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ORIGINAL PAPER

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Developing a novel approach to prioritizing irrigation tanks for conservation in the Tamiraparani river basin based on long term trends of waterbirds

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Abstract Natural wetlands are disappearing globally due to a multitude of factors. In contrast, man-made artificial wetlands (irrigation tanks) have proliferated due to agricultural expansion. Constructing irrigation tanks is an ancient practice widespread in India, and elsewhere around the world. The semi-arid plains of south India have the largest network of irrigation tanks and support diverse flora and fauna, especially waterbirds. However, research on waterbird diversity and abundance has been restricted to a few specific water bodies, and landscape scale data is lacking. In this study we analyse the trends in waterbird abundance based on total counts of birds done in January each year by over 100 volunteers across twelve years from 2011 onwards in 133 irrigation tanks of the Tamiraparani river basin, south India. We performed similar counts in the dry season for 4 years. We developed a novel approach of using total counts and abundance of species showing declining trends to prioritize tanks for conservation in this region. Trend analysis indicated insignificant variation in species richness, while total waterbird abundance declined marginally. Fourteen out of the 50 species showed declines, of which 12 were residents and 2 were winter migrants. At the family level ducks, jacanas, terns, wagtails and waders showed a significant negative trend and guild analysis indicated a decline in the abundance of species using wetland vegetation for food and foraging. We also observed that large reservoirs in the river basin serve as a refuge for waterbirds during periods of severe drought. Some tanks in summer provide vital foraging resource for birds during water scarcity. We prioritised a cluster of seven tanks in summer and winter respectively for future conservation efforts.

Keywords Irrigation tanks · Waterbirds · Trends · Important tanks

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Introduction

The importance of man-made wetlands to aquatic organisms has been highlighted by several studies worldwide (Jackson et al. 2020; Elphick et al. 2010; Chester and Robson 2012). Many of these investigations have demonstrated the significance of such wetlands as refuges for waterbirds (Froneman et al. 2001; Sebastian-Gonzalez et al. 2010; Sundar and Kittur 2013; Kumar et al. 2016; Lewis-Phillips et al. 2019), and how the loss of such wetlands can adversely impact biodiversity (Gibbs 1993). Irrigation tanks are man-made artificial wetlands of ancient origin established widely in several parts of the world. The Indian subcontinent has the largest concentration of such tanks (Narayanamoorthy 2007), which were primarily built for use by humans, but have become the only habitats for both resident and wintering birds in some locations (Srinivasulu et al. 1996; Abhisheka et al. 2013; Harisha and Hosetti 2018; Neelgund and Kadadevaru 2020) thereby supporting a diverse assemblage of species.

The Indian subcontinent is recognised as a key wetland region for waterbirds that use the Central Asian Flyway. More than 180 species use the flyway to migrate back and forth from their breeding grounds (Yong and Gurung 2017). A high proportion of the global population of the near-threatened Spot-billed Pelican *Pelecanus philippensis* is found in irrigation tanks of the region (Birdlife International 2003; Kannan and Manakadan 2005). The tanks are a regular wintering ground for the Trans Himalayan migrant Bar-headed Goose *Anser indicus* (Siddiqui and Balachandran 2008). Studying wetlands located in the migratory routes of waterfowl can provide insights into the threats along migratory pathway and inform conservation actions (Sung et al. 2021). However, the conservation potential of irrigation tanks has not been documented or prioritized like that of large wetlands, and landscape-level conservation planning for such wetlands is generally lacking (Sundar and Kittur 2013).

During the annual waterbird census conducted across the country small tanks were mostly ignored for monitoring as the focus was on large protected wetlands/Ramsar sites or those lying within urban areas or tanks that support nesting colonies of waterbirds. The southern peninsula of the Indian subcontinent is an important wintering area for waterbirds from the Palearctic region (Bird life International (2003). This region is dominated by irrigation tanks which are critical for the waterbirds during winter and hold water collected from the northeast monsoon, which can provide habitats and food sources for waterbirds prior to spring migration. Most of these tanks are small and a network of smaller wetlands may potentially harbour more or similar bird diversity compared to a single large wetland (Kacergyte et al. 2021). Despite the value of these wetlands to biodiversity and human well-being, they are largely missing from national and international legislation and policy frameworks (Hill et al. 2018). The recently released Wetlands (Conservation and Management) rules 2017 completely ignores irrigation tanks as potential sites for conservation.

Prioritising areas for conservation requires quantitative and systematic processes that captures biodiversity and landscape complexity (Brooks et al. 2006; Wilson et al. 2009). The high spatiotemporal variability of natural dry land wetlands is characterised by extreme variations in water availability (Ward et al. 1999). Even in irrigated artificial wetlands in dry areas, this variability exists though it is dampened by the effect of reservoirs supplying water to the small wetlands during the dry periods or during poor monsoons. However, the ecological effects of such artificially induced variability on aquatic biodiversity is poorly understood in the artificial wetland context and would require long-term ecological datasets at appropriate scales to address knowledge gaps (Bino et al. 2015). Recent country wide estimates of waterbirds in India based on citizen science data indicates a strong short term (5 year) decline of many species (SOIB 2020). Many of these records have come from popular sites, such as birdwatcher's hotspots, wildlife sanctuaries and parks reported in the media, however we need systematic monitoring from lesser known but potentially important regions to assess the trends of waterbirds for any prioritization effort. More so as irrigation tanks fed by rain or canals and not part of protected areas need to be assessed for bird diversity. Assessing trends of waterbirds in such areas and identifying priority areas for conservation is essential (Wang et al. 2018; Ethier et al. 2020).

The Tamiraparani river basin in south Tamil Nadu, India has numerous irrigation tanks. The perrenial river that orginates in the Western Ghats supplies water to over 1059 irrigation tanks through a network of large reservoirs and interlinking canal system that is more than 500 years old. All the tanks receive water by October (coinciding with the start of the North-east monsoon) and water is available until March–April. By late August–September many of them turn dry (lean period).

These tanks are the final wintering site for most of the migrants and provide foraging and nesting sites for resident birds. However, the few protected areas in the region do not adequately cover the distribution of waterbird populations, for example, several un-protected heronries and few protected areas in the basin support breeding populations of

Painted Storks *Mycteria leucocephala*, Spot-billed Pelicans (*Pelecanus philippensis)* and several other waterbird species (Subramanya 2005; Abhisheka et al. 2013; Ganesh et al. 2014; Frank et al.2021). In addition, for species that often change breeding sites, conservation and management interventions should be taken at a landscape level rather than at specific sites (Wyman et al. 2014). Prioritizing wetlands based on their importance as nest sites and major stopovers for migrants is much needed to conserve waterbirds, especially in areas that are at the limits of their migratory routes or critical breeding areas.

In this study, through an extensive annual winter monitoring program covering over 100 irrigation tanks spread over an area of ~ 3100 km^2 and sampled for 12 winters, we determine the trends in species richness and abundance of waterbirds in the region. In addition, we surveyed the tanks for 4 years in lean period to identify critical tanks that support waterbirds during water scarcity. Based on this study we identify critical wetlands for conservation using the winter and summer counts in the region. The objectives of the study are to:

A) Determine the trend in species richness and abundance of waterbirds across years for both resident and migratory species.
B) Identify particular species and guilds of waterbirds that show a decline across years
C) Priortize tanks for sustaining waterbird populations in the area.

