water quality (*Hoyer & Caneld, 1994*). Factors like human-induced disturbances, habitat loss, habitat alterations negatively influence the waterbird diversity and abundance (*Craig & Barclay, 1992*; *Chawaka et al., 2017*; *Golzar et al., 2019*; *Halassi et al., 2022*). Approximately 64% of the world's wetlands have been lost since 1900, with the South Asian region experiencing even greater declines. Inland wetlands are vanishing more rapidly than coastal wetlands (*Ramsar Fact Sheet, 2014*). Numerous wetlands in India, including ones in Tamil Nadu whose 7% geographical area is wetlands, face the risk of degradation and loss due to expanding developmental and commercial activities (*SAC, 2011*; *Fraser & Keddy, 2005*). Lakes, reservoirs, rivers, tanks, and ponds are the main forms of wetland areas in Tamil Nadu state (*SAC, 2011*). Small tanks primarily built to store water for domestic consumption and irrigation (*Subramanya, 2005*), provide excellent feeding and nesting sites for colonial nesting birds.

On the Southeast coast of India, Point Calimere and Gulf of Mannar are two Important Bird and Biodiversity Areas (IBAs) in Tamil Nadu forming important stopover sites of Central Asian Flyway (CAF) for long distance migratory birds, along with Chitrangudi and Kanjirankulam bird sanctuaries which are Ramsar sites (*Islam & Rahmani, 2004*; *Rashiba et al., 2022*). Tamil Nadu state has the highest number of Ramsar sites ($n = 16$,

20% of total Ramsar sites in India) (*Tamil Nadu Wetland Mission, 2024*). Among 25 sanctuaries in the state, 15 are bird sanctuaries, among which 11 are heronries (Chitrangudi, Kanjirankulam, Karaivetti, Koonthankulam, Melselvanoor–Kelselvanoor, Udayamarthandpuram, Vaduvoor, Vellode, Vedanthangal, Karikili, and Vettangudi). Thirunelveli, Ramanthapuram, and Kancheepuram districts have the maximum numbers of heronries in Tamil Nadu, followed by Madurai, Chennai, and Nilgiris districts (*Subramanya, 2005*). Various avifaunal diversity studies on waterbirds have been done in Tamil Nadu, in Tiruppur (*Priya & Varunprasath, 2018*); central Tamil Nadu (*Krishnaraj & Mathesh, 2023*); Pallikaranai, Chennai (*Raj et al., 2010*); Karaivetti, Ariyalur (*Gokula, 2010*); Vaduvoor, Tiruvarur (*Gokula & Raj, 2011*); Samanatham, Madurai (*Byju et al., 2023a*). *Guptha et al. (2011)* studied 69 wetlands across eight districts of Tamil Nadu, where they recorded 53 wetland species.

In Ramanathapuram district, avian studies have historically focused on coastal birds (*Ali & Ripley, 1987*; *Balachandran, 1990*). Recent studies from the district include the avifaunal distribution of islands of the Gulf of Mannar (*Byju, Raveendran & Ravichandran, 2023b*), Valinokkam (*Byju et al., 2023c*), Karangadu mangroves (*Byju et al., 2023d*) and Melselvanoor–Kelselvanoor Bird Sanctuary (MKBS) (*Byju, Raveendran & Ravichandran, 2023e*). These one-year study sites are the two Ramsar sites, Kanjirankulam Bird Sanctuary (KBS) and Chitrangudi Bird Sanctuary (CBS), MKBS, Sakkarakottai Bird Sanctuary (SBS), and Therthangal Bird Sanctuary (TBS). Despite having the maximum number of bird sanctuaries in the Ramanathapuram region, there is no available literature on comprehensive study that assessed the avifaunal diversity, and seasonal patterns. There is a significant gap in understanding the waterbirds, and the breeding populations from these sanctuaries due to insufficient data hindering the development of effective conservation strategies tailored to the specific ecological needs of the waterbirds in the region as all these rainfed sanctuaries faced tree wilting due to anthropogenic stress, removal of water from the tanks for agricultural purposes affecting the waterbird population. To address this research gap, we pursued the following objectives. (i) To assess and compare the diversity and composition of bird species across the five sanctuaries; their residential status, Convention on the conservation of migratory species (CMS) status and State of India's Birds (SOIB) status; (ii) To investigate the breeding diversity of waterbirds and document the breeding season, abundance, and nesting preferences of abundant waterbird species from all sanctuaries; (iii) To assess the relationship between the area of the sanctuaries and diversity and richness of breeding waterbirds, testing the hypothesis that larger areas support high diversity and richness; (iv) To assess various threats to the breeding waterbirds and contribute towards the management plan of the forest department for conservation measures of the wetlands and its breeding waterbird species.

MATERIALS & METHODS

Study area

The study area included five bird sanctuaries from Tamil Nadu on the southeast coast of India. They are (i) Chitrangudi Bird Sanctuary (CBS) (9°19′N and 78°28′E) has
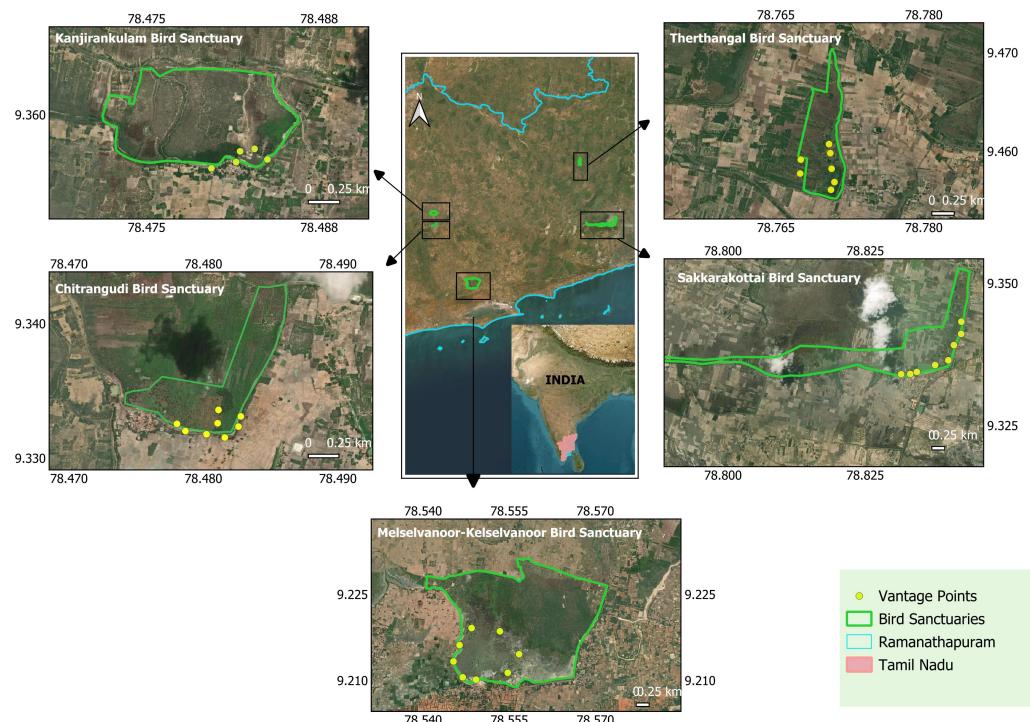
Figure 1 **Study areas and vantage points in all the five bird sanctuaries.** Study areas and vantage points in all the five bird sanctuaries of Ramanathapuram (map created using QGIS software with basemap ©ESRI Satellite).

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an area of 47.63 ha. (ii) Melselvanoor Kelaselvanoor Bird Sanctuary (MKBS) (9°13′–9°12′N and 78°32′–78°34′E) has a total ayacut area of 429.15 ha. (iii) Kanjirankulam Birds Sanctuary (KBS) (9°21′N and 78°30′E) has an area of 98 ha. (iv) Sakkarakottai Birds Sanctuary (SBS) (9°21′N and 78°48′E) has an estimated area of 230.49 ha. (v) Therthangal Bird Sanctuary (TBS) (9°27′N and 78°46′E) an area of 29.295 ha (Fig. 1). All the sanctuaries are seasonal water holding community tanks with one meter to five meters depth. Elevation of all sanctuaries ranges between 30 m to 100 m mean sea level. Between the tank embankments and the vegetation, there is approximately a 15–100 m wide water holding region. Agricultural lands surround the sanctuaries. The prominent tree, *Acacia nilotica* (Babul) offers conducive breeding and feeding grounds for the waterbirds. Besides this, trees like *Prosopis juliflora*, *Tamarindus indica*, *Ficus* spp., *Thespesia populnea*, *Albizzia amara*, and Palmyra *(Borassus flabellifer)* are also found (*Byju & Raveendran, 2023a*; *Byju & Raveendran, 2023b*; *Byju & Raveendran, 2024a*; *Byju & Raveendran, 2024b*; *Byju et al., 2024a*). The main habitat types observed in the sanctuaries included: Open-water habitat, agricultural land, trees like *Babul*, mesquite *Prosopis juliflora*, palmyra *Borassus flabellifer*, and tamarind *Tamarindus indica* trees on the bund bordering the wetland, grassland on the wetland area, and shrub habitat.

Three distinct seasons are experienced in all the sanctuary areas. The winter (November–February); summer (March–June); scanty rains (July–September); and monsoon (October–December) as monsoon and winter seasons overlap with an average rainfall of 350 mm to 900 mm annually. Most of the water collected in the tanks is from the Northeast monsoon. Ramanathapuram Wildlife Division gave verbal permission to conduct the work.

Data collection

A study on avifaunal diversity was conducted between April 2022 and March 2023. Twelve field visits (one per month) to assess the bird diversity, residential status, and breeding activity. Surveys were conducted in the morning (07.00 h–10.00 h) and the evening (16.00 h–19.00 h), during peak bird activity, following direct count and block count methods (*Bibby et al., 2000*; *Howes & Bakewell, 1989*). Three experienced observers and two field assistants conducted counts at vantage points: eight at CBS, five at KBS, seven at TBS, eight at SBS, and eight at MKBS separated by 100–200 m, depending on the landscape and visibility. Birds were counted for 15 min at each point, after a five-minute acclimation period. The observations recorded while moving from one scanning point to another were entered as incidental records. Birds were observed using Nikon binoculars (10×50) and photographed using a Canon 100–400 mm lens. Breeding activity of waterbirds was documented through fortnightly surveys, during the breeding season (the time the birds occupied the nests during incubation). Identification of active nests was achieved through monitoring of flights of adult birds between nests and feeding grounds. The number of nests was estimated employing standard methods such as ground counts or nest counts using binoculars and spotting scopes (*Gibbs et al., 1988*; *Dodd & Murphy, 1995*). Other methods were impractical for sites with few nests or those completely inaccessible, therefore we used perimeter counts based on visible nests and observed foraging flights from the colony boundary (*Dodd & Murphy, 1995*). The common name, scientific name, IUCN Red List status, and migratory status are followed (*Praveen & Jayapal, 2023*). Species residential status as Resident (R), Passage Migrant (PM), or Winter Visitor (WV) depending on the temporal patterns and duration of occurrence (*Grimmett et al., 2011*) while global Red List status (*IUCN, 2024*), Convention of the Conservation of Migratory Species of Wild Animals (CMS) protection status (*The Convention on Migratory Species, 2024*) and national bird abundance trends (*State of India's Birds, 2023*) were assessed for the recorded species. According to SOIB, the current population trend of the bird species in India is the average annual change in the species abundance over the past eight years (2015–2022). Different categories of current population trend indices are, Insufficient Data means too few reports, Trend Inconclusive means 95% confidence interval >2%, Rapid Decline is decline >2.7%, Decline is >1.1%, Increase is >0.9% and Rapid Increase is >1.6% (*State of India's Birds, 2023*). Potential threats to birds based on impact of threat index across sanctuaries were noted for management recommendations (*Borgman, 2011*).

