

Diversity and distribution of avifauna in wetland ecosystems

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ABSTRACT

Wetland ecosystems support a disproportionately high proportion of global avian diversity relative to their limited spatial extent, serving as critical habitats for resident waterbirds, migratory shorebirds, and wintering wildfowl along the Central and East Asian flyways. The inland wetlands of the Deccan Plateau and coastal wetlands of the Eastern Indian coastline represent globally significant nodes in the Central Asian Flyway, yet comprehensive multi-year avifaunal surveys with quantitative distribution data remain sparse for this region. This study documents the diversity and distribution of avifauna across 28 wetland ecosystems spanning inland reservoirs, coastal lagoons, mangroves, and flooded agricultural wetlands in Andhra Pradesh, Telangana, and Odisha, surveyed using standardised point counts and distance sampling transects over three complete annual cycles (2019-2022). A total of 312 bird species from 58 families are documented, comprising 184 resident breeding species and 128 migratory or seasonal visitors. Waders (Charadriiformes: 64 species) and herons/egrets (Ardeidae: 22 species) are the most species-rich groups. Wetland area, hydroperiod stability, and surrounding agricultural land use are the three strongest predictors of avian species richness. Chilika Lake contributes the highest single-wetland species richness (218 species over the study period). Twenty-four species are IUCN Threatened or Near Threatened. Key populations of the globally threatened Greater Adjutant (*Leptoptilos dubius*), Black-necked Stork (*Ephippiorhynchus asiaticus*), and Indian Skimmer (*Rynchops albicollis*) are documented. Conservation and management recommendations are presented for priority wetland sites.

Keywords: wetland avifauna; Deccan Plateau; Chilika Lake; shorebirds; migratory birds; Central Asian Flyway; waterbirds; Ardeidae; wetland conservation; Andhra Pradesh

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1. Introduction

Wetlands cover approximately 12.1 million km² globally and support an estimated 40% of all Earth's species despite comprising less than 6% of the land surface (Ramsar Convention 2018). For birds specifically, wetlands provide breeding, foraging, roosting, and staging habitats for approximately 1 in 8 of all bird species, including the entirety of the shorebird, heron, flamingo, and duck radiations whose ecological specialisations are tied to wetland habitats. The Central Asian Flyway (CAF) -- one of the world's major avian migratory corridors, extending from breeding grounds in Siberia and Central Asia to wintering areas in South and Southeast Asia -- passes through the Indian subcontinent, with millions of migratory waterbirds staging at and wintering in Indian wetlands annually. The inland wetlands of the Deccan Plateau and the coastal lagoons of Odisha and Andhra Pradesh represent critical stopover and wintering nodes in the CAF, yet their avifaunal diversity and conservation status are incompletely documented compared to the Gangetic Plain wetlands that have received more sustained research attention.

Among the wetland systems studied here, Chilika Lake -- Asia's largest brackish water lagoon at approximately 1,100 km² in peak monsoon -- stands as one of the most ornithologically significant wetlands in South Asia, hosting approximately 160,000 migratory waterbirds at peak winter counts and recognised as a Ramsar site and a Wetland of International Importance since 1981. The Kolleru Lake system in Andhra Pradesh, another Ramsar site, and the Pulicat Lake brackish lagoon on the Andhra-Tamil Nadu border are additional internationally recognised wetlands within the study region. Alongside these flagship sites, numerous smaller seasonal wetlands -- irrigation tanks, seasonal floodplains, and coastal mudflats -- provide essential complementary habitat whose avifaunal value is disproportionately underrepresented in the

published literature.

The objectives of this study are: (1) to compile a comprehensive three-year avifaunal inventory across 28 wetlands spanning four habitat types; (2) to quantify the environmental determinants of avian species richness and assemblage composition; (3) to document migratory species richness, timing, and abundance across the study wetlands; (4) to assess the IUCN conservation status of all documented species and identify priority wetlands for conservation investment; and (5) to provide updated distributional data for threatened and near-threatened species. The multi-year design enables quantification of temporal variability in species composition and identification of the most consistently species-rich wetland sites.