Study area

The study was conducted in the Tamiraparani river basin, falling within the Tirunelveli and Thoothukudi districts of southern Tamil Nadu (Fig. 1). The boundaries of the study area are between 8° 26′ 45″ and 9° 12′ 00″ E, 77° 09′ 00″

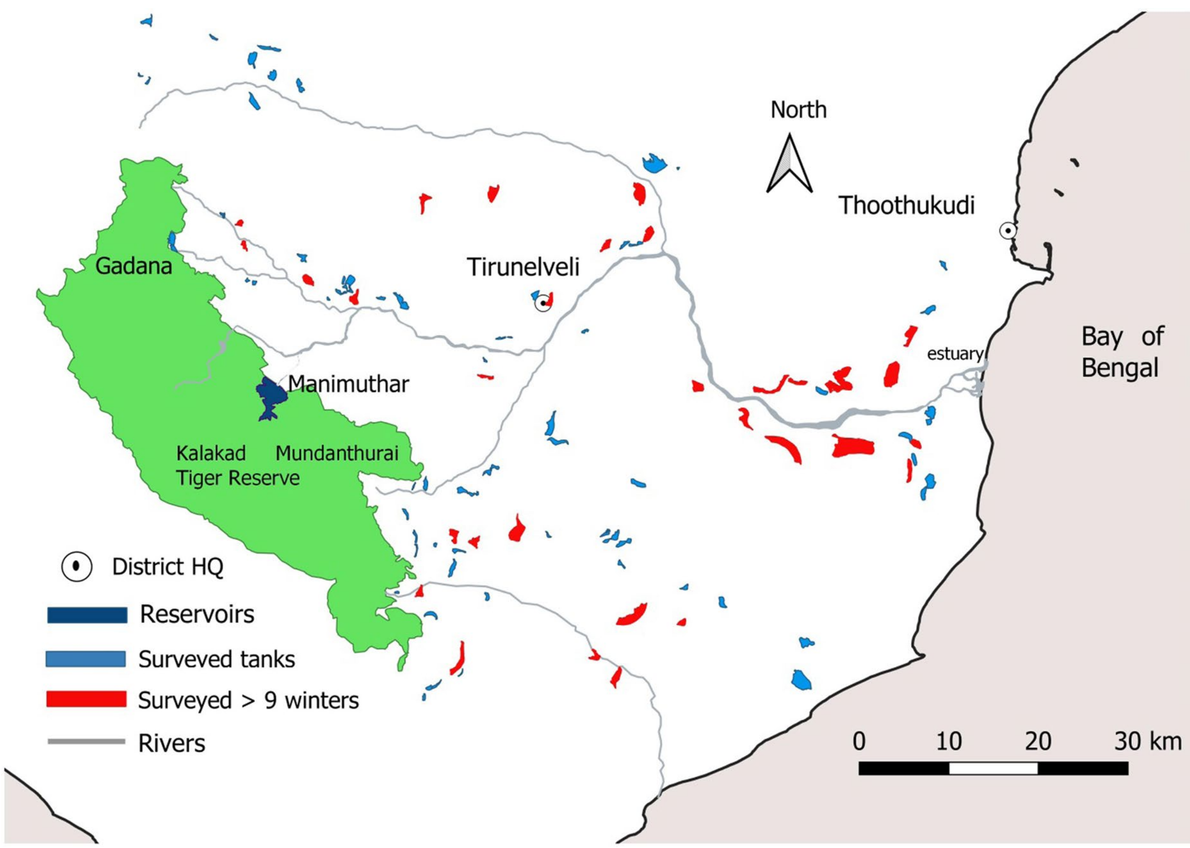

Fig. 1 Map of the Tamiraparni river basin indicating the wetlands/tanks surveyed during the mid-winter period of 2011–22

and 78° 08′ 30″ N. The entire basin covers an area of over 3100 km^2. The river is perennial and originates in the adjoining western Ghats (Kalakad Mundanthurai Tiger Reserve, Fig. 1.) mountains at an altitude of 1500 m. It traverses the hills and plains of the two districts for a distance of 126 km before draining into the Bay of Bengal. About 14 tributaries join the Tamiraparani river at various points along the river stretch. The plains of the two districts forming the river basin, lie in the leeward side of the western Ghats and have been classified as semi-arid zones. The main source of water is from rivers (through canals) and supplemented by monsoon rains. The region is influenced both by the north-east monsoon (October to December) and south-west monsoon (June–August). While the north-east monsoon affects the plains and lower elevation of the hills, the south-west monsoon is restricted to higher elevations.

Tanks in the basin vary in their size, depth and proportion of aquatic vegetation cover and are surrounded by a matrix of agricultural fields, habitation and roads. Many of the tanks in the basin have foreshore plantations of *Acacia nilotica* trees. These are consequently colonized by waterbirds to form heronries and pelicanries (Ganesh et al. 2014). The habitats in the irrigation tanks are chiefly open water and aquatic vegetation. Some of the common aquatic vegetation include *Eichornia crassipes*, *Pistia stratiotes* (free floating emergents), *Nelumbo nucifera*, *Nymphoides indica*, *Ipomea aquatica*, *Nymphaea pubescens* (rooted floating emergents), *Hydrilla verticillata*, *Vallisneria spiralis*, *Potamogeton nodosus* (submerged) and *Ipomoea carnea* (rooted emergent).

Methods

Irrigation tanks

Teams led by experienced surveyors visited a total of 133 tanks in the entire study period. Tanks chosen for the survey represented all tributaries of the river, rainfed and canal fed tanks. The number of waterbird surveys conducted per tank in the period 2011–2022 varied and totalled to 602 surveys. Tank surveys to document waterbirds varied between a minimum of 39 and a maximum of 68 tanks per year depending on time and logistics. Two reservoirs (dams) were surveyed only during the drought period (2017 January) when the other tanks did not hold any water due to low rainfall in 2016.

Waterbird survey

Teams of surveyors and volunteers conducted the waterbird counts during the last week of January every year from 2011 to 22. This period coincides with the mid-winter waterbird surveys done across the larger parts of Asia and in a period where migratory birds have settled in their final wintering sites (Li et al. 2009). In order to survey the tanks systematically and to involve public participation from the two districts, news regarding the waterbird survey were broadcast in local news and social media platforms. Interested citizens were encouraged to register for the survey and we trained the participants on the protocols involved in data collection and guidelines for the identification of waterbirds. Training of volunteers involved introduction to waterbird field guides, identification of waterbirds, census methods and guidelines to make entries in census data sheets. Volunteers assisted the experienced surveyors in either spotting or to make entries in data sheets to build capacity for future surveys. Identification and counting was solely done by the experienced surveyors. The participants were then segregated and assigned to survey a group of tanks with the lead taken by an experienced surveyor capable of identifying the waterbirds and familiar with counting techniques. The survey was completed within two days and tanks were surveyed during bright daylight hours between 6:30 am–10:00 am and 3:00–5:00 pm with a single team assigned to cover 6–7 tanks and surveyors were advised to abandon surveys during rain, however during the surveys no such events were witnessed. Counts were always supervised by the experienced surveyor and other participants were assigned to record data. Surveyors and volunteers made use of 8 × 40, 10 × 50, 12 × 50 binoculars, spotscopes for large tanks and digital cameras to document and identify birds. Birds were exclusivley recorded by sightings alone and the aid of calls were only used by the experienced surveyor to locate birds and not for detection.

Teams walked along the tank bund and the immediate periphery between the edge of the high water line and farmland to document water bird species richness and abundance in the tank. Waterbirds were identified to the species level and were marked as unidentified when they were located too far for confident identification.