Data processing

Alpha diversity Indices like Shannon-Weiner Diversity Index (H), Pielou's Evenness Index, Menhinick's Index for richness and Dominance Index (D) which implies presence of

one or few dominating species in the site, were performed to understand the overall community structure of breeding waterbirds in each sanctuary (*Kitikidou et al., 2024*). Whittaker's Beta-diversity Index measures the similarity in diversity between the study sites (*Whittaker, 1972*). Kruskal–Wallis test was performed to understand whether there was a statistically significant difference in the abundance of breeding waterbirds among the five sanctuaries (*Kruskal & Wallis, 1952*). The correlation between sanctuary area and the breeding waterbirds diversity was confirmed by Pearson correlation analysis. Further, principal component analysis (PCA) was performed to assess whether some waterbird families were more strongly associated with specific sanctuaries, using abundances of each waterbird family recorded in the sanctuaries as a variable (*Jolliffe, 2002*). Bray–Curtis cluster analysis, and individual rarefaction analysis were done for breeding waterbirds to understand the similarity in diversity and species accumulation among the sanctuaries and overall comprehensive community structure for each bird sanctuary (*Gotelli & Colwell, 2001*). All the analysis was done using Paleontological Statistics (PAST) Software version 4.17. Heatmap of species abundnace and other graphs were plotted using R version 4.4.1. Threats to breeding waterbirds were analysed for their extent of impact based on severity score, scope score and irreversibility score of the threat categories. Severity was assessed based on potential impacts of the threats or degrees of damage to the species; scope score was assessed based on the geographical extent to which the threat affects the landscape, whether the threat impacts the entire sanctuary, half of the sanctuary or create localized effect on a small portion of the sanctuary; based on whether the effects of these threats can be reversed or they create a permanent damage, irreversibility score was assessed. Four-scale measurements were used for all these scores as follows: 4 = extremely high, 3 = high, 2 = medium, and 1 = low. Total was calculated using the formula: Total = 2*(severity + scope) + irreversibility (*Margoluis & Salafsky, 1998*; *Rajashekara & Venkatesha, 2017*). Based on the results, threats were classified as High, Medium, and Low categories.

RESULTS

Avifauna

We recorded 131 species of birds compiled from all the sanctuaries together. The maximum number of bird species was recorded from KBS (123) followed by CBS (122), MKBS (117), SBS (116), and TBS (96). Based on the residential status, Resident birds (R) were predominant with 78% ($n = 102$) of the total species recorded whereas, Winter Visitors (WV) contributed 21% ($n = 28$). One species, Rosy Starling *Pastor roseus*, a Passage Migrant (PM) was common to all the sanctuaries. Table 1 summarizes the avifaunal list (order & family wise) compiled from all five sanctuaries with residential status and IUCN Red List categories. Twenty-seven bird species in the sanctuaries are protected under the CMS (Table 2). The avifaunal species listed in Appendix II of CMS correspond to migratory species that need international cooperation and international agreements for conservation and management (*The Convention on Migratory Species, 2024*). The national trends of the avifauna recorded from all sanctuaries, 40.4% of species populations are stable; rapid increase (4.5%); increase (4.5%); decline (12.9%); rapid decline (11.4%); trend inconclusive (23.6%) as per assessment by *State of India's Birds (2023)* (Table 3).

Table 1 Avifaunal data depicting species, families, residents, migrants and IUCN status from the five sanctuaries.

	CBS	KBS	MKBS	SBS	TBS
Total species	122	123	117	116	96
Number of orders	19	19	19	19	18
Number of families	53	53	52	52	45
% of Residents (n = number of species)	80 ($n = 98$)	73 ($n = 98$)	83 ($n = 98$)	83 ($n = 96$)	86 ($n = 83$)
% of Winter migrants (n = number of species)	19 ($n = 23$)	19 ($n = 24$)	15 ($n = 18$)	16 ($n = 19$)	12 ($n = 12$)
Least concerned species[*]	120	121	115	114	94
Near threatened species[*]	1	1	1	1	2
Vulnerable species[*]	1	1	1	1	0

Notes.
CBS, Chitrangudi Bird Sanctuary; KBS, Kanjirankulam Birds Sanctuary; MKBS, Melselvanoor Kelaselvanoor Bird Sanctuary; SBS, Sakkarakottai Bird Sanctuary; TBS, Therthangal Bird Sanctuary.
*Classified according to IUCN Red List category.

Except for some species, most bird species observed are common to all the five sanctuaries. Passeriformes order was predominant with 22 families and 41 species in CBS, MKBS, KBS, and SBS, except for TBS which is only represented by 18 families and 29 species. Family Ardeidae predominated in all the sanctuaries (represented by 11 species in CBS, MKBS, and KBS; 10 in SBS and TBS respectively). According to the IUCN Red List status, two Near Threatened species namely, Asian Woolly-necked Stork *Ciconia episcopus* (only recorded in TBS) and, Spot-billed Pelican *Pelecanus philippensis* and one Vulnerable species Indian Spotted Eagle *Clanga hastata* are commonly found in all the five sanctuaries. Migratory species such as Northern Shoveler *Spatula clypeata*, Baillon's Crake *Zapornia pusilla*, and resident birds like Watercock *Gallicrex cinerea*, were recorded only in TBS. Similarly, in KBS, we recorded the winter visitor Green Sandpiper *Tringa ocropus* which was not recorded from other sanctuaries. Table 3 summarizes the avifaunal list of all sanctuaries depicting the presence or absence of species with SOIB trends.

Breeding waterbird diversity

We recorded 55 waterbird species recorded from all sanctuaries. Out of which 51% of species ($n = 28$) are breeding in these wetlands. Grey Heron *Ardea cinerea*, Black-crowned Night Heron *Nycticorax nycticorax*, Purple Heron *Ardea purpurea*, Asian Openbill *Aanastomus oscitans*, Black-headed Ibis, and Little Cormorant *Microcarbo niger* were found to breed in all the five sites. Five species namely Common Moorhen *Gallinula chloropus*, Pheasant-tailed Jacana *Hydrophasianus chirurgus*, Grey Headed Swamphen *Porphyrio poliocephalus*, White-breasted Waterhen *Amaurornis phoenicurus,* and Little Grebe *Tachybaptus ruficollis* were least common, found to breed only in SBS (Fig. 2). Except for SBS, Asian Openbill nested predominantly in the other four sanctuaries followed by Painted Stork, Black-headed Ibis, and Spot-billed Pelican. It was observed in all the sanctuaries that Spot-billed Pelicans and Painted Storks occupy the large *Acacia nilotica* trees which are dominantly cultivated as fuel wood for nearby villagers in all the tanks. Trees like *Prosopis juliflora* are occupied by Asian Openbill while Black-headed Ibis occupy the canopy. Cormorants, egrets, and pond

Table 2 Convention For Migratory Species of Wild Animals. Bird Species which are protected under Convention For Migratory Species of Wild Animals (CMS).

S. No	Species	CMS status
1	Purple Heron	Appendix II
2	Eurasian Wigeon	Appendix II
3	Common Teal	Appendix II
4	Northern Pintail	Appendix II
5	Knob-billed Duck	Appendix II
6	Garganey	Appendix II
7	Northern Shoveler	Appendix II
8	Eurasian Coot	Appendix II
9	Baillon's Crake	Appendix II
10	Common Redshank	Appendix II
11	Common Snipe	Appendix II
12	Wood Sandpiper	Appendix II
13	Common Sandpiper	Appendix II
14	Marsh Sandpiper	Appendix II
15	Green Sandpiper	Appendix II
16	Eurasian Spoonbill	Appendix II
17	Glossy Ibis	Appendix II
18	Great Egret	Appendix II
19	Little Stint	Appendix II
20	Temminck's Stint	Appendix II
21	Black-winged Stilt	Appendix II
22	Common Kestrel	Appendix II
23	Black Kite	Appendix II
24	Booted Eagle	Appendix II
25	Shikra	Appendix II
26	Oriental Honey Buzzard	Appendix II
27	Western Marsh Harrier	Appendix II

herons occupy the lower strata of the habitat. Abundance of all breeding waterbird species in each sanctuary in the breeding months is represented in Fig. 3. The overall trend in the monthly abundance of breeding waterbirds in each sanctuary showed that in TBS, highest abundance was recorded in November and December, whereas in SBS it was in January and February. In MKBS, CBS and KBS, the abundance increased slightly from October to November and remained almost similar until February (Fig. 4).

Chitrangudi Bird Sanctuary

CBS supports 42 species of waterbirds and 13 species are recorded to be breeding. The waterbirds breeding season (incubating in nests) started from November 2022 to February 2023. For two species, Glossy Ibis and Oriental Darter, the breeding season started in December 2022.

Table 3 Checklist of all the five bird sanctuaries. Avifaunal checklist of all the five bird sanctuaries with migration, IUCN and SOIB status.