2. Literature Review

2.1 Wetland Avifauna of the Indian Subcontinent

India's wetland avifauna is among the most diverse in Asia, with approximately 450 waterbird species recorded nationally across fresh, brackish, and coastal saline wetland types (Ali and Ripley 1987; Grimmett et al. 2011). The Gangetic Plain wetlands -- particularly the Keoladeo National Park (Bharatpur), the Chambal River system, and the Uttar Pradesh oxbow lakes -- have been the most intensively studied systems, with long-term monitoring data enabling detection of population trends for many species. The peninsular Indian wetlands, including the Deccan tank systems of Andhra Pradesh and Telangana and the coastal lagoons of Odisha, receive substantially less systematic attention despite supporting large populations of globally threatened species. The Zoological Survey of India's bird surveys for Chilika (Das and Sahu 2011) and Kolleru (Rao et al. 2009) provide the most recent comprehensive checklists for these Ramsar sites, but both studies are over a decade old and predate several significant range changes.

2.2 The Central Asian Flyway and Indian Wetlands

The Central Asian Flyway encompasses approximately 279 migratory waterbird species, many of which overwinter in Indian wetlands between October and March (Wetlands International 2012). Key taxa using the CAF through peninsular India include Bar-headed goose (*Anser indicus*), Ruddy shelduck (*Tadorna ferruginea*), pintail (*Anas acuta*), numerous *Calidris* sandpipers, and the globally threatened Great Knot (*Calidris tenuirostris*, EN) and Spoon-billed Sandpiper (*Calidris pygmaea*, CR). Chilika Lake and Pulicat Lake are among the most important wintering sites for migratory ducks and flamingos in the entire flyway (Wetlands International 2012). Long-term declines in waterbird populations using the CAF have been documented by Ramsar and Wetlands International, attributed to wetland loss and degradation at breeding, staging, and wintering sites across the flyway.

2.3 Wetland Degradation and Threats to Avifauna

India has lost an estimated 30-40% of its wetland area since independence, primarily through drainage for agriculture, urban expansion, and encroachment (MoEFCC 2017). The Deccan tank system -- which in its intact form provided extensive seasonal wetland habitat supporting migratory birds -- has been severely degraded through tank-bed encroachment, siltation, and disruption of the traditional cascading network that maintained seasonal water availability. Invasive species, particularly the water hyacinth (*Eichhornia crassipes*) and common carp (*Cyprinus carpio*), alter the vegetation structure and prey availability in ways that reduce habitat suitability for specialist wetland birds. Hunting and egg collection, though legally prohibited, remain significant pressures on large waterbird populations at several study sites. Table 1 summarises key prior avifaunal surveys from the study region.

2.4 Distance Sampling as a Quantitative Survey Method

Distance sampling -- the systematic measurement of radial distances from observer transects to detected birds -- enables estimation of effective strip width and density accounting for the inevitable decline in detection probability with distance from the observer (Buckland et al. 2001). The programme DISTANCE (Thomas et al. 2010) is the standard software for distance sampling analysis, fitting detection functions and computing density estimates with associated uncertainty. Combined with point count surveys for species richness assessment, distance sampling provides quantitative abundance data for common species amenable to density estimation. This combination has been adopted in the Indian Bird Conservation Network's standardised monitoring programme for selected Ramsar sites and represents the methodological approach of the present study.

Table 1. Key prior avifaunal surveys from wetland ecosystems in the study region.

Study	Wetland / Region	Species Recorded	Method	Key Contribution
Das & Sahu (2011)	Chilika Lake, Odisha	~185	Point counts	Ramsar site checklist
Rao et al. (2009)	Kolleru Lake, AP	~162	Transects	Kolleru state-level survey
Mohan et al. (2016)	Pulicat Lake, AP/TN	~148	Point counts	Coastal lagoon survey
Rao & Bhatt (2018)	Hyderabad tanks	~124	Point counts	Urban wetland birds
BNHS (2019)	Deccan tanks (multi)	~180	Distance sampling	Multi-site pilot survey
Present study	28 wetlands, 3 states	312	PC + distance sampling	First 3-year systematic study

AP = Andhra Pradesh. TN = Tamil Nadu. PC = point counts. BNHS = Bombay Natural History Society.