Waterbirds were grouped based on genera if species identification was uncertain. Species count for all waterbird species encountered was tabulated in a data sheet with the help of volunteers at the time of the survey. Only wetland dependent species were counted. In tanks where the single observer could not count all species, division of tasks to count different groups and families by different observers were employed and inexperienced members of a team assisted in filling in data forms and registering habitat-related variables. Total count/complete census was employed in all tanks to count the waterbirds (Gibbons 2006; Bibby et al. Bibby et al. 2000). The time spent in each tank varied depending on the size of the tank.

A pre-winter dry season survey during periods of water scarcity was done in September 2019, 2020, 2021 and 2022 by using the same census techniques. This survey was to identify critical tanks that could buffer waterbird populations during the dry period.

Guild classification of waterbirds

Since many of the waterbird species are migrants from the Palaearctic region to the Indian subcontinent, the foraging strata and feeding guild classifications of waterbirds that we used followed Wilman et al. (2014). Based on personal observations, and habitats available in the irrigation tanks, we created an additional foraging stratum classification for vegetation dependent waterbirds. Birds classed under vegetation strata are dependent on the reeds and other vegetation in the tanks for both foraging and breeding. These include: White-breasted Waterhen *Amaurornis phoenicurus*, Watercock *Gallicrex cinerea*, Purple Swamphen *Porphyrio porphyrio*, Pheasant-tailed Jacana *Hydrophasianus chirurgus*, Painted Snipe *Rostratula benghalensis*, Bronze-winged Jacana *Metopidius indicus*, Yellow Bittern *Ixobrychus sinensis*, and Black Bittern *Dupetor flavicollis*.

Prioritising tanks

Tanks were sorted from high to low based on the average of the total counts of birds for the entire winter sampling period of 12 years and four September sampling years to identify tanks with most number of birds. Tanks common to all surveyed years were only used. Counts of migratory, resident species, feeding guild, declining families and species were ranked 1,2,3.. based on count numbers, from high to low. This is a novel approach as it prevents the bias of a single large tank or group such as ducks which are often high in numbers, affecting the ranking thereby giving weightage to the presence of other groups and species. The total rank was obtained by summing all the individual ranks. Top 15 tanks with lowest rank (high counts) were selected for each season.

Data analysis

Data cleaning and analysis were carried out using Microsoft Excel®, PAST® and R version 4, R Studio (2019), and Quantum GIS 3.14.15. Data cleaning involved the cross verification of uncommon species by co-ordinators writing to surveyors, and in case of high counts of common species to confirm the occurrence of large congregations, Outliers were not excluded since the abundance of waterbirds species is known to be skewed over 12 years of monitoring and all data recorded was considered for analysis. To avoid spurious results caused by rare and infrequent species, we selected species with at least 70 individuals recorded in 9 + surveys years.

Population trend

To quantify wintering bird population trends, we used generalized additive mixed models (GAMM) to determine non-linear population trends (Knape 2016) and specifically used for waterbirds (Wang et al. 2018). We used the package *poptrend* in R program to fit a log-linear model of bird abundance with year as a fixed variable and site as a random factor using a quasi-poisson distribution (Knape 2016; R Core Team 2019). We chose the data distribution based on the examination of model residuals (Bell et al. 2020) and this varied between species. Since the focus of analysis was to get uncertainity in trends, we used random year effects to give more realistic estimates of long-term trends using automatic selection of df as recommended by Knape 2016. We used the smoothing option in *poptrend* to display significant changes in trends between years. The trend graphs in the *poptrend* module indicates significant short term (between years) changes. The solid lines indicates estimated long-term trends. The trend lines are colored for the period with significantly increasing (green) or decreasing (orange) trends. Vertical lines and blue shaded areas indicate the 95% confidence intervals. The green rectangle at the bottom of panels indicate periods with significantly positive curvature and orange rectangles for negative trend. The y-axis shows the partial residuals of the years in the generalized additive mixed models.

We used the function *change* in package poptrend to estimate the percentage of population change; we considered that there was a significant trend when the standard errors did not overlap with zero. The function *change* computes the estimated change between two chosen time points using a GAM model. When random effects are present, the change is computed for the underlying linear or smooth trend term. Positive values indicated increasing trends whereas negative values indicated decreasing trends. (Wang et al. 2018; Sung et al. 2021).

Results

Species richness and abundance

A total of 94 species were identified from the 133 tanks sampled. Of these 89 species were recorded in 31 wetlands that were sampled for 9–12 years. Of the total count of the birds 59% were resident birds that accounted for 52 species, and, remaining 37 species were migratory birds. The most abundant species were Common Coot *Fulica atra*, Cattle Egret *Bubulcus ibis* and Lesser Whistling Duck *Dendrocygna javanica* contributing to 29% of total numbers. Little Cormorant *Microcarbo niger*, Cattle Egret, Indian Pond Heron *Ardeola grayii* and Little Egret *Egretta garzetta* were the most widespread species found in more than 70% of the tanks surveyed.

Waterbird trends

Long term linear trends in species richness (with 95% confidence intervals) show a marginal decline −2.4% (−26%, 30%) but not significantly across years. However, short term trends show a drastic decline during 2017, the year following the drought of 2016 and increased in 2018 (Fig. 2). The long term trend in total abundance showed a stronger decline −65% (−78%, −44%) with considerable short term variations between years (Fig. 2). Similarly total counts of migrant waterbirds declined significantly -64%(-85%, -18%) but only marginally in resident waterbirds −27%,(−61%, 46%) (Fig. 3). In all the categories there is some recovery after 2020. Of the 50 species for which reliable trend estimates could be obtained, 14 species showed a declining trend of which 12 were residents and 2 winter migrants (Table 1, Fig. 4). There was only one species, the Darter that showed an increasing trend.

When compared with nation wide trends trends (SOIB 2020), ten species that declined in our study area also declined across the country (Table 2). Only the Red-naped Ibis *Pseudibis papillosa* showed a contrasting trend.

Influence of drought

There was a drastic decline in bird abundance and mean richness during Jan 2017 due to drought in 2016 when both the setting-in and retreating monsoons failed. Mean abundance declined by 69.7% and mean richness by 53.9% from the previous year. In the drought year, the highest number of birds were recorded in Manimuthar reservoir (2342 birds), which was 30% of the total birds recorded during the survey in 2017. Northern Pintail (1000 birds), Comb Duck (872 birds) formed the vast majority of the birds recorded in the reservoir.