Scientific name	Common name	Migration status	IUCN status	Species recorded					Population trend in India (*State of India's Birds, 2023*)
				CBS	KBS	MKBS	TBS	SBS	
Order: Galliformes									
Family: Phasianidae									
Pavo cristatus	Indian Peafowl	R	LC	*	*	*	*	*	Rapid Increase
Francolinus pondicerianus	Grey Francolin	R	LC	*	*	*	*	*	Increase
Order: Anseriformes									
Family: Anatidae									
Anas Penelope	Eurasian Wigeon	WV	LC	*	*	-	-	*	Decline
Anas crecca	Common Teal	WV	LC	*	*	*	-	*	Rapid Decline
Anas acuta	Northern Pintail	WV	LC	*	*	*	-	*	Rapid Decline
Sarkidiornis melanotos	Knob-billed Duck	R	LC	*	*	*	*	*	Trend Inconclusive
Anas poecilorhyncha	Indian Spot-billed Duck	R	LC	*	*	*	*	*	Stable
Spatula querquedula	Garganey	WV	LC	*	*	*	*	*	Rapid Decline
Anser indicus	Bar-headed Goose	WV	LC	*	*	-	-	-	Decline
Dendrocygna javanica	Lesser Whistling Duck	R	LC	-	-	-	*	*	Stable
Spatula clypeata	Northern Shoveler	WV	LC	-	-	-	*	-	Rapid Decline
Order: Podicipediformes									
Family: Podicipedidae									
Tachybaptus ruficollis	Little Grebe	R	LC	*	*	*	*	*	Trend Inconclusive
Order: Piciformes									
Family: Picidae									
Dinopium benghalense	Black-rumped Flameback	R	LC	*	*	*	*	*	Trend Inconclusive
Family:Megalaimidae									
Psilopogon haemacephalus	Coppersmith Barbet	R	LC	*	*	*	*	*	Stable
Order: Bucerotiformes									
Family: Upupidae									
Upupa epops	Common Hoopoe	R	LC	*	*	*	*	*	Trend Inconclusive
Order: Coraciiformes									
Family: Coraciidae									
Coracias benghalensis	Indian Roller	R	LC	*	*	*	*	*	Decline
Family: Alcedinidae									
Ceryle rudis	Pied Kingfisher	R	LC	*	*	*	-	*	Decline
Halcyon smyrnensis	White-throated Kingfisher	R	LC	*	*	*	*	*	Trend Inconclusive
Alcedo atthis	Common Kingfisher	R	LC	*	*	*	*	*	Trend Inconclusive
Halcyon pileata	Black-capped Kingfisher	WV	LC	*	*	*	-	-	Rapid Decline
Family: Meropidae									
Merops orientalis	Green Bee-eater	R	LC	*	*	*	*	*	Stable
Merops philippinus	Blue-tailed Bee- eater	WV	LC	*	*	*	*	*	Rapid Increase
Order: Cuculiformes									

Table 3 (*continued*)

Scientific name	Common name	Migration status	IUCN status	Species recorded					Population trend in India (*State of India's Birds, 2023*)
				CBS	KBS	MKBS	TBS	SBS	
Family: Cuculidae									
Centropus sinensis	Greater Coucal	R	LC	*	*	*	*	*	Rapid Increase
Eudynamys scolopaceus	Asian Koel	R	LC	*	*	*	*	*	Increase
Clamator jacobinus	Pied Cuckoo	R	LC	*	*	*	*	*	Stable
Hierrococcyx varius	Common Hawk Cuckoo	R	LC	*	*	*	*	*	Rapid Increase
Order: Psittaciformes									
Family: Psittacidae									
Psittacula krameri	Rose-ringed Parakeet	R	LC	*	*	*	*	*	Trend Inconclusive
Order: Strigiformes									
Family: Strigidae									
Athene brama	Spotted Owlet	R	LC	*	*	*	*	*	Not Available
Order: Columbiformes									
Family: Columbidae									
Columba livia	Rock Pigeon	R	LC	*	*	*	*	*	Increase
Streptopelia decaocto	Eurasian Collared-Dove	R	LC	*	*	*	*	*	Increase
Spilopelia senegalensis	Laughing Dove	R	LC	*	*	*	*	*	Trend Inconclusive
Spilopelia chinensis	Spotted Dove	R	LC	*	*	*	*	*	Increase
Order: Apodiformes									
Family: Apodidae									
Cypsiurus balasiensis	Asian Palm- swift	R	LC	*	*	*	*	*	Insufficient Data
Apus melba	Alpine Swift	R	LC	*	*	*	-	*	Stable
Order: Gruiformes									
Family: Rallidae									
Gallinula chloropus	Eurasian Moorhen	R	LC	*	*	*	-	*	Stable
Porphyrio Poliocephalus	Grey-headed Swamphen	R	LC	*	*	*	*	*	Stable
Amaurornis phoenicurus	White-breasted Waterhen	R	LC	*	*	*	*	*	Trend Inconclusive
Fulica atra	Eurasian Coot	R	LC	*	*	*	*	*	Decline
Zapornia pusilla	Baillon's Crake	WV	LC	-	-	-	*	-	Rapid Decline
Gallicrex cinerea	Watercock	R	LC	-	-	-	*	-	Stable
Order: Charadriiformes									
Family: Rostratulidae									
Rostratula benghalensis	Greater Painted Snipe	WV	LC	*	*	-	-	-	Stable
Family: Scolopacidae									
Tringa totanus	Common Redshank	WV	LC	*	*	-	-	*	Decline
Gallinago gallinago	Common Snipe	WV	LC	*	*	-	-	*	Trend Inconclusive
Tringa glareola	Wood Sandpiper	WV	LC	*	*	*	*	*	Decline
Actitis hypoleucos	Common Sandpiper	WV	LC	*	*	*	*	*	Decline
Tringa stagnatilis	Marsh Sandpiper	WV	LC	*	-	-	-	*	Rapid Decline
Tringa ocropus	Green Sandpiper	WV	LC	-	*	-	-	-	Stable
Calidris minuta	Little Stint	WV	LC	-	*	*	-	-	Rapid Decline
Calidris temminickii	Temminck's Stint	WV	LC	-	*	*	-	-	Trend Inconclusive

Table 3 (*continued*)

Scientific name	Common name	Migration status	IUCN status	Species recorded					Population trend in India (*State of India's Birds, 2023*)
				CBS	KBS	MKBS	TBS	SBS	
Family: Jacanidae									
Hydrophasianus chirurgus	Pheasant-tailed Jacana	R	LC	*	*	*	*	*	Decline
Family: Burhinidae									
Burhinus indicus	Indian Stone-curlew	R	LC	*	*	*	-	*	Insufficient data
Family: Charadriidae									
Charadrius dubius	Little Ringed Plover	WV	LC	*	*	*	-	*	Rapid Decline
Vanellus malabaricus	Yellow-wattled Lapwing	R	LC	*	*	*	-	*	Stable
Vanellus indicus	Red-wattled Lapwing	R	LC	*	*	*	*	*	Trend Inconclusive
Family: Recurvirostridae									
Himantopus himantopus	Black-winged Stilt	R	LC	*	*	*	*	*	Trend Inconclusive
Family: Laridae									
Chlidonias hybrida	Whiskered Tern	WV	LC	*	*	*	*	*	Rapid Decline
Order: Falconiformes									
Family: Falconidae									
Falco tinnunculus	Common Kestrel	WV	LC	*	*	*	-	*	Rapid Decline
Order: Accipitriformes									
Family: Accipitridae									
Milvus migrans	Black Kite	R	LC	*	*	*	-	*	Trend Inconclusive
Elanus caeruleus	Black-winged Kite	R	LC	*	*	*	*	*	Decline
Hieraaetus pennatus	Booted Eagle	WV	LC	*	*	*	*	*	Trend Inconclusive
Accipiter badius	Shikra	R	LC	*	*	*	*	*	Stable
Pernis ptilorhynchus	Oriental Honey Buzzard	R	LC	*	*	*	*	*	Stable
Clanga hastata	Indian Spotted Eagle	R	VU	*	*	*		*	Trend Inconclusive
Haliastur indus	Brahminy Kite	R	LC	*	*	*	*	*	Stable
Circus aeruginosus	Western Marsh Harrier	WV	LC	-	-	-	*	-	Decline
Order: Suliformes									
Family: Anhingidae									
Anhinga melanogaster	Oriental Darter	R	LC	*	*	*	*	*	Stable
Family: Phalacrocoracidae									
Microcarbo niger	Little Cormorant	R	LC	*	*	*	*	*	Stable
Phalacrocorax carbo	Great Cormorant	R	LC	*	*	*	*	*	Stable
Phalacrocorax fuscicollis	Indian Cormorant	R	LC	*	*	*	*	*	Trend Inconclusive
Order: Pelicaniformes									
Family: Ardeidae									
Lxobrychus sinensis	Yellow Bittern	R	LC	*	*	*	*	*	Trend Inconclusive
Ardea cinerea	Grey Heron	R	LC	*	*	*	*	*	Trend Inconclusive
Ardea purpurea	Purple Heron	R	LC	*	*	*	*	*	Stable
Egretta garzetta	Little Egret	R	LC	*	*	*	*	*	Trend Inconclusive
Bubulcus ibis	Cattle Egret	R	LC	*	*	*	*	*	Stable
Ardea alba	Great Egret	R	LC	*	*	*	*	*	Trend Inconclusive
Ardea intermedia	Intermediate Egret	R	LC	*	*	*	*	*	Trend Inconclusive
Ardeola grayii	Indian Pond Heron	R	LC	*	*	*	*	*	Stable
Nycticorax nycticorax	Black-crowned Night Heron	R	LC	*	*	*	*	*	Stable

Table 3 (*continued*)

Scientific name	Common name	Migration status	IUCN status	Species recorded					Population trend in India (*State of India's Birds, 2023*)
				CBS	KBS	MKBS	TBS	SBS	
Butorides striata	Striated Heron	R	LC	*	*	*	*	*	Trend Inconclusive
Egretta gularis	Western Reef Heron	R	LC	*	*	*	-	-	Decline
Family: Threskiornithidae									
Threskiornis melanocephalus	Black-headed Ibis	R	LC	*	*	*	*	*	Stable
Plegadis falcinellus	Glossy Ibis	R	LC	*	*	*	*	*	Stable
Pseudibis papillosa	Red-naped Ibis	R	LC	*	*	*	*	*	Stable
Platalea leucorodia	Eurasian Spoonbill	R	LC	*	*	*	*	-	Rapid Decline
Family: Pelecanidae									
Pelecanus philippensis	Spot-billed Pelican	R	NT	*	*	*	*	*	Rapid Decline
Order: Ciconiiformes									
Family: Ciconiidae									
Anastomus oscitans	Asian Openbill	R	LC	*	*	*	*	*	Trend Inconclusive
Mycteria leucocephala	Painted Stork	R	LC	*	*	*	*	*	Decline
Ciconia episcopus	Asian Woolly-necked Stork	R	NT	-	-	-	*	-	Decline
Order: Passeriformes									
Family: Campephagidae									
Coracina macei	Large Cuckooshrike	R	LC	*	*	*	-	*	Stable
Family: Oriolidae									
Oriolus kundoo	Indian Golden Oriole	WV	LC	*	*	*	-	*	Stable
Family: Artamidae									
Artamus fuscus	Ashy Wood Swallow	R	LC	*	*	*	*	*	Stable
Family: Vanghidae									
Tephrodornis pondicerianus	Common Woodshrike	R	LC	*	*	*	-	*	Stable
Family: Laniidae									
Lanius vittatus	Bay-backed Shrike	R	LC	*	*	*	-	*	Stable
Lanius cristatus	Brown Shrike	WV	LC	*	*	*	*	*	Stable
Lanius schach	Long-tailed Shrike			-	-	-	*	-	Stable
Family: Dicruridae									
Dicrurus macrocercus	Black Drongo	R	LC	*	*	*	*	*	Stable
Family: Monarchidae									
Terpsiphone paradisi	Indian Paradise-flycatcher	R	LC	*	*	*	-	*	Stable
Family: Corvidae									
Dendrocitta vagabunda	Rufous Treepie	R	LC	*	*	*	*	*	Stable
Corvus macrorhynchos	Indian Jungle Crow	R	LC	*	*	*	*	*	Stable
Corvus splendens	House Crow	R	LC	*	*	*	*	*	Trend Inconclusive
Family: Sturnidae									
Acridotheres tristis	Common Myna	R	LC	*	*	*	*	*	Stable
Pastor roseus	Rosy Starling	PM	LC	*	*	*	*	*	Rapid Decline
Sturnia pagodarum	Brahminy Starling	R	LC	*	*	*	-	*	Trend Inconclusive