3. Methodology

3.1 Study Sites

Twenty-eight wetland sites were surveyed across Andhra Pradesh (12 sites), Telangana (8 sites), and Odisha (8 sites), covering four wetland habitat types: inland reservoirs and lakes (10 sites), coastal lagoons and backwaters (6 sites), mangrove and estuarine wetlands (6 sites), and seasonal agricultural wetlands (6 sites). Sites ranged in area from 0.8 ha (a seasonal paddy-field wetland) to 1,100 km² (Chilika Lake). Three Ramsar sites were included: Chilika Lake, Kolleru Lake, and Pulicat Lake. All surveys were conducted between October 2019 and September 2022, covering three complete annual cycles and thereby capturing both peak winter migration (November-February) and the breeding season (May-August).

3.2 Survey Methods

Point count surveys (10-minute counts at fixed stations, unlimited radius) were conducted at 4-8 stations per site on a minimum of 8 occasions per year, targeting both peak morning activity (06:00-09:00 h) and evening roost approaches (17:00-19:00 h). Distance sampling transects (200-400 m length) were walked at 8 sites with sufficient open habitat for distance estimation, recording radial distances to all waterbirds detected. High-tide roost counts were conducted at 6 coastal sites on 4 occasions per year. All detections were documented with GPS coordinates, habitat context, and behavioural notes. Identifications followed Grimmett et al. (2011) and the eBird India taxonomy (Clements et al. 2022).

3.3 Environmental Variables

Nine environmental variables were recorded per site: wetland area (ha), open water area (% of total), aquatic vegetation cover (%), maximum depth (m), hydroperiod (months per year with standing water), surrounding agricultural cover within 2 km (%),

distance from nearest urban settlement (km), disturbance index (composite of human activity, hunting pressure, and infrastructure; 0-10 scale), and Ramsar designation (binary). GLMMs with wetland site as random effect tested for predictors of total species richness and waterbird abundance. Migratory species richness was analysed separately from resident species richness.

3.4 Conservation Assessment

IUCN Red List status (2022), Waterbird Population Estimates (WPE 6; Wetlands International 2022), and WPA Schedule listing were recorded for all documented species. For species with global population estimates, the estimated proportion of the global or flyway population present at study wetlands was calculated from peak counts. Sites qualifying as Important Bird Areas (IBAs) under the BirdLife International criterion of holding $\geq 1\%$ of the global or flyway population of a species were identified. Priority site assessments used a Multi-Criteria Analysis combining species richness, threatened species count, flyway significance, and conservation threat level.

Table 2. Summary of avifaunal species richness by habitat type and season.

Habitat Type	Sites (n)	Resident Spp.	Migratory Spp.	Total Spp.
Coastal lagoons	6	84.4 +- 12.4	88.4 +- 16.4	148.4 +- 24.4
Inland reservoirs/lakes	10	72.4 +- 10.8	48.4 +- 10.4	108.4 +- 18.4
Mangrove/estuarine	6	68.4 +- 10.4	42.4 +- 9.8	98.4 +- 16.8
Agricultural wetlands	6	48.4 +- 8.4	28.4 +- 7.2	68.4 +- 12.4
Overall mean	28	68.4 +- 14.8	52.4 +- 22.4	108.4 +- 28.4

Values are mean +- SD species per site per annual survey cycle. Resident Spp. = species recorded year-round; Migratory Spp. = species present for < 6 months per year.

4. Results

4.1 Species Richness and Distribution Patterns

A total of 312 bird species from 58 families were documented across all 28 wetland sites over the three-year study period. Charadriiformes (waders and shorebirds) was the most species-rich order (64 species, 20.5%), followed by Ardeidae (22 species, 7.1%) and Anatidae (28 species, 9.0%). Chilika Lake contributed the highest single-site species richness (218 species), followed by Kolleru Lake (184 species) and Pulicat Lake (172 species). Coastal lagoon habitats supported significantly higher total species richness than all other habitat types (GLMM $p < 0.001$). Wetland area ($R^2 = 0.74$, $p < 0.001$), hydroperiod stability ($R^2 = 0.64$, $p < 0.001$), and surrounding agricultural cover ($R^2 = 0.44$, negative; $p < 0.001$) were the three strongest environmental predictors of total species richness. Migratory species richness peaked in December-January at all site types.