We compared the trends at the species and family level before and after the 2017 drought period to understand the effect of 2016 drought on long term trends. Ten out of 50 species for which reliable trend could be estimated declined in the time period 2011–2016 before the drought. Six species declined after the drought 2018–2022 period. Only Red-naped Ibis, Bronze winged Jacana and

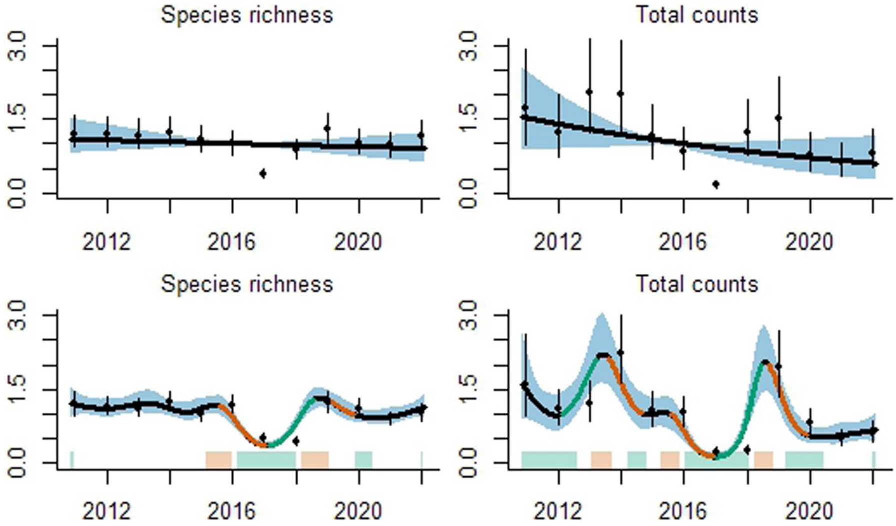

Fig. 2 Pattern of species richness and abundance recorded between the years 2011–2022. The top two graphs show long term trends and the bottom two short term trends. Solid coloured lines indicate estimated trends. The trend lines are coloured green for significantly increasing and orange for decreasing trends respectivley. Vertical lines and blue shaded areas indicate the bootstrap 95% confidence intervals. The green and orange rectangles at the bottom of graph panels indicate periods with significantly positive and negative curvature

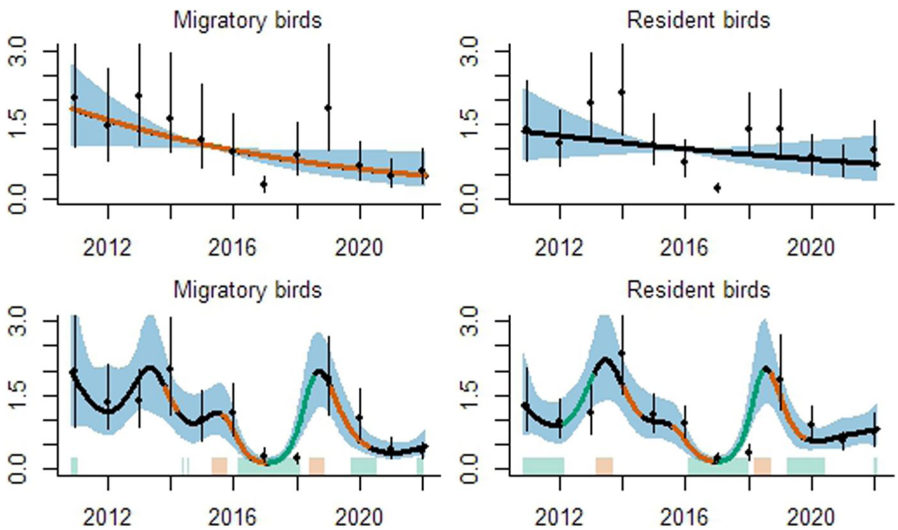

Fig. 3 Pattern of species richness and abundanceof waterbirds recorded between the years 2011–2022

Purple Swamphen continued to decline after the drought year. Many common and abundant species such as the Little cormorant and Cattle egret showed a declining trend after the drought. However, 7 species showed a positive trend after the drought this included the kingfishers, Bar-headed Goose and Black-tailed Godwit. Total abundance and migrants continued to decline before drought but was stable after that. The species rich invertebrate feeding guild (14sp) showed a declining trend prior to the drought year and not later. The overall trend was also not declining and it had one species (Gull-billed Tern) that was declining (Table 3). The fish eating guild contained 17species two of

Table 1 Estimated percentage change in abundance for 50 waterbird species in the irrigation tanks of Tamiraparani river basin from 2011 to 2022 calculated by generalized additive mixed models using the package poptrend in software R

Species	Family	Feeding guild	Strata guild	2011–2022	2011–2016	2017–2022
Winter Migrants						
Bar-headed Goose (*Anser indicus*)	Ducks	Plant seed	Shallow water	108% (−11%, 389%)	7.9% (−56%, 178%)	719% (150%, 2367%)
Eurasian Wigeon (*Anas penelope*)	Ducks	Plant seed	Deep and shallow water	−99% (−100%, 2374%)	19% (−86%, 883%)	−97% (−100%, 8730%)
Northern Shoveller (*Anas clypeata*)	Ducks	Invertebrate	Shallow water	−98% (−100%, 600%)	−56% (−99%, 1396%)	−99% (−100%, 149%)
Northern Pintail (*Anas acuta*)	Ducks	Plant seed	shallow water	−44% (−86%, 129%)	−44% (−77%, 46%)	−67% (−93%, 68%)
Garganey (*Anas querquedula*)	Ducks	Omnivore	Deep and shallow water	−18% (−54%, 56%)	21% (−87%, 941%)	−20% (−91%, 506%)
Western Marsh Harrier (*Circus aeruginosus*)	Raptor	Vertfishscav	Shallow water	**−96% (−100%, −23%)**	−37% (−81%, 136%)	−83% (−97%, 30%)
Black-tailed Godwit (*Limosa limosa*)	Waders	Invertebrate	Shallow water	140% (−30%, 713%)	−100% (−100%, 2292%)	1685% (234%, 8255%)
Green Sandpiper (*Tringa ochropus*)	Waders	Invertebrate	Water edge	−68% (−97%, 248%)	−84% (−99%, 228%)	**−92% (−99%, −43%)**
Wood Sandpiper (*Tringa glareola*)	Waders	Invertebrate	Water edge	−20% (−81%, 252%)	**−87% (−98%, −11%)**	269% (−16%, 1804%)
Common Sandpiper (*Actitis hypoleucos*)	Waders	Omnivore	Water edge	139% (−78%, 2644%)	245% (−69%, 4138%)	−71% (−94%, 50%)
Gull-billed Tern (*Gelochelidon nilotica*)	Terns	Invertebrate	Deep and shallow water	**−82% (−95%, −26%)**	−59% (−87%, 29%)	250% (−61%, 3054%)
Whiskered Tern (*Chlidonias hybridus*)	Terns	Vertfishscav	Water edge	239% (10%, 916%)	−76% (−91%, −37%)	2.4% (−48%, 105%)
Yellow Wagtail (*Motacilla flava*)	Wagtails	Invertebrate	Land	−99% (−100%, 45367%)	−87% (−100%, 943%)	−97% (−100%, 2117%)
Resident Birds						
Lesser Whistling-Duck (*Dendrocygna javanica*)	Ducks	Plant seed	Deep and shallow water	−68% (−100%, 7355%)	87% (−76%, 1281%)	−73% (−96%, 129%)
Comb Duck (*Sarkidiornis melanotos*)	Ducks	Plant seed	Shallow water	1334% (−78%, 54,618%)	2440% (−47%, 91,969%)	−74% (−96%, 70%)
Cotton Pygmy-goose (*Nettapus coromandelianus*)	Ducks	Plant seed	Deep and shallow water	**−79% (−93%, −45%)**	−72% (−99%, 466%)	15% (−95%, 2338%)

Table 1 (continued)