Table 3 (continued)

Scientific name	Common name	Migration status	IUCN status	Species recorded					Population trend in India (*State of India's Birds, 2023*)
				CBS	KBS	MKBS	TBS	SBS	
Family: Hirundinidae									
Cecropis daurica	Red-rumped Swallow	R	LC	*	*	*	-	*	Stable
Hirundo rustica	Barn Swallow	WV	LC	*	*	*	*	*	Decline
Family: Pycnonotidae									
Pycnonotus cafer	Red-vented Bulbul	R	LC	*	*	*	*	*	Trend Inconclusive
Family: Timaliidae									
Turdoides affinis	Yellow-billed Babbler	R	LC	*	*	*	*	*	Stable
Turdoides malcolmi	Large Grey Babbler	R	LC	*	*	*	-	*	Stable
Family: Cisticolidae									
Prinia socialis	Ashy Prinia	R	LC	*	*	*	*	*	Increase
Prinia inornata	Plain Prinia	R	LC	*	*	*	*	*	Stable
Orthotomus sutorius	Common Tailorbird	R	LC	*	*	*	*	*	Rapid Increase
Cisticola juncidis	Zitting Cisticola	R	LC	*	*	*	*	*	Stable
Family: Acrocephalidae									
Acrocephalus dumetorum	Blyth's Reed Warbler	WV	LC	*	*	*	*	*	Stable
Family: Alaudidae									
Eremopterix griseus	Ashy-crowned Sparrow Lark	R	LC	*	*	*	-	*	Trend Inconclusive
Galerida cristata	Jerdon's Bushlark	R	LC	*	*	*	*	*	Stable
Alauda gulgula	Oriental Skylark	R	LC	*	*	*	-	*	Rapid Decline
Family: Muscicapidae									
Muscicapa dauurica	Asian Brown Flycatcher	WV	LC	*	*	*	-	*	Stable
Copsychus fulicatus	Indian Robin	R	LC	*	*	*	*	*	Stable
Copsychus saularis	Oriental Magpie Robin	R	LC	*	*	*	*	*	Stable
Saxicola caprata	Pied Bushchat	R	LC	-	-	-	*	-	Stable
Family: Nectariniidae									
Cinnyris lotenius	Loten's Sunbird	R	LC	*	*	*	-	*	Rapid Increase
Cinnyris asiaticus	Purple-rumped Sunbird	R	LC	*	*	*	*	*	Trend Inconclusive
Cinnyris asiaticus	Purple Sunbird	R	LC	*	*	*	*	*	Trend Inconclusive
Family: Ploceidae									
Ploceus philippinus	Baya Weaver	R	LC	*	*	*	*	*	Stable
Family: Estrildidae									
Euodice malabarica	Indian Silverbill	R	LC	*	*	*	*	*	Trend Inconclusive
Lonchura malacca	Tricoloured Munia	R	LC	*	*	*	-	*	Stable
Family: Dicaeidae									
Dicaeum concolor	Pale-billed Flowerpecker	R	LC	*	*	*	*	*	Stable
Family: Passeridae									
Passer domesticus	House Sparrow	R	LC	*	*	*	*	*	Decline
Gymnoris xanthocollis	Yellow-throated Sparrow	R	LC	*	*	*	-	*	Stable
Family: Motacillidae									
Motacilla maderaspatensis	White-browed Wagtail	R	LC	*	*	*	*	*	Stable
Anthus rufulus	Paddyfield Pipit	R	LC	*	*	*	*	*	Decline

Notes.
*Presence.
⁻Absence.
R, Resident; WV, Winter visitor; PM, Passage migrant; CR, Critically Endangered; EN, Endangered; LC, Least Concern; NT, Near Threatened; VU, Vulnerable.
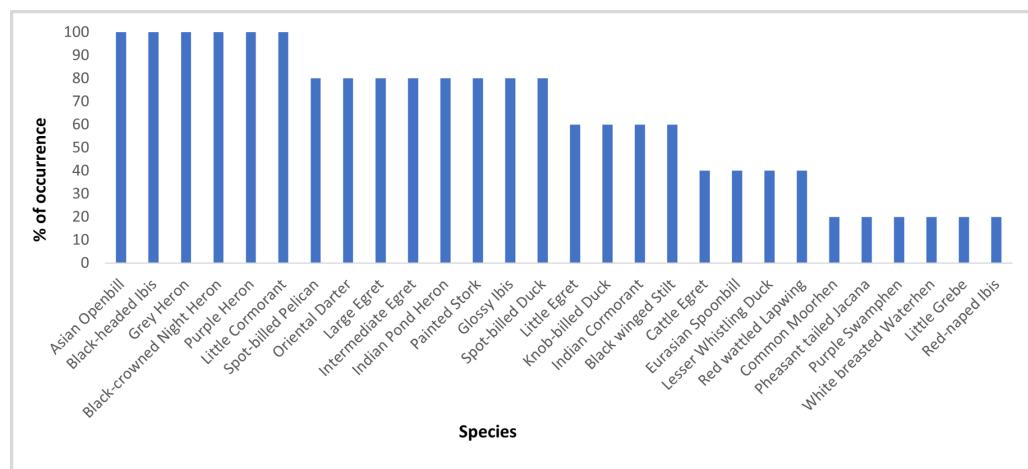
Figure 2 Breeding waterbirds in sanctuaries. Percentage of occurrence of breeding waterbirds in all the sanctuaries.

Full-size 🖼 DOI: 10.7717/peerj.18899/fig-2

Figure 3 Abundance of waterbirds. Monthly abundance of breeding waterbirds in each sanctuary.

Full-size 🖼 DOI: 10.7717/peerj.18899/fig-3

Kanjirankulam Bird Sanctuary

In KBS, 49 species of waterbirds were recorded and 14 species are breeding. For all the species breeding season starts from November 2022 and extends until February 2023 except for Spot-billed Duck and Knob-billed Duck which breeds during January and February 2023. Interestingly, Oriental Darter, Cattle Egret *Bubulcus ibis*, Little Egret, Glossy Ibis *Plegadis falcinellus*, Eurasian Spoonbill and Black-winged Stilt *Himantopus himantopus* which were found to nest at the nearby sanctuaries were not reported from here.
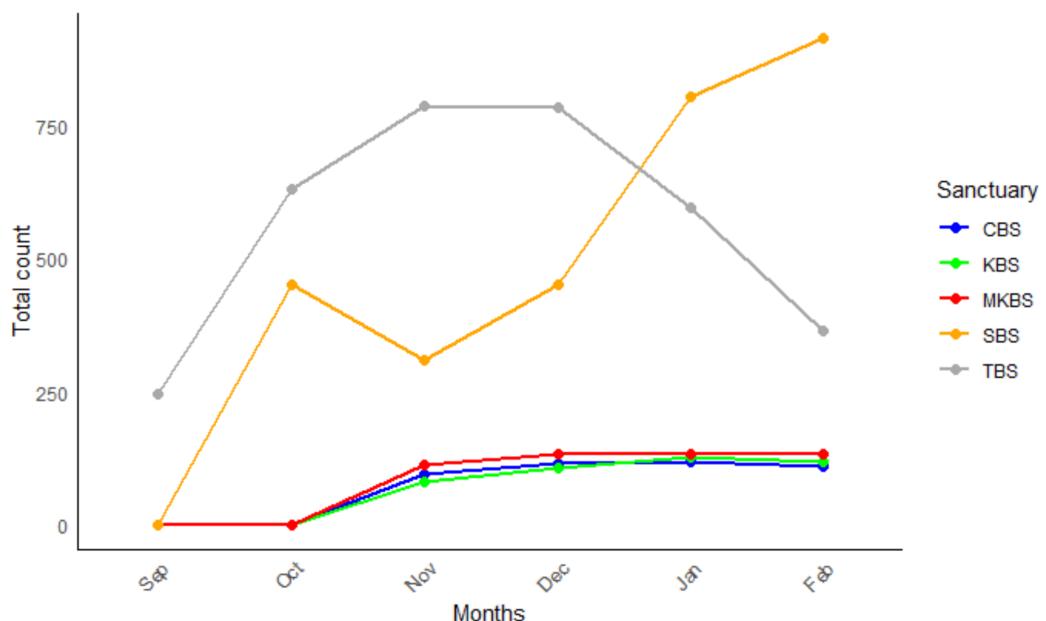
Figure 4 **Monthly abundance of breeding waterbirds.** Trend in monthly abundance of breeding waterbirds across five sanctuaries.

Full-size 🖻 DOI: 10.7717/peerj.18899/fig-4

Melselvanoor–Kelselvanoor Bird Sanctuary

MKBS provided a breeding habitat for 19 waterbird species. The breeding season starts in November 2022 and extends until February 2023 for all the species with no exception. Four species—Oriental Darter, Painted Stork, Black-headed Ibis, and Spot-billed Pelican—nest together in this sanctuary.

Sakkarakottai Bird Sanctuary

SBS recorded 43 species of waterbirds and 17 species breed here. The breeding season in this sanctuary is from October 2022 to February 2023.

Therthangal Bird Sanctuary

TBS recorded 40 species of waterbirds and 23 breeds here. The breeding season (birds incubating in nests) started in September 2022 and extended until February 2023. Three species, like Black-headed Ibis, Oriental Darter, and Spot-bellied Pelican, nest together in this sanctuary. Red-naped Ibis is found to breed only in TBS.