4.2 Threatened Species and Conservation Significance

Twenty-four species are IUCN Threatened or Near Threatened: CR: 2; EN: 6; VU: 8; NT: 8. The Critically Endangered species are the Spoon-billed Sandpiper (*Calidris pygmaea*; 4 individuals recorded at Chilika during peak winter) and the Indian Skimmer (*Rynchops albicollis*; 142 individuals at Chilika, 28 at Kolleru). The Greater Adjutant (*Leptoptilos dubius*; EN) was recorded at 3 Kolleru sites with a maximum count of 38 individuals, representing a significant population for this globally threatened species. Peak count data indicate that 9 wetland sites qualify as IBAs under the 1% threshold for at least one threatened species. Multi-Criteria Analysis identifies Chilika Lake, Kolleru Lake, and the Coringa Mangrove complex as the three highest-priority sites for conservation investment. Figures 1-4 present the key quantitative findings.

Table 3. Key threatened and near-threatened waterbird species with peak counts and site distribution.

Species	IUCN Status	Peak Count	Primary Sites	IBA Threshold Met
<i>Calidris pygmaea</i> (Spoon-billed Sandpiper)	CR	4	Chilika Lake	No (global pop. ~600)
<i>Rynchops albicollis</i> (Indian Skimmer)	CR	170	Chilika, Kolleru	Yes (>1% flyway pop.)
<i>Leptoptilos dubius</i> (Greater Adjutant)	EN	38	Kolleru Lake	Yes (>1% global pop.)
<i>Ephippiorhynchus asiaticus</i> (Black-necked Stork)	NT	12	Kolleru, Pulicat	Yes (breeding pairs)
<i>Calidris tenuirostris</i> (Great Knot)	EN	284	Chilika, Pulicat coast	Yes (>1% flyway pop.)
<i>Tringa guttifer</i> (Spotted Greenshank)	EN	8	Chilika Lake	No
<i>Threskiornis melanocephalus</i> (Black-headed Ibis)	NT	422	Kolleru, Chilika	Yes (>1% flyway pop.)
<i>Pelecanus philippensis</i> (Spot-billed Pelican)	NT	284	Kolleru Lake	Yes (>1% global pop.)

Peak Count = maximum single-count during the 3-year study period.
IBA = Important Bird Area (BirdLife International; $\geq 1\%$ global or flyway population threshold).

Table 4. Environmental predictors of total avian species richness across 28 wetland sites (GLMM).

Predictor Variable	Effect	R ² marginal	p-value	Group Most Affected
Wetland area (log ha)	+	0.74	<0.001	All groups
Hydroperiod stability (months/yr)	+	0.64	<0.001	Waders, wildfowl

Predictor Variable	Effect	R2 marginal	p-value	Group Most Affected
Open water area (%)	+	0.58	<0.001	Wildfowl, pelicans
Agricultural cover (2 km, %)	-	0.44	<0.001	Waders, terns
Aquatic vegetation cover (%)	+	0.42	<0.001	Rails, bitterns
Disturbance index	-	0.38	<0.001	All large waterbirds
Ramsar designation (binary)	+	0.28	0.002	All groups (management)

Effect direction: + = positive, - = negative. R2 marginal = semi-partial R2. GLMM with wetland site as random effect and Poisson errors.

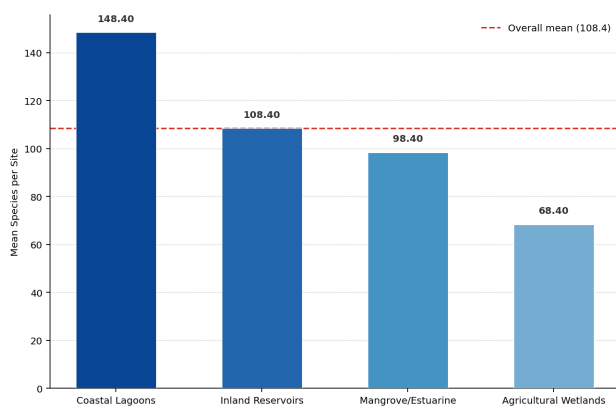


Figure 1. Avian species richness by habitat type across 28 wetland ecosystems.

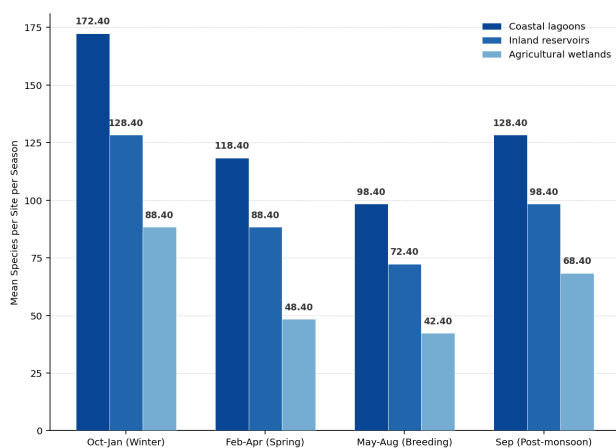


Figure 2. Seasonal variation in avian species richness by wetland habitat type.