Species	Family	Feeding guild	Strata guild	2011–2022	2011–2016	2017–2022
Indian Spot-billed Duck (*Anas poecilorhyncha*)	Ducks	Plant seed	Shallow water	**−62% (−77%, −30%)**	**−76% (−92%, −30%)**	−27% (−70%, 76%)
Little Grebe (*Tachybaptus ruficollis*)	Ducks	Invertebrate	Deep and shallow water	−77% (−90%, −49%)	**−72% (−90%, −8.7%)**	185% (14%, 644%)
Painted Stork (*Mycteria leucocephala*)	Storks	Vertfishscav	Shallow water	19% (−58%, 349%)	−58% (−92%, 124%)	156% (−19%, 838%)
Asian Openbill Stork (*Anastomus oscitans*)	Storks	Invertebrate	Shallow water	23% (−85%, 1094%)	−64% (−96%, 226%)	791% (216%, 2374%)
Black-headed Ibis (*Threskiornis melanocephalus*)	Ibis	Vertfishscav	Shallow water	108% (1.9%, 394%)	7.9% (−55%, 164%)	719% (159%, 2145%)
Red-naped Ibis (*Pseudibis papillosa*)	Ibis	Omnivore	Land	**−76% (−93%, −16%)**	**−74% (−92%, −12%)**	**−71% (−91%, −3.4%)**
Glossy Ibis (*Plegadis falcinellus*)	Ibis	Invertebrate	Shallow water	464% (−80%, 15,429%)	305% (−91%, 11,042%)	−42% (−95%, 691%)
Eurasian Spoonbill (*Platalea leucorodia*)	Egrets	Invertebrate	Shallow water	−90% (−100%, 126%)	−84% (−99%, 236%)	191% (−91%, 16,318%)
Indian Pond Heron (*Ardeola grayii*)	Heron	Omnivore	Shallow water	11% (−57%, 171%)	−4.4% (−61%, 132%)	130% (−7%, 475%)
Grey Heron (*Ardea cinerea*)	Heron	Vertfishscav	Shallow water	**−54% (−78%, −5.9%)**	**−66% (−84%, −25%)**	109% (−14%, 372%)
Purple Heron (*Ardea purpurea*)	Heron	Vertfishscav	Water edge	−63% (−91%, 58%)	28% (−29%, 144%)	35% (−41%, 214%)
Cattle Egret (*Bubulcus ibis*)	Egrets	Invertebrate	Land	79% (−4.3%, 229%)	−17% (−68%, 150%)	**−73% (−86%, −44%)**
Large Egret (*Casmerodius albus*)	Egrets	Vertfishscav	Shallow water	−44% (−79%, 53%)	**−79% (−93%, −35%)**	109% (−23%, 456%)
Median Egret (*Mesophoyx intermedia*)	Egrets	Vertfishscav	Shallow water	**−48% (−73%, −6.1%)**	−41% (−85%, 122%)	−7.2% (−71%, 185%)
Little Egret (*Egretta garzetta*)	Egrets	Vertfishscav	Shallow water	−35% (−74%, 78%)	−85% (−96%, −44%)	4% (−59%, 160%)
Spot-billed Pelican (*Pelecanus philippensis*)	Ducks	Vertfishscav	Deep water	**−57% (−79%, −10%)**	−71% (−93%, 8.2%)	−30% (−75%, 103%)
Darter (*Anhinga melanogaster*)	Cormorants	Vertfishscav	Deep water	70% (−67%, 1044%)	−15% (−81%, 285%)	167% (−28%, 851%)
Little Cormorant (*Phalacrocorax niger*)	Cormorants	Vertfishscav	Deep water	−37% (−80%, 102%)	19% (−62%, 228%)	−74% (−90%, −30%)

Table 1 (continued)

Species	Family	Feeding guild	Strata guild	2011–2022	2011–2016	2017–2022
Indian Cormorant (*Phalacrocorax fuscicollis*)	Cormorants	Vertfishscav	Deep water	99% (−93%, 6497%)	24% (−96%, 2938%)	55% (−94%, 3676%)
Brahminy Kite (*Haliastur indus*)	Raptor	Vertfishscav	Deep and shallow water	16% (−56%, 188%)	−20% (−71%, 114%)	16% (−52%, 181%)
White-breasted Waterhen (*Amaurornis phoenicurus*)	Rails	Omnivore	Vegetation	66% (−91%, 2637%)	39% (−95%, 2262%)	284% (−76%, 6321%)
Purple Swamphen (*Porphyrio porphyrio*)	Rails	Plant seed	Vegetation	**−99% (−100%, −49%)**	−29% (−63%, 42%)	**−99% (−100%, −47%)**
Common Moorhen (*Gallinula chloropus*)	Rails	Omnivore	Deep and shallow water	−15% (−81%, 302%)	−74% (−95%, 76%)	−69% (−91%, 7.2%)
Common Coot (*Fulica atra*)	Ducks	Plant seed	Deep and shallow water	−61% (−93%, 122%)	−60% (−92%, 76%)	−46% (−90%, 141%)
Pheasant-tailed Jacana (*Hydrophasianus chirurgus*)	Jacana	Omnivore	Vegetation	**−65% (−82%, −28%)**	−45% (−92%, 312%)	34% (−69%, 432%)
Bronze-winged Jacana (*Metopidius indicus*)	Jacana	Plant seed	Vegetation	**−100% (−100%, −91%)**	**−60% (−83%, −0.98%)**	**−100% (−100%, −72%)**
Black-winged Stilt (*Himantopus himantopus*)	Waders	Invertebrate	Shallow water	4.9% (−70%, 250%)	−82% (−97%, 4.8%)	−38% (−75%, 56%)
Red-wattled Lapwing (*Vanellus indicus*)	Waders	Invertebrate	Land	−16% (−64%, 71%)	−36% (−73%, 52%)	43% (−35%, 210%)
Little Ringed Plover (*Charadrius dubius*)	Waders	Invertebrate	Land	−92% (−100%, 147%)	−93% (−100%, 155%)	98% (−97%, 10,502%)
River Tern (*Sterna aurantia*)	Terns	Omnivore	Deep water	−31% (−100%, 16,670%)	−33% (−75%, 65%)	−28% (−64%, 41%)
White-breasted Kingfisher (*Halcyon smyrnensis*)	Kingfisher	Vertfishscav	Water edge	1.3% (−42%, 80%)	−97% (−100%, −82%)	288% (75%, 812%)
Lesser Pied Kingfisher (*Ceryle rudis*)	Kingfisher	Vertfishscav	Deep water	**−63% (−84%, −16%)**	−53% (−83%, 40%)	404% (39%, 1704%)

Table 1 (continued)

Species	Family	Feeding guild	Strata guild	2011–2022	2011–2016	2017–2022
White-browed Wagtail (*Motacilla maderaspatensis*)	Wagtails	Invertebrate	Land	**−76% (−91%, −23%)**	−15% (−82%, 300%)	71% (−79%, 1260%)

Species marked in bold are indicating declining trends. Tanks that were sampled for 9 and more years were only used in the analysis