Community structure of breeding waterbirds in the five sanctuaries

The Shannon-Weiner Index (H) revealed the highest breeding waterbird diversity at MKBS (2.54) followed by KBS (2.39), SBS (2.3), CBS (2.29), and the lowest at TBS (2.23). Dominance indices indicated balanced communities in CBS, KBS, and MKBS, while SBS and TBS, were dominated by a few species like Asian Open-bill, Painted Stork and Spot-billed Pelican. The Evenness Index revealed high evenness in CBS (0.7) and KBS (0.7), followed by MKBS (0.6), SBS (0.5), and TBS (0.4). Menhinick's Index ranked MKBS highest in species richness (0.8), followed by CBS (0.6) and KBS (0.6), with SBS and
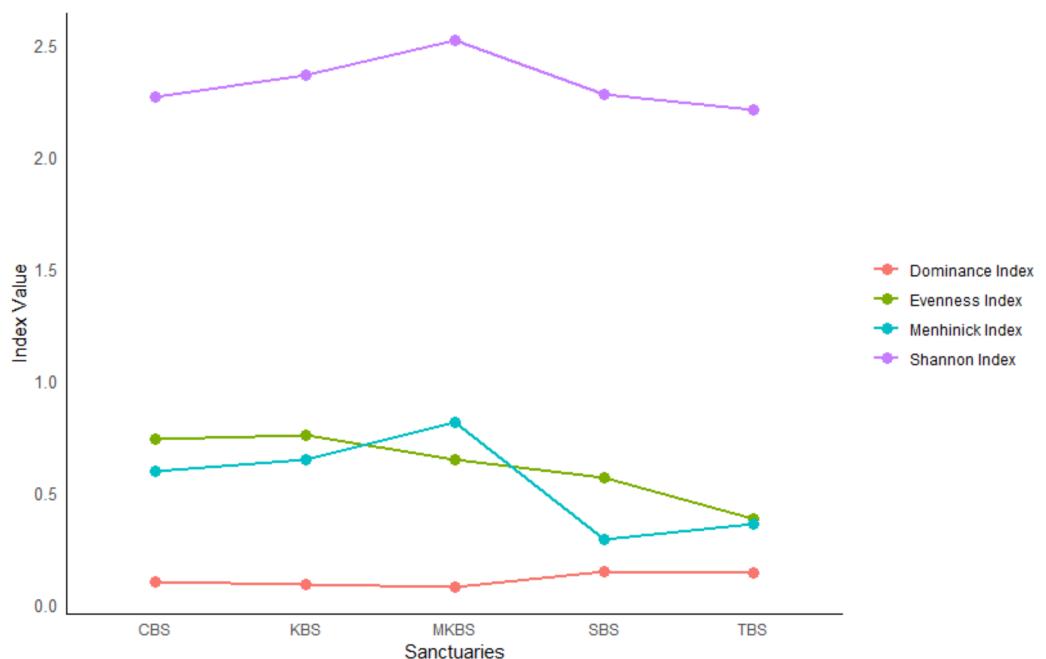
Figure 5 Diversity indices for waterbirds. Alpha diversity indices for breeding waterbirds in the sanctuaries.

Full-size 🖼 DOI: 10.7717/peerj.18899/fig-5

Table 4 Whittaker beta diversity profile of the sanctuaries in pairs.

	CBS	KBS	MKBS	SBS	TBS
CBS	0	0.25926	0.1875	0.6	0.27778
KBS	0.25926	0	0.21212	0.48387	0.24324
MKBS	0.1875	0.21212	0	0.5	0.095238
SBS	0.6	0.48387	0.5	0	0.4
TBS	0.27778	0.24324	0.095238	0.4	0

TBS showing the lowest richness (0.3) (Fig. 5 and Table S1). Overall, MKBS exhibited the highest diversity, and species richness with low dominance, whereas, TBS showed the lowest diversity, richness, and evenness dominated by a few species. These indices together provide a comprehensive view of the community structure for each bird sanctuary. Whittaker's beta diversity profile revealed that CBS and KBS are highly similar to MKBS. MKBS and TBS showed high similarity in diversity with each other. SBS showed distinctness in diversity and more similarity to TBS than to other sanctuaries (Table 4). In general, lower values in Whittaker's beta-diversity index indicate high similarity between the sites. Kruskal–Wallis test showed that there is no statistically significant difference ($p = 0.406 > 0.05$) in breeding waterbird diversity and richness among the sanctuaries. Further, the positive correlation between the area of the sanctuaries to the breeding waterbird diversity ($r = 0.8$, $p = 0.074$) and richness ($r = 0.4$, $p = 0.424$) was confirmed by Pearson correlation analysis although the correlation was not statistically significant.
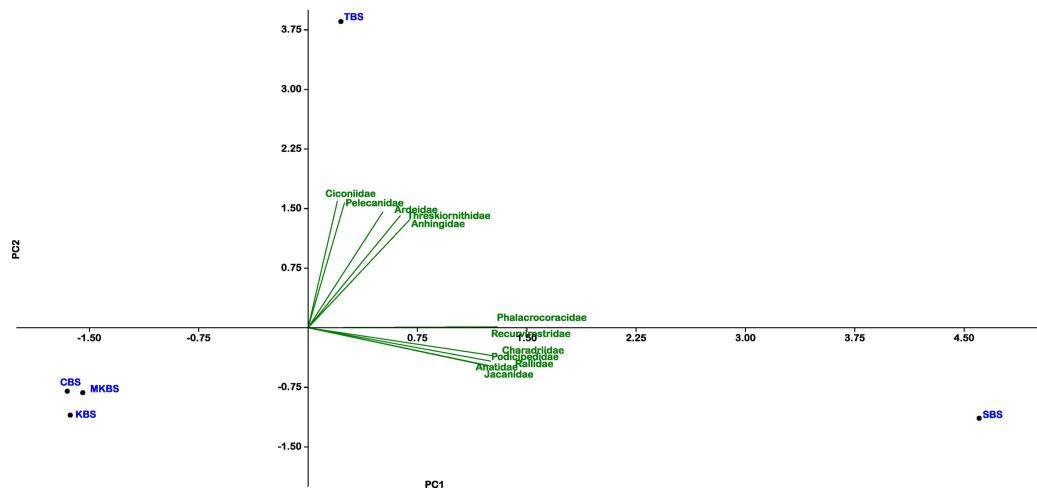
Figure 6 Principal component analysis plot of various breeding waterbird families and sanctuaries.

Full-size ⬚ DOI: 10.7717/peerj.18899/fig-6

Table 5 Principal component analysis (Eigenvalues and variance values).

PC	Eigenvalue	% variance
1	7.25489	60.457
2	4.66775	38.898
3	0.06002	0.50017
4	0.017339	0.14449

The PCA analysis showed the association of families like Ciconiidae, Pelecanidae, Anhingidae, Ardeidae, Threskiornithidae specifically within TBS, whereas families Jacanidae, Anatidae, Rallidae, Podicipedidae, Phalacrocoracidae and Recurvirostridae more associated with SBS and comparatively less to TBS. CBS, MKBS and KBS did not show specific associations with any particular families and showed a negative correlation with other families (Fig. 6). Eigenvalues of the components are given in Table 5. Rarefaction curves (Fig. 7) indicated TBS had the highest curve, (20 species, 3,500 individuals) suggesting further sampling may uncover more species. MKBS had 19 taxa, and SBS, though lower in richness (17 taxa), appeared sufficiently sampled. KBS and CBS showed the lowest species richness with only 13 and 14 taxa respectively, and fewer than 500 individuals. Bray–Curtis cluster analysis (Fig. 8) showed SBS and TBS shared the most similar species, while KBS and MKBS formed a closely related cluster. CBS is closely related to the cluster of KBS and MKBS. The largest dissimilarity is between the SBS and TBS and the combined cluster of CBS, KBS, and MKBS.

Potential threats

The present study recorded potential threats to the wetlands due to anthropogenic activities. Threats were categorized to assess the severity on the breeding waterbirds in all the sanctuaries. Water unavailability and nesting tree unavailability were the high ranked threats to the breeding waterbirds. Firewood collection, recreation and other human
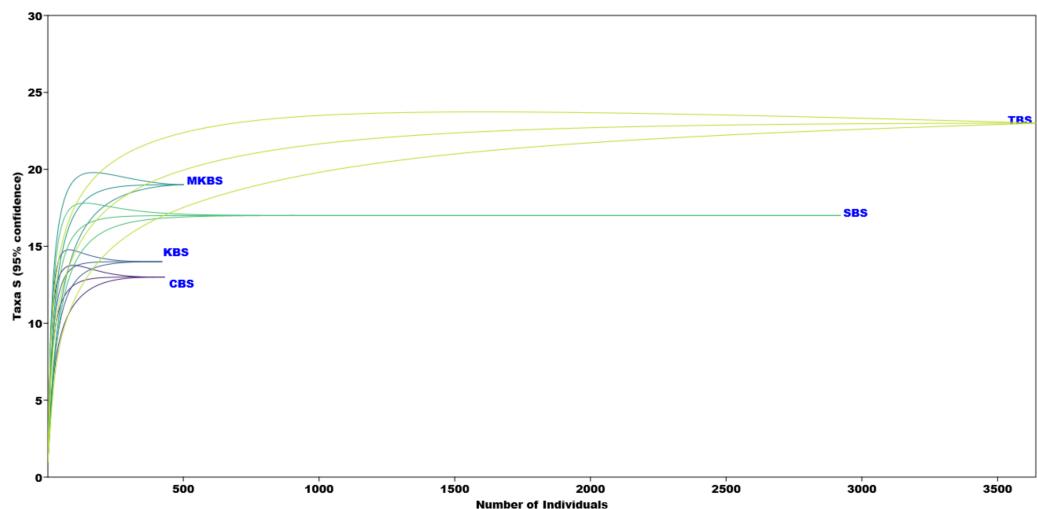
Figure 7 Individual rarefaction curve of the five sanctuaries.
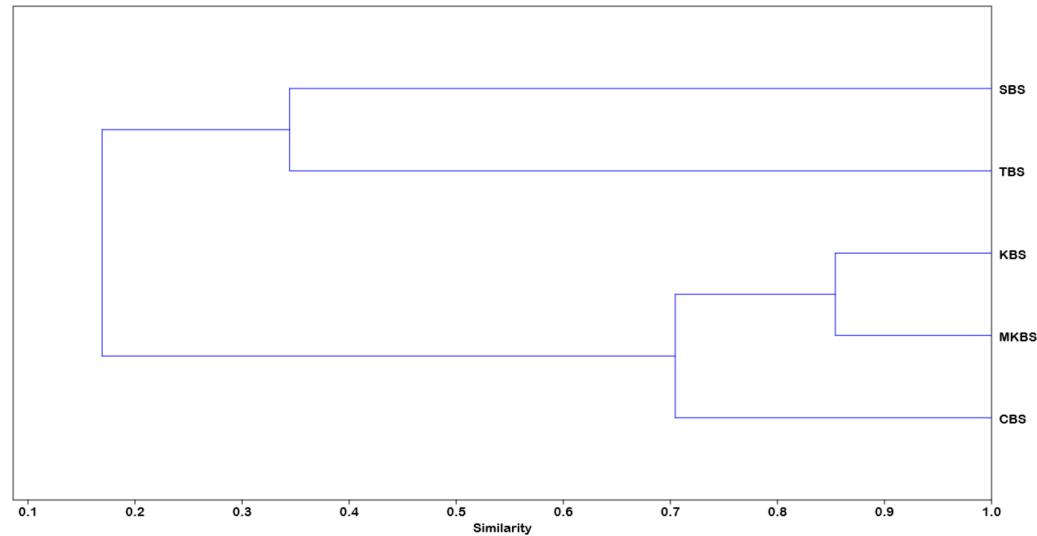
Figure 8 Cluster analysis of the sanctuaries based on Bray–Curtis similarity index.

disturbances were the medium category threats whereas livestock grazing, presence of invasive species, overfishing and feral dogs were the low impact threats, considering the severity, extent of impact and degree of irreversibility of the damage (Table S2).