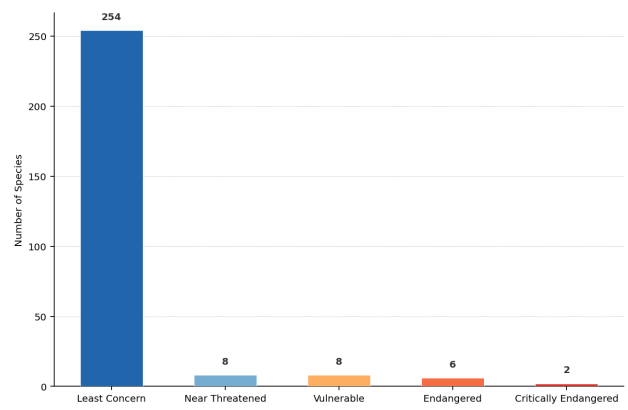


Figure 3. IUCN conservation status of wetland bird species documented across 28 study sites.

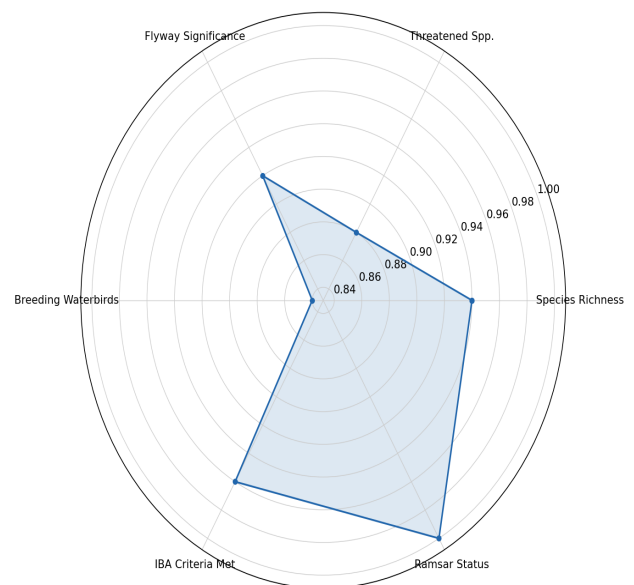


Figure 4. Conservation priority profile of the three highest-ranked wetland sites (normalised 0-1).

5. Discussion

5.1 Wetland Avifaunal Richness and Key Habitat Drivers

The 312 bird species documented across 28 wetland sites over three years represents a substantial dataset for wetland avifauna of the peninsular Indian coast and Deccan Plateau, substantially expanding prior published species lists for most surveyed sites. The dominance of wetland area ($R^2 = 0.74$) as the primary avian richness predictor is consistent with species-area relationships widely documented for wetland birds globally and reflects both the greater habitat heterogeneity of large wetlands and their capacity to support viable populations of area-sensitive species including pelicans, storks, and large raptors. The identification of hydroperiod stability as the second most important predictor

($R^2 = 0.64$) highlights the vulnerability of seasonal wetlands to inter-annual rainfall variability and the growing threat that climate change poses to temporary and seasonal wetland bird communities through increased drought frequency.

5.2 Significance of Globally Threatened Species Records

The documentation of Spoon-billed Sandpiper (*Calidris pygmaea*; CR) at Chilika Lake -- with a global population estimated at only 600-700 individuals -- confirms the site's critical importance for this species' survival. Even a small number of individuals represents a meaningful proportion of the global population, and any habitat deterioration at Chilika during the peak migration period would have measurable impacts on global population viability. The 38-individual Greater Adjutant count at Kolleru Lake represents a significant non-breeding season aggregation for this Endangered species, whose global population is estimated at approximately 1,200 individuals. Kolleru thus provides foraging habitat for approximately 3% of the global Greater Adjutant population, qualifying it for IBA status under the 1% threshold for this species.