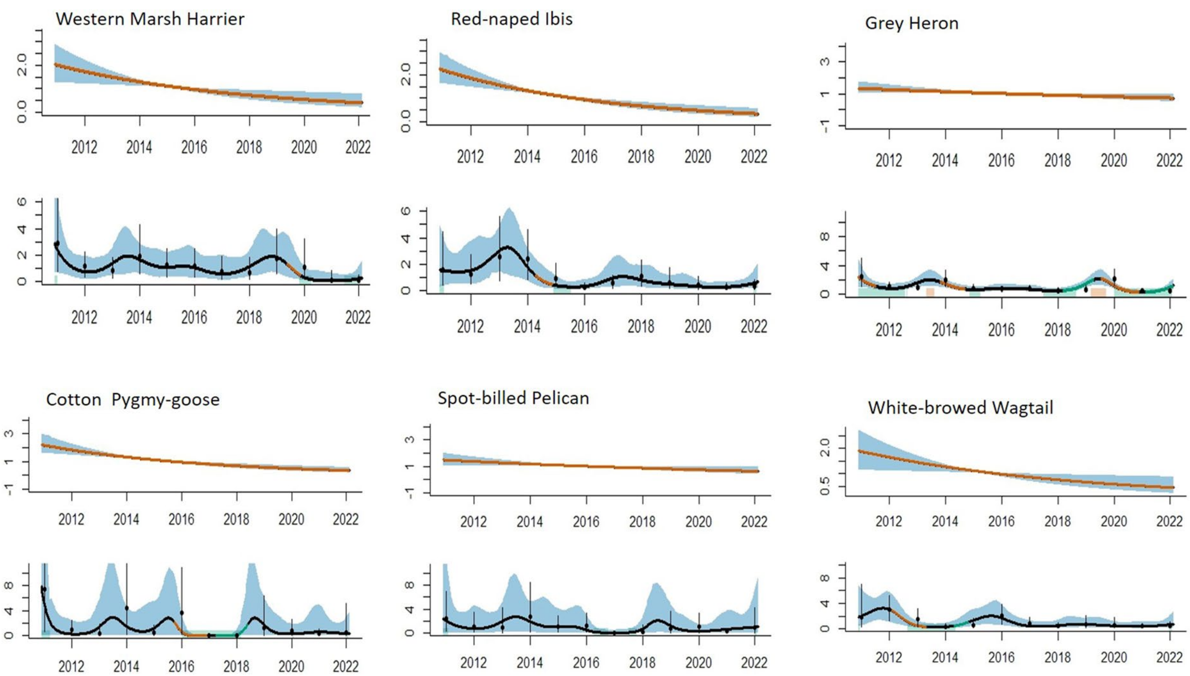

Fig. 4 Waterbird species showing a declining trend. The solid red indicates significant trend. Both long term linear trend and short term fluctutations are indicated in the two figures for each species

which showed a declining trend but the guild as a group did not show a consistent decline both before and after drought year. Plant feeding guild (10sp) declined significantly overall and included two declining species; Bronze-winged Jacana and Purple Swamphen. The omnivore guild did not show any decline and had one species Red-naped Ibis on decline. We did not do a separate trend analysis at the strata level because of fewer samples. At the family levels ducks decline before and after the drought year while herons and kingfishers show a positive trend after the drought. Plovers and Swamphens show only overall decline.

Priority tanks

Priority tanks were selected based on the total winter and dry season counts, counts of declining species and family groups and diversity of feeding guilds in the tanks (Table 4). We selected the top 15 tanks from winter and summer sampling based on the abundance of the birds in the tanks which together accounted for 60% of the total abundance found in the area. In winter Arumugamangalam, Maanur, Kadambakulam, Vijaynarayanam, Prancheri periyakulam, Tenkaraikulam, Nallur,Velur, Melpudukudi Sunai, Srivaikundam Kaspa, Peykulam are important while in

Table 2 SOIB trends of waterbirds that showed a declining trend in our study area

Species	Current trend (2015–2020)	Long term trend (> 25 years)
Cotton Pygmy-goose	Strong Decline	Strong Decline
Indian Spot-billed Duck	Moderate Decline	Stable
Little Grebe	Strong Decline	Stable
Red-naped Ibis	Uncertain	Strong Increase
Grey Heron	Uncertain	Stable
Median Egret	Strong Decline	Stable
Spot-billed Pelican	Uncertain	Uncertain
Western Marsh Harrier	Uncertain	Stable
Purple Swamphen	Strong Decline	Uncertain
Pheasant-tailed Jacana	Uncertain	Moderate Decline
Bronze-winged Jacana	Moderate Decline	Stable
Gull-billed Tern	Uncertain	Strong Decline
Lesser Pied Kingfisher	Strong Decline	Moderate Decline
White-browed Wagtail	Strong Decline	Moderate Decline

Table 3 Percentage change calculated by *change* function at the family/group level with drought and without drought year (2017)

Guilds	2011–2022	2011–2016	2018–2022
Total	**−65% (−78%, −44%)**	**−56% (−72%, −31%)**	−37% (−61%, 1.2%)
Migrants	**−64% (−85%, −18%)**	**−88% (−95%, −72%)**	−54% (−94%, 250%)
Residents	−27% (−61%, 46%)	−42% (−70%, 21%)	−36% (−65%, 17%)
Omnivore	5.2% (−50%, 102%)	−30% (−67%, 42%)	−48% (−71%, −6.1%)
Plant matter	**−82% (−95%, −36%)**	−36% (−80%, 89%)	−65% (−94%, 79%)
Invertebrates	**−61% (−75%, −37%)**	**−61% (−82%, −12%)**	10% (−44%, 112%)
Fish eaters	8.2% (−47%, 115%)	−37% (−73%, 38%)	1.3% (−51%, 100%)
Family			
Cormorants	58% (−39%, 306%)	17% (−55%, 210%)	−26% (−63%, 61%)
Ducks	**−91% (−97%, −74%)**	**−60% (−82%, −21%)**	**−69% (−89%, −2%)**
Egrets	29% (−46%, 202%)	−40% (−71%, 42%)	−27% (−90%, 311%)
Herons	−38% (−64%, 8.2%)	−45% (−69%, 2.8%)	71% (5.5%, 174%)
Kingfishers	6.1% (−49%, 141%)	−81% (−92%, −49%)	450% (96%, 1353%)
Plovers	**−73% (−92%, −1.3%)**	−67% (−90%, 16%)	24% (−69%, 398%)
Raptors	−8.8% (−60%, 118%)	−25% (−68%, 87%)	33% (−47%, 241%)
Storks	51% (−71%, 643%)	−52% (−92%, 154%)	288% (−26%, 1913%)
Swamphens/Rails/Jacanas	**−79% (−93%, −36%)**	−26% (−70%, 77%)	−23% (−66%, 70%)
Terns	−8.9% (−63%, 138%)	−73% (−99%, 612%)	93% (−26%, 363%)
Waders	11% (−50%, 152%)	−45% (−79%, 43%)	15% (−43%, 124%)
Wagtails	−94% (−100%, 140%)	−81% (−99%, 382%)	−62% (−99%, 1888%)

Groups marked in bold show declining trend

the dry season Kadambakulam, Melpudukudi Sunai, Karungulam, Perungulam, Srivaikundam Kaspa, Tenkarikulam, Velur, and Prancheri periyakulam, are important for waterbird congregations and richness. Seven tanks Armugamangalam, Kadambakulam, Melpudukudi Sunai, Srivaikundam Kaspa, Vagaikulam, Prancheri periyakulam and Tenkarikulam are common to both winter and summer. While most of these are large tanks concentrated to the east end of Thoothkudi district some like Vagaikulam and Prancheri are smaller and in the central part of the sampling area. Such tanks need to be prioritised for conservation efforts in addition to the other tanks mentioned.

Table 4 Identification of *priority* tanks based on winter and summer samples, the declining mean abundance of migratory species, resident species, families, and foraging guilds. Ranks are given for each group and species based on their mean counts in the tanks. The total rank score is sum of species, family, guild present in the tanks sampled. The top 15 tanks are shown here that account for 60% of the abundance. A low total rank signifies high priority tanks (last column).