DISCUSSION

This study provided a comprehensive assessment of the avifaunal diversity across five bird sanctuaries, emphasizing the importance of these wetlands in supporting a rich diversity of bird species, particularly waterbirds. The study recorded 131 bird species across five sanctuaries, with the highest species richness observed in MKBS, followed by CBS, KBS,

Byju et al. (2025), *PeerJ*, DOI 10.7717/peerj.18899

18/30

SBS, and TBS. These wetlands play a crucial role in supporting diverse bird populations as evident form our results, particularly waterbirds with 51% being wetland-dependent and 21% winter visitors highlighting their biodiversity importance (*BirdLife International, 2017*; *Ma et al., 2010*). Passeriformes dominated in CBS, MKBS, KBS, and SBS, consistent with global patterns as the most diverse avian order (*Grimmett et al., 2011*). Ardeidae was the most common family, indicating the suitability of these wetlands for herons and egrets (*Byju, Raveendran & Ravichandran, 2023e*). The presence of Near-Threatened species Spot-billed Pelican across all sanctuaries along with the Vulnerable Indian Spotted Eagle, and one more Near-Threatened Asian Woolly-necked Stork in TBS emphasizes the conservation value of these habitats (*IUCN, 2024*). TBS was unique in recording migratory species like the Northern Shoveler and Bailon's Crake, as well as resident species like the Watercock highlighting the need for tailored conservation strategies for each sanctuary, acknowledging their unique contributions to regional biodiversity (*Mukherjee, Borad & Parasharya, 2002*). The study recorded notable breeding colonies of Asian Openbill, Grey Heron, and Black-crowned Night Heron. The preference of Spot-billed Pelicans and Painted Storks for native *Acacia nilotica* trees, and the stratified nesting behaviour observed, where different species occupy different canopy levels, reflect the ecological complexity of these habitats (*Subramanya, 1996*).

In earlier studies on heronries in Tamil Nadu, *Frank, Gopi & Pandav (2021)* found no nesting records in CBS, KBS, and SBS between 2017 and 2019 with MKBS and TBS not included in that study. *Byju, Raveendran & Ravichandran (2023e)* studied MKBS avifauna between 2016 and 2019 and recorded 115 bird species, including 19 breeding waterbirds. They observed Red-naped Ibis breeding at MKBS, which was not recorded breeding during the current study, while Black-winged Stilt which they did not observe breeding, was recorded as breeding which occurred from November to February in the present study (*Byju, Raveendran & Ravichandran, 2023e*). This year (2022–2023) our regular study with the forest department in CBS revealed significantly fewer nesting species and reduced diversity compared to the previous year's nesting populations. Regular breeders like Knob-billed Duck *Sarkidiornis melanotos*, Spot-billed Duck *Anas poecilorhyncha*, Eurasian Spoonbill *Platalea leucorodia,* and Spot-billed Pelican did not nest in CBS due to sparse rainfall and water scarcity. Similarly, some species breeding in nearby sanctuaries did not breed in KBS.

Diversity and community structure across sanctuaries

Our hypothesis—that wetland area positively affects bird diversity and species richness—was broadly supported by the results, though nuances were evident in the distribution patterns among sanctuaries as MKBS, the largest sanctuary had the highest breeding waterbird diversity and the smallest sanctuary TBS had the lowest. These findings underscore the ecological importance of wetland heterogeneity, structural diversity, and habitat size in supporting complex waterbird communities. The Shannon-Weiner index (H) indicated that MKBS exhibited the highest diversity ($H = 2.54$) and suggesting a well-balanced avian community (*Magurran, 2004*), followed by KBS, SBS, CBS and TBS. Conversely, TBS showed the lowest diversity ($H = 2.23$) indicating a community structure

dominated by a few species, likely due to habitat degradation or limited resources (*Ludwig & Reynolds, 1988*) This is further reinforced by the dominance indices, which revealed balanced communities in CBS, KBS and MKBS, but community dominance by certain species in SBS and TBS. These patterns confirm that habitat complexity within larger wetlands likely fosters diverse avian assemblages through niche diversification. In terms of total area, MKBS and TBS are the largest and the smallest sanctuaries, respectively. It is evident by the correlation analysis that there is a strong positive relationship between sanctuary area and breeding waterbird diversity and richness. Larger the wetlands, more are the microhabitats and hence, they support greater bird diversity (*Paszkowski & Tonn, 2000*).

Species richness and evenness among sanctuaries

Species richness, as quantified by Menhinick's Index, was highest at MKBS (0.8), with CBS and KBS following closely. SBS and TBS exhibited the lowest species richness values, indicating a restricted avian community in these areas, potentially due to smaller habitat size or fewer habitat types available to meet varied ecological needs. The Evenness Index, showing high evenness in CBS and KBS, further suggests a balanced distribution of species in these sanctuaries, where resources or niches may be more evenly distributed. Conversely, TBS, dominated by a few species, showed lower evenness, aligning with expectations that smaller or less varied wetlands may support more specialized assemblages where particular species outcompete others. These indices collectively indicate that MKBS's large area and CBS and KBS's habitat structures contribute positively to both species richness and evenness. Studies by *Fairbairn & Dinsmore (2001)* and *Riffel, Keas & Burton (2001)* demonstrated that wetland area and heterogeneity are the important features affecting bird richness.

Beta diversity and inter-site community similarity

Whittaker's beta diversity profile highlights community similarities and distinctions among the sanctuaries. MKBS was most similar to CBS and KBS, with TBS and SBS showing distinct diversity profiles. SBS shared more similarities with TBS than other sanctuaries, suggesting that these smaller sites may host more unique assemblages. The high similarity observed between CBS, KBS, and MKBS could be attributed to shared habitat characteristics or landscape connectivity, which allows species to exploit resources across these areas. Lower values in Whittaker's index reflect this close similarity, suggesting possible species overlap or similar community dynamics facilitated by comparable habitat features.

Relationship between wetland area, bird diversity, and richness

A Kruskal–Wallis test confirmed no statistically significant difference in waterbird diversity and richness across the sanctuaries ($p = 0.406$), suggesting that each sanctuary supports comparable community richness and diversity levels despite some ecological and structural variations. However, a positive Pearson correlation ($r = 0.8$, $p = 0.074$) between sanctuary area and waterbird diversity suggests that larger sanctuaries tend to support more diverse communities. While the correlation between area and species richness was positive ($r = 0.4$) but not statistically significant ($p = 0.424$), the results nonetheless suggest a

trend supporting the hypothesis that larger wetland areas tend to foster greater species richness.

Species assemblage patterns and habitat associations

The PCA provided additional insights into species assemblage patterns and habitat associations across sanctuaries. TBS was associated with families such as Ciconiidae, Pelecanidae, Anhingidae, Ardeidae, and Threskiornithidae, which may reflect its unique ecological attributes or niche specialization supporting these groups. On the other hand, families like Jacanidae, Anatidae, Rallidae, Podicipedidae, Phalacrocoracidae, and Recurvirostridae were more strongly associated with SBS, suggesting habitat characteristics or resources better suited to these families. CBS, MKBS, and KBS did not show specific family associations, indicating that their habitats may provide a broader, less specialized environment, allowing for a more generalized assemblage without strong affiliations. This generalist habitat structure might contribute to the observed balanced community structure in these sanctuaries.

Species status (CMS, SOIB)

As 20.6% of the species recorded from the study sites are enlisted in *The Convention on Migratory Species (2024)*, the significance of these sanctuaries for avifauna is critical for conservation management as this is the first study from all sanctuaries which could initiate international collaboration for species conservation. SOIB status assessment was considered for a better underting of the species distribution in all the five sanctuaries as there was no previous studies and published literature from these important sites for waterbirds. However, SOIB assessment considered the frequency of reporting to calculate the indices of abundance, which does not directly measure the population size. A 'complete checklist' in the e-Bird citizen science platform is considered to assess the frequency of reporting (*State of India's Birds, 2023*), which could be biased or contain errors due to bird detection and identification errors, inaccessibility of the birding locations due to seasonal changes or difficult terrains (*Maitreyi, 2024*). For the 'Insufficient Data' index, there are no measurable limits or range, hence this could be treated as a general trend and emphasize the value of our study due to data deficiency.

Implications on conservation and management

Many migratory birds' flight paths depend on well-functioning wetlands (*Ens, Piersma & Tinbergen, 1994*; *Ntiamoa-Baidu et al., 1998*). Apart from resident and breeding birds, our study sites receive migratory birds majorly from families of Scolopacidae, Anatidae, Accipitridae, Charadriidae, Laridae, and Oriolidae. This remarkable diversity of avifauna in these study areas can be attributed to a wide range of feeding niches. The findings on threats have critical implications for conservation and habitat management in sanctuaries. As our results of threat ranking revealed, water unavailability is an extremely high threat in all the sanctuaries except TBS, where there is better availability of water as the area of TBS is much lesser. Another high ranked threat was nest tree unavailability which persists in all the sanctuaries. Although each of the five study sites has a large geographical area in water retention, the actual water holding area during the breeding season was much smaller due

to reliance on rainfall, which is also impacted by climate change and altered monsoon patterns, finally affecting colonial breeding waterbirds (*Cavitt et al., 2014*). As the water availability decreased, trees wilted, reducing the number of suitable nesting sites (personal observations). The primary roosting and nesting tree, *Acacia nilotica*, is also declining due to altered monsoon patterns, emphasizing the need for planting native species that are more resilient to drought and excess water conditions, to support waterbird breeding populations. Fluctuating water levels influence ecological factors like the size, depth, and vegetation affecting the availability of suitable breeding and roosting sites (*MacArthur, MacArthur & Preer, 1962*; *Karr & Roth, 1971*; *Pearman, 2002*) and shaping waterbird populations and species distribution in wetlands (*Wiens, 1989*; *Mukherjee, Borad & Parasharya, 2002*; *Ma et al., 2010*).The neighboring agricultural lands play a significant role in providing food resources for all these varieties of bird species (*Byju et al., 2024b*), especially in April when the water level in the waterbody recedes, allowing for the cultivation of crops like paddy *Oryza sativa*, cotton *Gossypium herbaceum*, and chilly *Capsicum annuum*, which attracts numerous birds. Therefore, conservation strategies should prioritize habitat preservation and structural diversification, especially in smaller wetlands like TBS and CBS, where specialized or less diverse habitats may restrict community diversity.