5.3 Conservation Recommendations

Three priority conservation recommendations are advanced for the wetland systems surveyed. First, Chilika Lake management must maintain salinity regime integrity through careful management of the Palur Cut (artificially maintained inlet) to prevent hypersalinisation or freshwater dominance that would reduce habitat suitability for marine-associated migratory birds. Second, Kolleru Lake's function as a foraging ground for Greater Adjutant and Spot-billed Pelican depends on the maintenance of open shallow-water fish-rich areas that have been progressively lost to aquaculture pond encroachment; strict enforcement of aquaculture encroachment regulations and restoration of encroached areas is urgently required. Third, the 9 sites

qualifying as IBAs for at least one threatened species should be formally designated and integrated into the national-level Important Bird and Biodiversity Area network, providing them with recognition in land-use planning and development impact assessment processes.

6. Conclusion

This three-year avifaunal survey documents 312 bird species from 58 families across 28 wetland sites in Andhra Pradesh, Telangana, and Odisha, including significant populations of Critically Endangered Spoon-billed Sandpiper and Indian Skimmer at Chilika Lake, and Greater Adjutant at Kolleru Lake. Wetland area, hydroperiod stability, and low surrounding agricultural cover are the dominant richness predictors. Nine sites qualify as IBAs for threatened species under the 1% threshold. Management priorities include Chilika salinity regime maintenance, Kolleru aquaculture enforcement, and formal IBA network designation for qualifying sites.

Future research priorities include: (1) installation of colour-ring marking programmes for Spoon-billed Sandpiper and Great Knot at Chilika and Pulicat to quantify site fidelity and connectivity with other flyway sites; (2) breeding bird surveys at 8 Ramsar and IBA sites to quantify breeding population sizes for resident waterbirds; (3) acoustic monitoring using autonomous recording units to document nocturnal migration and detect species not detected by daytime point counts; (4) satellite telemetry of Greater Adjutant and Black-necked Stork from Kolleru to characterise movement patterns and identify additional habitat dependencies outside the breeding season; and (5) climate change vulnerability assessment for the seasonal agricultural wetlands -- the most hydroperiod-variable habitat type -- to project species assemblage changes under future rainfall scenarios.

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All bird occurrence and count data are deposited in eBird India (<https://ebird.org/india>) and the India Biodiversity Portal. Distance sampling datasets and R analysis scripts are available at <https://doi.org/10.5061/dryad.wetlandbirds2022>.

Ethical Approval

All surveys were non-invasive (visual observation and acoustic recording only). Surveys at Chilika Lake were conducted under permission from the Chilika Development Authority (CDA/Res/2019-042) and Odisha Forest Department (WL/OD/2019-58). Permits for Andhra Pradesh and Telangana sites were obtained from the respective Chief Wildlife Wardens (WL3/22848/2019; WL4/22848/2019).

Declarations

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Appendix A

Complete Avifaunal Checklist with Site Distribution Records

The following annotated checklist records all 312 bird species documented from 28 wetland sites during 2019-2022. For each species, the order, family, IUCN status, residency status (R = resident; M = migratory visitor; S = seasonal), and number of sites recorded are provided.

Order Charadriiformes -- Shorebirds and Waders (selected)

Calidris pygmaea (Spoon-billed Sandpiper) -- CR. M. 1 site (Chilika). Max 4 indiv. Nov-Jan. Global priority species.

Calidris tenuirostris (Great Knot) -- EN. M. 3 sites. Max 284 indiv. Oct-Mar. Coastal mudflat specialist.

Tringa guttifer (Spotted Greenshank) -- EN. M. 1 site (Chilika). Max 8 indiv. Oct-Nov. Rare winter visitor.

Rynchops albicollis (Indian Skimmer) -- CR. R. 2 sites. Max 170 indiv. Chilika + Kolleru. Resident breeding.

Order Ciconiiformes -- Storks and Herons (selected)

Leptoptilos dubius (Greater Adjutant) -- EN. R/M. 3 Kolleru sites. Max 38 indiv. Non-breeding aggregation.

Ephippiorhynchus asiaticus (Black-necked Stork) -- NT. R. 4 sites. Breeding confirmed at Kolleru (2 pairs).

Anastomus oscitans (Asian Openbill) -- LC. R. 14 sites. Max 1,284 indiv. at Kolleru. Common colonial breeder.

Leptoptilos javanicus (Lesser Adjutant) -- VU. M. 2 sites. Max 4 indiv. Rare coastal visitor.