WINTER	Mean species richness	Mean Counts	Migra tory	Resident	Plant matter	Inverte brates	Ducks	Plovers	Swam-phens/ jacanas	Total Rank
Kadamba kulam	13	4929	3114	1817	1862	318	4257	33	198	78
Velur	11	2438	1002	1437	1399	212	1883	7	63	135
Arumugamangalam	10	2959	609	2351	1789	144	2292	8	304	162
Mel pudukudi sunai	10	1270	441	833	738	120	1109	6	52	178
Nallur	12	1230	394	837	578	153	781	6	56	178
Peykulam	11	976	245	732	335	114	491	5	50	262
Vagaikulam	12	753	41	712	87	299	116	11	15	282
Tenkaraikulam	10	1206	748	459	494	114	839	13	6	294
Srivaikundam kaspa	10	1055	475	580	250	139	593	1	11	302
Vijayanarayanam	9	943	411	539	313	140	410	22	2	319
Authoor	10	601	78	523	268	69	338	5	36	318
Perurkulam	10	690	121	569	230	58	296	2	42	321
Karungulam	9	759	319	441	252	149	454	3	25	340
Maanur	6	766	409	361	172	154	386	33	1	347
Prancheri periyakulam	12	324	27	297	139	50	154	13	19	352
SUMMER										
Kadamba kulam	9	564	43	521	20	208	136	25	23	155
Perungulam	8	2510	244	2266	1	1207	658	19	1	176
Vagaikulam	9	286	5	281	21	104	77	16	27	193
Rajavallipuram	6	408	9	399	33	79	225	27	40	199
Arumugamangalam	8	1196	0	1196	89	287	621	2	125	204
Karungulam	8	418	26	392	11	71	187	4	12	204
Srivaikundam kaspa	5	716	25	690	92	193	452	3	102	208
Mel Pudukudi Sunai	7	622	2	620	9	57	425	6	8	221
Prancheri periyakulam	8	336	5	331	11	24	262	2	12	244
Palamadai	6	288	7	282	3	97	122	6	9	249
Adaichani periyakulam	7	257	9	248	0	86	105	5	0	263
Kalkurichi kulam	6	271	85	186	0	52	133	14	0	267
Thirukurangudi	7	210	1	209	0	65	102	10	0	279
Sivakalai	7	268	2	267	6	56	204	2	6	281
Thenkaraikulam	5	245	15	231	0	69	58	3	0	285

Tanks important in both seasons are in bold

Discussion

The survey in the Tamiraparani river basin, south India is the first comprehensive long term assessment of waterbirds at irrigation tanks in a river basin and at a landscape level in the country, while previous surveys targeted specific tanks (Srinivasulu et al. 1996; Neelgund and Kadadevaru 2020), or were either assessed for a shorter duration, or were primarily concentrated around urban centres (Chakrapani et al.

1990; Krishna et al. 1996; Sundar and Kittur 2013). Thus, this long-term survey has helped understand species composition in the tanks, their abundance and distribution, population trends and aided identification of important tanks for waterbird conservation in this river basin.

The twelve year survey revealed that the waterbird community in the irrigation tanks of Tamiraparani basin was dominated by species of the family *Anatidae, Ardeidae* and *Scolopacidae* (in terms of number of species) which was similar to other irrigation tanks in the country (Srinivasulu et al. 1996; Ali et al. 2013; Kumar et al. 2016; Neelgund and Kadadevaru 2020). Globally these three families are the most diverse bird groups (in addition to *Rallidae*) in freshwater wetlands (Dehorter and Guillemain 2008). Individual species counts also indicated a similar trend with members of the family *Anatidae, Ardeidae and Rallidae* dominating in terms of abundance. Though species richness was high in Scolopacids, they were less abundant in comparison to other groups. Worldwide, dabbling and wading birds (mostly *Anatidae, Ardeidae and Scolopacidae*) are the most dominant waterbird groups (Ma et al. 2010).

Across the twelve years, there was variation in species richness and abundance. The trend in species richness was stable, but there was a higher fluctuation in abundance with highs in 2013, 2014 and low in 2017. The high abundance in 2013 was due to migrant duck flocks and Common Coot congregations. Together they comprised 42% of total abundance (Coot 20.7%, Unidentified ducks 21.8%). In 2014, the high abundance was due to Common

Coot congregations which contributed to 32.8% of total bird numbers. Approximately 82% of overall Coot numbers were recorded during 2013 and 2014. Coots are both migratory and resident in most parts of the world (Gorenzel et al. 1981; Ali & Ripley 1987; Guillemain et al.2014) and sudden appearances of Coots in wetlands are known to alter water bird abundance significantly (White 1987). Pooled counts excluding the ones from Coots did not alter the trend − 82% (− 93%, − 53%). The high abundance in 2013, 14 from the study area could be due to the arrival of winter migrants in large numbers; However, the subsequent years did not show such a trend and the causal factors could not be established.

Influence of drought

In 2017, bird abundance was low due to poor north-east and south west monsoon rains in 2016 leading to drought. Total rainfall during the north-east monsoon season decreased by 75% from the previous year (2015) in Thoothukudi district and by 83% in Tirunelveli district. During this year (2017), 68% of the surveyed tanks had little or no water. Large tanks in Thoothukudi district which consistently report high bird numbers, recorded very low abundance during 2017. In such situations, waterbirds shift to alternative habitats where conditions are more favourable (Gaines et al. 2000; White 1987). Coastal wetlands have been known to provide alternative habitats to waterbirds when inland wetlands turn dry (Derksen and Eldridge 1980; Barbaree et al. 2020). However, we did not undertake surveys along the coasts and hence could not ascertain the importance of coastal wetlands as refuge for waterbirds during the drought period. The nearest coastal wetlands to the study area are in Thoothukudi on the eastern side and Kanyakumari district in the southern side. Winter migrants and residents were reported from a few coastal sites during the drought period from the two districts (ebird.org).

Drought did not affect long term trends of species but showed strong short term trends with several species showing recovery after drought and then declining. A few (12) waterbird species such as Red-wattled Lapwings and Painted Storks showed a concurrent increase in abundance in the drought period and corresponding decline in the high rainfall period. The strong decline of resident species such as the Grey Heron did not correspond with low rainfall, probably indicating better adaptability to dry conditions and availability of wet mud conditions in wetlands. Similarly Black-winged Stilts, seem to have found the conditions during the drought period favourable.

There are few large reservoirs in the region which are fed by perennial rivers and holds water even in drought periods. These reservoirs are often deep and not normally suitable for benthic feeders, but appear to become important for birds during droughts and even in dry season when water levels are reduced. Manimuthar dam (a large reservoir in the foothills of Kalakad Mundanthurai Tiger Reserve, Fig. 1) supported significant numbers of Northern Pintail and Comb Duck in the aftermath of the drought in 2016.

The highest count of Comb Duck for the entire eleven year period was recorded at this site. Approximately 75% of the Comb Duck population in the study area had taken refuge in the reservoir during the drought period. Comb Ducks largely use inland wetlands for foraging and hence reservoirs could be critical habitats during drought. Reservoirs constructed for human welfare provide habitats for waterbirds elsewhere (Pandey 1993; Leslie et al.1994; Afdhal et al. 2012) and are very important water bird sanctuaries in areas where natural wetlands have disappeared due to prolonged drought (Joolae et al. 2011). Hence large reservoirs must be included in water bird counts and evaluated for their ability to buffer waterbirds during severe water stress.