This study also observed the other medium and low category threats common to habitat and breeding waterbirds in all the sanctuaries, like proximity to human settlements and urban expansion (*Roshnath & Sashikumar, 2019*) which create disturbances as firewood collection, fishing or recreation by people, cattle feeding on the bark of the nesting trees during dry season which decayed the tree, leading to tree death (*Byju et al., 2024a*), domestic dogs disturbing and preying on waterbirds as observed in all the sanctuaries (*Mundkur & Langendoen, 2019*), invasive species like *Prosopis juliflora* and *Ipome a carnea* taking over a major extent of these sanctuaries and the removal of *Prosopis* trees without a replacement strategy, has negatively impacted species like the Asian Openbill and cormorants, which preferred nesting in these trees.. Sometimes waterbodies are also seen choked with water Hyacinth *Eichhornia crassipes*, which reduces feeding and roosting habitat for ducks and other waterbird species in freshwater that reduces oxygen and sunlight for native plants and fishes (*Lowe et al., 2000*; *Szabo & Mundkur, 2017*).

Management recommendations

Human-wildlife conflicts over resources, such as fishing and water rights, further challenge bird conservation (*Bosselmann, Engel & Taylor, 2008*). To mitigate these threats, enhanced patrolling to limit overfishing, along with controlling firewood collection is essential, as dead trees provide crucial roosting sites. Collaboration with government agencies is needed to ensure perennial water in the sanctuaries, with occasional desilting and tank deepening to improve water-holding capacity (*Anand, 1999*). Raising public awareness and training local communities to monitor waterbird populations and threats can foster greater protection and conservation efforts (*Szabo et al., 2016*).

CONCLUSIONS

To fully understand the ecological dynamics, seasonal bird abundance, diversity, and conservation in these five sanctuaries, long-term scientific studies, rigorous monitoring, and community involvement are essential. In summary, wetland size plays a critical role in shaping bird species richness and overall abundance, while the complexity of bird communities, indicated by species diversity, is more linked with habitat diversity, supporting the hypothesis that wetland area and habitat structure significantly influence avian community diversity, richness and evenness. Recent work on CAF reported a declining population trend of 100 waterbird species stressing the importance of forests and inland wetlands (*Mundkur & Selvaraj, 2023*). This research lays a foundation for future studies on wetland ecology, offering critical data for avian biodiversity conservation and sustainable wetland management across protected habitats.

Competing Interests

Balu Alagar Venmathi Maran is an Academic Editor for PeerJ.

Author Contributions

- Hameed Byju conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Hegde Maitreyi performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Raveendran Natarajan analyzed the data, authored or reviewed drafts of the article, and approved the final draft.

- Reshmi Vijayan analyzed the data, authored or reviewed drafts of the article, and approved the final draft.
- Balu Alagar Venmathi Maran analyzed the data, authored or reviewed drafts of the article, and approved the final draft.

Field Study Permissions

The following information was supplied relating to field study approvals (i.e., approving body and any reference numbers):

Gulf of Mannar Wildlife Division and the Wildlife Warden for permitting to conduct the fieldwork. Permission was given verbally.

Data Availability

The following information was supplied regarding data availability:

The raw data of water birds used for statistical analysis are available in the Supplementary File.

Supplemental Information

Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.18899#supplemental-information.

REFERENCES

Ali S, Ripley SD. 1987. *Compact handbook of the birds of India and Pakistan.* New York: Oxford University Press.

Anand J, Byju H, Nefa A, Abhijith S, Reshi OR, Aarif KM. 2023. Conservation significance of Changaram wetlands—a key wintering site for migratory shorebirds and other waterbirds in the western coast of Kerala, India. *Journal of Threatened Taxa* **15(1)**:22410–22418 DOI 10.11609/jott.8089.15.1.22410-22418.

Anand S. 1999. Effect of desilting of the Veeranam lake on its wildlife and fisheries resources and socioeconomic consequences. M.Sc. Dissertation, A.V.C. College (Autonomous), Mannampandal.

Balachandran S. 1990. Studies on the coastal birds of Mandapam and the neighbouring islands (Peninsular India). Ph.D. Thesis, Annamalai University, Annamalai Nagar, India.

Bibby CJ, Burgess ND, Hill DA, Mustoe S. 2000. *Bird census techniques.* Belgium: Academia Press.

BirdLife International. 2017. Waterbirds are showing widespread declines, particularly in Asia. *Available at http://datazone.birdlife.org/sowb/casestudy/waterbirds--are--showing--widespread--declines--particularly--in--asia* (accessed on 9 February 2024).

Borgman KL. 2011. A review of human disturbance impacts on waterbirds. *Audubon, California* **376**:1–23.

Bosselmann K, Engel R, Taylor P. 2008. Governance for sustainability—issues, challenges, successes. IUCN Environmental Policy and Law Paper No. 70. Gland.

Byju H, Maitreyi H, Raveendran N, Reshmi V. 2024a. Avifaunal diversity assessment and conservation significance of Therthangal Bird Sanctuary, Ramanathapuram, Tamil Nadu: insights about breeding waterbirds. *Journal of Threatened Taxa* **16(9)**:25802–25815 DOI 10.11609/jott.8999.16.9.25802-25815.

Byju H, Raveendran N. 2023a. Study on bird migratory pattern with respect to change in Habitation for waterbirdwaterbirds and land birds in Chitrangudi Bird sanctuary (Ramsar site) of Wildlife Division, Ramanathapuram. Final Report 2022-23. Iragukal Amritha Nature Trust, Madurai, Tamil Nadu, 32.

Byju H, Raveendran N. 2023b. Study on bird migratory pattern with respect to change in Habitation for waterbirdwaterbirds and land birds in Melaselvanor–Keelaselvanor Bird sanctuary area of Wildlife Division, Ramanathapuram. Final Report 2022-23. Iragukal Amritha Nature Trust, Madurai, Tamil Nadu, 33.

Byju H, Raveendran N. 2024a. Study on bird migratory pattern with respect to change in Habitation for waterbirdwaterbirds and land birds in Kanjirankulam Bird sanctuary (Ramsar site) of Wildlife Division, Ramanathapuram. Final Report 2023-24. Iragukal Amritha Nature Trust, Madurai, Tamil Nadu, 1–28.

Byju H, Raveendran N. 2024b. Study on bird migratory pattern with respect to change in Habitation for waterbirdwaterbirds and land birds in Sakkarakottai Bird sanctuary of Wildlife Division, Ramanathapuram. Final Report 2023-24. Iragukal Amritha Nature Trust, Madurai, Tamil Nadu, 1–28.

Byju H, Raveendran N, Ravichandran S, Rashmi V. 2023a. A checklist of the avifauna of Samanatham tank, Madurai, Tamil Nadu, India. *Journal of Threatened Taxa* **15(9)**:23857–23869 DOI 10.11609/jott.8419.15.9.23857-23869.

Byju H, Raveendran N, Ravichandran S. 2023b. Distribution of avifauna in twenty-one islands of the Gulf of Mannar Biosphere Reserve, South East India. *Journal of Threatened Taxa* **15(2)**:22574–22585.

Byju H, Raveendran N, Ravichandran S. 2023e. An Updated Checklist of Avifauna from Melselvanoor–Keelselvanoor Bird Sanctuary, Ramanathapuram, Tamil Nādu, India. *Advances in Zoology and Botany* **11(3)**:181–193 DOI 10.13189/azb.2023.110304.

Byju H, Raveendran N, Ravichandran S, Kishore R. 2023c. Importance of conserving a critical wintering ground for shorebirds in the Valinokkam Lagoon—a first study of the avifaunal distribution of the southeastern coast of India. *Journal of Threatened Taxa* **15(8)**:23696–23709.

Byju H, Raveendran N, Ravichandran S, Kishore R. 2023d. An annotated checklist of the avifauna of Karangadu mangrove forest, Ramanathapuram, Tamil Nadu, with notes on the site's importance for waterbird conservation. *Journal of Threatened Taxa* **15(3)**:22813–22822 DOI 10.11609/jott.8356.15.3.22813-22822.

Byju H, Rubeena KA, Shifa CT, Athira TR, Jishnu K, Singh J, Sohil A, Kushwah S, Kumar A, Anand J, Rajaneesh KM, Manokaran S, Gijjappu DR, Reshi OR, Sharma N, Junaina KK, Raveendran N, Mumthaz TMV, Nasser M, Muzaffar SB, Nefla A, Rahman SM, Aarif KM. 2024b. Transitioning wintering shorebirds to agroecosystem: a thorough evaluation of habitat selection and conservation concern. *Diversity* **16**:23 DOI 10.3390/d16010023.

Canterbury GE, Martin TE, Petit DR, Petit LJ, Bradford DF. 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. *Conservation Biology* **14**:544–558 DOI 10.1046/j.1523-1739.2000.98235.x.

Cavitt JF, Jones SL, Wilson NM, Dieni JS, Zimmerman TS, Doster RH, Howe WH. 2014. Atlas of breeding colonial waterbirds in the interior western United States. Research Report. U.S. Department of the Interior, Fish and Wildlife Service, Denver, Colorado.

Chapman LJ, Balirwa J, Bugenyi FWB, Chapman C, Crisman T. 2001. Wetlands of East Africa: biodiversity, exploitation, and policy perspectives. In: Gopal B, Junk WJ, Davis JA, eds. *Biodiversity in wetlands: assessment, function and conservation, v. 2.* Backhuys Publishers, 101–131.

Chawaka SN, Mereta ST, Goethals PLM, Lens L, Boets P. 2017. Effects of human-induced environmental changes on bird diversity and abundance in natural wetlands of Southwest Ethiopia. *Waterbirds* **40(2)**:129–143 DOI 10.1675/063.040.0205.

Craig RJ, Barclay JS. 1992. Seasonal dynamics of bird populations in small New England wetlands. *The Wilson Bulletin* **104**:148–155.

Dodd MG, Murphy TM. 1995. Accuracy and precision of techniques for counting Great Blue Heron nests. *Journal of Wildlife Management* **59(4)**:667–673 DOI 10.2307/3801942.

Ens BJ, Piersma T, Tinbergen JM. 1994. Towards predictive models of bird migration schedules: theoretical and empirical bottlenecks. NIOZ-Rapport 1994-5. Nederlands Instituut voor Onderzoek der Zee, The Netherlands, 27.

Fairbairn S, Dinsmore J. 2001. Local and landscape level influences of wetland bird communities of the praire pothole region of Iowa, USA. *Wetlands* **21**:41–47 DOI 10.1672/0277-5212(2001)021[0041:LALLIO]2.0.CO;2.

Frank SJD, Gopi GV, Pandav B. 2021. Heronry distribution and site preference dynamics of tree-nesting colonial waterbirds in Tamil Nadu. *PeerJ* **9**:e12256 DOI 10.7717/peerj.12256.

Fraser LH, Keddy PA. 2005. *The world's largest wetlands: ecology and conservation.* Cambridge: Cambridge University Press.

Gibbs JP, Woodward S, Hunter ML, Hutchinson AE. 1988. Comparison of techniques for censusing Great Blue Heron nests. *Journal of Field Ornithology* **59**:130–134.

Gokula V. 2010. Avifauna of Karaivetti Bird Sanctuary, Tamil Nadu, India. *Zoo's Print Journal* **28(6)**:23–29.