Declining waterbirds

We identified 14 species that showed apparent decline. Only two of these (Western Marsh Harrier, Gull billed Tern) were migratory species and the remaining were breeding species in the study area. The national level effort to understand the trends of birds (SOIB 2020) also indicated declines in the above mentioned species. However the findings do not discuss the reasons behind their decline. In Tamil Nadu there is large scale hunting of waterbirds to meet the food market demand, especially large waterbirds such as Spoonbills, Egrets and Spot-billed Pelicans (Ramachandran et al. 2017; thehindu.com 2020; conservationindia.org 2012). Poaching of eggs and juvenile Spot-billed Pelicans led to loss of pelicanries in Kolleru (Andhra Pradesh) and Moondradaipu in the study landscape (Birdlife international 2003; Ganesh et al. 2014). Other than hunting, south Indian wetlands face a multitude of challenges all of which could affect water bird populations. These include conversion to agriculture and aquaculture, cutting of nesting trees, disturbance from fishing activity and use of pesticides in agriculture (Birdlife international 2003: Frank et al. 2021). Gastrointestinal parasites have been a major factor resulting in high mortality rates of Spot-billed Pelicans in southern Karnataka and northern Andhra Pradesh (Kumar et al. 2019; thehindu.com 2022). Parasitic infestation cannot be ruled out in the case of pelican decline as few dead birds were found in the tanks and requires further investigation.

Decline in waders (Family *Scolopacidae*) population in the study area correspond to the global pattern of decline (Zockler et al. 2003; Balachandran 2007). Though species richness was high in waders, they were less abundant in comparison to other groups. Waders rarely foray in large numbers into inland wetlands, which could account for overall low abundance in the sampled tanks. Moreover, when the counts were taken in January, water level was high in the irrigation tanks and the tank margins often covered with dense vegetation which could deter waders. In general, waders prefer natural water bodies along the coast rather than inland wetlands (Bellio et al. 2009), where their food and habitat requirements are met. Tidal fluctuations in coastal areas favours proliferation of invertebrate prey and provide ideal foraging grounds for waders. However, even in coastal areas in the country, their population has declined due to reclamation for salt pans, declining rainfall, and human disturbance (Balachandran 2007). In the study area wader counts were higher in seasonal tanks like Vijayanarayanam where shorelines are devoid of vegetation and proliferation of invasive species is limited. Hence, studying wader abundance in relation to water level fluctuation is required to further explore the potential contribution of these tanks to wader conservation in this region.

The decline of migratory species such as Western Marsh Harrier can be attributed to loss of marshes and grasslands. The large tanks in this region that could have potentially harboured the harrier and even the Cotton Pygmy-Goose are covered by vegetation such as *Eichornea* sp and other invasive and non invasive plant species which are avoided by the Geese. There are only few tanks away from the Tamiraparani river such as Vijaynarayanan and Nanguneri that attracts these birds due to the shore line covered with grassy meadows providing ideal foraging areas for the harriers and even Bar-headed Geese. Many of the meadows around tanks and in adjoining areas are recently cleared scrub and fallow to create real estate and thus may be productive for short periods until the scrub vegetation recovers in the plots. One such feeding and roosting ground of the Western Marsh Harrier in Paruthipadu was cleared to accommodate *Eucalyptus* plantations. Marsh Harriers have declined because of the loss of major roost site that was converted to plantations in the study area in 2017. An independent study on harrier populations also confirms a drastic decline of the species in the region after the loss of the roost site (Saravanan et al. 2021).

Are declining trends a matter of concern?

Country wide assessment of population trends of waterbirds in India was made available from crowd sourced data (SOIB 2020). Ten species (Bronze-winged Jacana, Pheasant-tailed Jacana, Cotton Pygmy-goose, Gull-billed Tern, Lesser Pied Kingfisher, Little Grebe, Little Ringed Plover, Median Egret, Purple Swamphen and White-browed Wagtail) showed declining trend across the country and such a trend was concurrent in the study landscape,

Waterbird trends for countries that fall in the Central Asian flyway, are not accessible and trend comparisons across existing studies are not possible. However, Waterbird Population Estimate (WPE) trends are available for south Asia (Wetlands International 2022). Common Teal which was abundant in large tanks in Tirunelveli in the latter part of the nineteenth century (Flemming 1898) are now found infrequently and in less numbers in both the districts, which is similar to WPE trends. WPE trends also agree with our trends for the Grey Heron. Three species showing a declining trend here, also showed a declining trend in China; namely Common Teal, Grey Heron and Spot-billed Pelican (Wang et al. 2018; Sung et al. 2021) and Common Teal in Japan (Kasahara and Koyama 2010).

Important refuge for resident and migrating waterbirds

Our method of prioritizing tanks by incorporating an index of declining species enabled tanks such as Vijayanarayanam that support species like Bar-headed Goose and Waders to become prominent even though they do not rank in the top 10 priorities based only on total abundance of birds. Many of the prioritized tanks have floating and emergent vegetation along with invasive *Ipomoea carnea* on the shoreline which offer various strata and niche for waterbirds to forage and rest in abundant flocks. The prioritization method also places high priority on large tanks such as Kadambakulam, the largest tank in the region, that contain extensive shorelines and habitat heterogeneity, and those that harbour high concentrations of other non-red list species that require conservation attention.

Tanks such as Kadambakulam show the effect of seasonality since they are extremely important for ducks, Grey Heron congregations, and Jacanas owing to large swathes of emergent and floating vegetation in the winter. However, the tank is low priority during the dry period, when other tanks in the cluster such as Perungulam and Arumugamagalam support higher waterbird diversity. Ranking of sites with relevance to species helps us to ascertain their importance at various stages in the season and for various guilds. Arumugamangalam is a tank that supports waterbirds both during winter and during the dry period and is thus an important site amidst the cluster of tanks in the region.

Apart from the abundance and heterogenous habitats provided by these tanks, their ability to hold water during the dry period is important as most tanks remain dry or with very low water during summer (e.g., September). During this period, the large tanks in Thoothukudi district which receive water directly from the Tamiraparani river tend to support high water bird abundance. Such large tanks can partially offset the impacts of low water levels in other tanks and must be prioritized for conservation efforts. The cluster of tanks that support birds in winter and summer need to be conserved along with those that are critical only during the winter and summer. Prioritizing tanks of high conservation value for birds as we have done here can be utilized in other areas to ascertain the value of wetlands for conservation.

Conclusion

In landscapes were water availability in irrigation tanks vary between month and years, prioritising tanks based on both wet and dry periods over the long term where water availability is very important. Assessing status of waterbirds during the dry period is very important as a majority of the waterbirds are resident or local migrants and water availability is critical to them for breeding.

Conservation of irrigation tanks in the the landscape is critical because nation wide assessments present a grim picture for waterbirds (SOIB 2020). Many of the trends assessed here conform to the national level trends and a further investigation into the reason behind their decline has to be taken up on species specific basis in future. Moreover, global trends indicate degradation and loss of natural wetlands (Ma et al. 2010). In such a situation man-made wetlands maintained for human use are important for supporting waterbird populations since they serve a dual purpose of irrigating and holding habitats for waterbirds. Though, natural wetlands are important for some groups of waterbirds (Bellio et al. 2009) and perform more functions than artificial wetlands (Ma et al. 2004), the absence of large natural wetlands nearby makes the irrigation tanks very important habitats for waterbirds. Water and wildlife managers should adequately address the requirements of conserving specific wetland habitats, mitigating threats, and manage the tanks efficiently for the benefit of birds and people.

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Data availability The data that support the findings of this study are available from the corresponding author, [TG], upon reasonable request.

Declarations

Competing Interests The authors have not disclosed any competing interests.

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