Gokula V, Raj PA. 2011. Birds of Vaduvoor Bird Sanctuary, Tamil Nadu, India: an annotated checklist. *Zoo's Print Journal* **26(6)**:20–24.

Golzar E, Esfandabad BS, Morshedi J, Naderi M, Jozi SA. 2019. Effect of human-induced activities on waterbirds diversity and abundance in three wetlands of international importance in Iran. *Contemporary Problems of Ecology* **12**:658–666 DOI 10.1134/S199542551906012X.

Gotelli NJ, Colwell RK. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* **4(4)**:379–391 DOI 10.1046/j.1461-0248.2001.00230.x.

Grimmett R, Inskipp A. 2007. *A guide to the birds of India.* India: Bloomsbury.

Grimmett R, Inskipp C, Inskipp T, Allen R. 2011. *Birds of the Indian subcontinent.* London: Christopher Helm.

Guptha MB, Sridharan N, Vijayan L, Thiyagesan K, Sandaliyan S, Somasundaram S. 2011. Status of major wetlands and wetland birds in Kanyakumari, Coimbatore, Thanjavur, Thiruvarur, Perambalur, Cuddalore, Nagapattinam, and Trichy districts in Tamil Nadu. *World Journal of Zoology* **6**:235–242.

Halassi I, Elafri A, Boutabia L, Telailia S. 2022. Monitoring human disturbance: factors affecting escape behaviour of waterbirds in North African wetlands. *African Journal of Ecology* **60**:523–532 DOI 10.1111/aje.12949.

Howes JG, Bakewell D. 1989. *Shorebird studies manual.* Kula Lumpur: Asian Wetland Bureau.

Hoyer MV, Caneld DE. 1994. Bird abundance and species richness on Florida lakes: influence of trophic status, lake morphology, and aquatic macrophytes. In: *Aquatic birds in the trophic web of lakes.* Dordrecht: Springer, 107–119.

Islam ZM, Rahmani AR. 2004. *Important bird areas in India.* Oxford: Oxford University Press.

IUCN. 2024. The IUCN Red List of Threatened Species. Version 2024-2. *Available at* https://www.iucnredlist.org.

Jolliffe IT. 2002. *Principal component analysis. Springer series in Statistics.* New York: Springer.

Karr J, Roth R. 1971. Vegetation structure and avian diversity in several new world areas. *The American Naturalist* **105(945)**:423–435 DOI 10.1086/282735.

Kattan GH, Franco P. 2004. Bird diversity along elevational gradients in the Andes of Colombia: area and mass effects. *Global Ecology and Biogeography* **13**:451–458 DOI 10.1111/j.1466-822X.2004.00117.x.

Kitikidou K, Milios E, Stampoulidis A, Pipinis E, Radoglou K. 2024. Using biodiversity indices effectively: considerations for forest management. *Ecologies* **5**:42–51 DOI 10.3390/ecologies5010003.

Krishnaraj V, Mathesh S. 2023. Correlation of stagnant wetland depths and their ecological status in the Central Tamil Nadu District, Tamil Nadu. *Environmental Science and Pollution Research* **30(18)**:51955–51976 DOI 10.1007/s11356-023-25855-3.

Kruskal WH, Wallis WA. 1952. Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association* **47(260)**:583–621 DOI 10.1080/01621459.1952.10483441.

Kumar A, Kankaujia A. 2014. Wetlands: significance, Threats and their Conservation. *GREEN Quarterly Newsletter-Directorate of Environment, U.P* **7(3 & 4)**:3–22.

Lagos NA, Paolini P, Jaramillo E, Lovengreen C, Duarte C, Contreras H. 2008. Environmental processes, water quality degradation, and decline of waterbird populations in the Rio cruces wetland, Chile. *Wetlands* **28**:938–950 DOI 10.1672/07-119.1.

Lowe S, Browne M, Boudjelas S, De Poorter M. 2000. *100 of the world's worst invasive alien species: a selection from the global invasive species database.* Auckland: Invasive Species Specialist Group.

Ludwig JA, Reynolds JF. 1988. *Statistical ecology: a primer on methods and computing.* New York: John Wiley & Sons.

Ma Z, Cai Y, Li B, Chen J. 2010. Managing wetland habitats for waterbirds: an international perspective. *Wetlands* **30(1)**:15–27 DOI 10.1007/s13157-009-0001-6.

MacArthur R, MacArthur J, Preer J. 1962. On bird species diversity. II. Prediction of bird census from habitat measurements. *The American Naturalist* **96(888)**:167–174 DOI 10.1086/282219.

Magurran AE. 2004. *Measuring biological diversity.* Oxford: Blackwell Publishing.

Maitreyi H. 2024. State of India's birds report-a brief review. *Zoo's Print* **39(1)**:119–124.

Margoluis R, Salafsky N. 1998. *Measures of success: designing, managing, and monitoring conservation and development projects.* Washington, D.C.: Island Press.

Mukherjee A, Borad CK, Parasharya BM. 2002. A study of the ecological requirements of waterfowl at man-made reservoirs in Kheda District, Gujarat, India, with a view towards conservation, management, and planning. *Zoos' Print* **17(5)**:775–785 DOI 10.11609/JoTT.ZPJ.17.5.775-85.

Mundkur T, Langendoen T. 2019. *Analysis of the AWC 2019 Wetland and waterbird assessment questionnaire.* The Netherlands: Asian Waterbird Census Newsletter.

Mundkur T, Selvaraj R. 2023. Central Asian Flyway –Situation Analysis: the status of migratory birds and their habitats and recommendations for their conservation. Report by BirdLife International, Cambridge DOI 10.13140/RG.2.2.32281.80480.

Ntiamoa-Baidu Y, Piersma T, Wiersma P, Poot M, Battley P, Gordon C. 1998. Water depth selection, daily feeding routines and diets of waterbirds in coastal lagoons in Ghana. *Ibis* **140(1)**:89–103 DOI 10.1111/j.1474-919X.1998.tb04545.x.

Paracuellos M. 2006. How can habitat selection affect the use of a wetland complex by waterbirds? *Biodiversity & Conservation* **15(14)**:4569–4582 DOI 10.1007/s10531-005-5820-z.

Paszkowski C, Tonn W. 2000. Community concordance between the fish and aquatic birds of lakes in northern Alberta, Canada: the relative importance of environmental and biotic factors. *Freshwater Biology* **43**:421–443 DOI 10.1046/j.1365-2427.2000.00512.x.

Pearman PB. 2002. The scale of community structure: habitat variation and avian guilds in the tropical forest understory. *Ecological Monographs* **72(1)**:19–39 DOI 10.1890/0012-9615(2002)072[0019:TSOCSH]2.0.CO;2.

Piersma T, Lindström Å. 2004. Migrating shorebirds as integrative sentinels of global environmental change. *IBIS* **146(Suppl.1)**:61–69 DOI 10.1111/j.1474-919X.2004.00329.x.

Praveen J, Jayapal R. 2023. Taxonomic updates to the checklists of birds of India and the South Asian region. *Indian BIRDS* **18(5)**:131–134.

Priya PJ, Varunprasath K. 2018. Survey of Wetlands in and around Tiruppur District, Tamil Nadu, India. *Annual Research & Review in Biology* **27(2)**:1–13 DOI 10.9734/ARRB/2018/41419.

Raj PPN, Ranjini J, Dhanya R, Subramaniyan J, Azeez PA, Bhupathy S. 2010. Consolidated checklist of birds in the Pallikaranai Wetlands, Chennai, India. *Journal of Threatened Taxa* **2(8)**:1114–1118 DOI 10.11609/JoTT.o2220.1114-8.

Rajashekara S, Venkatesha MG. 2017. Impact of threats on avifaunal communities in diversely urbanized landscapes of the Bengaluru city, south India. *Zoology and Ecology* **27(3–4)**:202–222 DOI 10.1080/21658005.2017.1380366.

Rajpar MN, Zakaria M. 2010. Indah Wetland Reserve, Selangor Peninsular Malaysia. *Journal of Biological Sciences* **10(7)**:658–666 DOI 10.3923/jbs.2010.658.666.

Ramsar Fact Sheet. 2014. Wetlands-why should I care? *Available at https://www.ramsar. org/sites/default/files/documents/library/factsheet1_why_should_i_care_0.pdf* (accessed on 16 Feb 2015).

Rashiba AP, Jishnu K, Byju H, Shifa CT, Anand J, Vichithra K, Xu Y, Nefla A, Muzaffar SB, Aarif KM. 2022. The paradox of shorebird diversity and abundance in the West Coast and East Coast of India: a comparative analysis. *Diversity* **14**:885 DOI 10.3390/d14100885.

Riffel SÌL, Keas BE, Burton TM. 2001. Area and habitat relationships of birds in great lakes coastal wet meadows. *Wetlands* **21**:492–450 DOI 10.1672/0277-5212(2001)021[0492:AAHROB]2.0.CO;2.

Roshnath R, Sashikumar C. 2019. Conservation challenges of the heronries in Kerala. *Journal of the Bombay Natural History Society* **116**:63–67.

SAC. 2011. *Space Application Centre (SAC) National Wetland Atlas.* Ahmedabad. India: Space Applications Centre, Indian Space Research Organisation, 310.

Sekercioglu CH. 2012. Bird functional diversity and ecosystem services in tropical forests, agroforests and agricultural areas. *Journal of Ornithology* **153**:153–161 DOI 10.1007/s10336-012-0869-4.

State of India's Birds. 2023. Range, trends, and conservation status. *Available at https://stateofindiasbirds.in/* (accessed on 4 September 2024).

Subramanya S. 1996. Distribution, status and conservation of Indian heronries. *Journal of the Bombay Natural History Society* **93(3)**:459–486.

Subramanya S. 2005. Heronries of Tamil Nadu. *Indian Birds* **1(6)**:126–140.

Szabo JK, Choi C-Y, Clemens RS, Hansen BD. 2016. Conservation without borders—solutions to address migratory shorebird declines in the east Asian-Australasian flyway. *Emu* **116**:215–221 DOI 10.1071/MU15133.

Szabo J, Mundkur T. 2017. Conserving wetlands for migratory waterbirds in South Asia. In: Prusty BaK, ChandRa R, Azeez PA, eds. *Wetland science: perspectives from South Asia.* Cham: Springer Verlag, 105–127.

Tamil Nadu Wetland Mission. 2024. Bird Sanctuaries in Tamil Nadu. *Available at https://www.tnswa.org/bird-santuary-in-tn* (accessed on May 2023).

The Convention on Migratory Species. 2024. Species. *Available at https://www.cms.int/en/species* (accessed on 04 September 2024).

Urfi AJ, Sen M, Megnathan T. 2005. Counting birds in India: methodologies and trend. *Current Science* **89(12)**:1997–2003.

Whittaker RH. 1972. Evolution and measurement of species diversity. *Taxon* **21**:213–251 DOI 10.2307/1218190.

Wiens JA. 1989. *The ecology of bird communities.* Cambridge: Cambridge University Press.