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Review

Transitioning Wintering Shorebirds to Agroecosystem: A Thorough Evaluation of Habitat Selection and Conservation Concern

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Abstract: Habitat fragmentation and degradation in natural wetlands has resulted in declines in the populations of shorebirds in the Indian subcontinent. Shorebirds rely on these wetlands as wintering or stop-over sites along the southern extent of the Central Asian Flyway. Shorebirds are known to utilize agroecosystems as alternate foraging habitats. The suitability of agroecosystems as foraging areas for overwintering migratory shorebirds has not been well studied in the Indian subcontinent. We conducted a comprehensive assessment of published literature and compiled field observations to investigate the importance of inland and coastal agroecosystems for shorebirds in India. We assessed the shorebird populations at natural wetlands: mudflats and mangroves of Kadalundi Vallikkunnu Community Reserve (KVCR) and Puthuvypu sand beach, as well as adjacent agroecosystems on the west coast of India, including Sanketham Wetlands, Manthalakkadavu, Vazhakkad, Elamaram, Kodinhi, and Kooriyad. On the east coast, we assessed the natural wetland habitats of Valinokkam, Point Calimere, and Pichavaram and evaluated inland agroecosystems in regions, such as Jammu and Kashmir, Punjab, Rajasthan, Gujarat, Uttar Pradesh, Tamil Nadu, and Kerala. Fifty-three shorebird species utilize diverse agroecosystems from various parts of India. While studies on the use of agroecosystems by shorebirds are limited on the east coast, evidence suggests that major wintering sites are adjacent to paddy fields, fostering substantial shorebird diversity. In Pichavaram, Point Calimere, and Gulf of Mannar regions, 22 shorebird species utilize agroecosystems, including the notable near-threatened Eurasian Curlew. Seventeen of these species are winter arrivals, highlighting the crucial role agroecosystems play as stopover areas. On the west coast, 19 shorebird species appear to utilize agroecosystems in Kooriyad, Manthalakkadavu, Vazhakkad, Sanketham Wetlands, Elamaram, and Kodinhi. Few species use agricultural fields in the north (Jammu and Kashmir). Paddy fields, that are flooded as part of the cropping cycle, support diverse prey species, such as macroinvertebrates, amphibians, and small fish, that could attract and support migratory shorebirds. Agricultural practices like fallowing, flooding, and ploughing could further increase the abundance and accessibility of prey for shorebirds, drawing them in greater numbers. It is crucial to recognize that unsustainable and unethical agricultural methods could detrimentally affect shorebird numbers. The accumulation of pesticide residues and the contamination from heavy metals could also threaten shorebirds. As a result, there is an urgent need for detailed research to better evaluate the importance of agroecosystems in supporting resident or migratory shorebirds. Systematic studies that explain the population dynamics, habitat selection trends, habitat utilization, and the over-summering behavior of the migratory birds at agroecosystems are needed. Implementing sustainable conservation strategies and adopting environmentally friendly agricultural practices are essential to support the rich biodiversity of the region.

Keywords: agriculture; artificial wetlands; foraging; waterbird; natural wetlands; migratory birds

1. Introduction

On a global scale, shorebird populations are declining in all migratory flyways [1–3]. The shortest flyway, the Central Asian Flyway (CAF), of which India is a major country, is no exception from this massive declining trend [2–6]. This declining trend can be attributed to the loss and degradation of foraging and roosting habitat for shorebirds in recent years as a result of unsustainable human interventions [7–9]. This had a significant impact on the survival [10] and breeding success [11] of birds. The primary causes are unethical use and exploitation of natural resources and unscientific management strategies [12,13] that resulted in the destruction and disappearance of natural wetlands. This corresponded with major environmental changes influencing nutrient cycling and mobilization, which had impacts across many trophic levels, causing declines in many aquatic species [13–16].

The alterations in sediment and hydrological variables, global climatic change, unethical and unsustainable human developmental activities, etc., have accelerated habitat fragmentation and degradation in natural wetlands [17]. This has resulted in the decline in population and abundance of shorebirds including migrants that rely on these wetlands as wintering or stop-over sites [3,17,18]. The adverse conditions in their wintering sites have led the shorebirds to find alternative foraging and roosting habitats during difficult times. A few studies have highlighted the role of the rice field ecosystem as an alternative for avian conservation in North America and Europe [19,20]. Even though many shorebirds forage on the exposed intertidal zones during their wintering period [21] (Supplementary Table S1), some use nearby agroecosystems for foraging and roosting [22]. The utility of these alternate sites as potential foraging grounds is yet to be fully understood in temperate zones [23]. The loss of foraging habitats, in addition to the declining survival rate of the shorebirds, could also lead to competition on alternate grounds [24].

Though 90% of global rice production is from Asia [25,26], studies on shorebirds that use agroecosystems in this area are limited [19,27–29]. In recognition of the importance of this ecosystem, the Ramsar Convention on Wetlands of International Importance [30] addressed the significance of rice fields in conservation. Agroecosystems have been designated as "Important Bird Areas" under Birdlife International's global program which recognizes them as sites of high conservation value [31]. All these designations by the international agencies highlight the potential importance of agroecosystems as alternate roosting and feeding habitats for shorebirds.

One of the prime examples of habitat loss is the conversion of natural wetlands into shrimp farms in several Asian countries including India, over the past three decades driven by increasing demands of population growth and economic development [32,33]. This conversion was so widespread that massive areas, such as mangroves and adjoining mudflats, were converted into shrimp farms, thereby affecting migratory waterbirds that were wintering in the areas [13,34]. Furthermore, habitat degradation of the natural wetlands due to anthropogenic developmental activities forced the shorebirds to shift their foraging grounds to nearby agricultural fields as these sites have the potential to meet the nutritional requirements of the shorebirds [16,35]. Waterlogged agricultural fields are flooded or inundated as part of the cropping cycle [36] or occur when excess water accumulates due to heavy rainfall, poor drainage, or other factors. This provides suitable habitats for macroinvertebrates (especially polychaetes, crabs, crayfish, and shrimps), small fish, and larval amphibians, which serve as important prey for waterbirds including shorebirds [37]. The area of rice cultivation is generally vast compared to the area of natural wetland habitats; thus, these flooded rice fields help birds survive temporarily by providing suitable habitats with food and shelter for them [38–40]. These temporary wetland-like conditions can have various ecological implications and attract different species, including breeding shorebirds [41]. Shorebirds find alternative feeding and roosting grounds during the winter, including artificial wetlands [42], agricultural ponds [43], salt pans [44], and paddy fields [25,45,46]. These alternate agroecosystems can potentially become buffers for natural habitat loss [46–49]. Only a few reports of these alternative foraging locations are available worldwide, such as those from the Italian Po Valley [50], Extremadura in Spain [49], and the rice fields of West Africa, where 1.7 million and 730,000 wetland-related birds are reported to harbor at coastal rice fields and inland rice fields, respectively [40].

In waterbird surveys that are typically limited to large wetlands, small wetlands close to agricultural land that support waterbird populations are either ignored or inadequately studied [51]. Similarly, the alternative feeding and roosting sites of shorebirds, such as agroecosystems, are ignored during regular surveys and censuses of shorebirds. Hence, the published literature on the intensive investigations on alternative habitats for shorebirds is limited in CAF, in general, and from Indian coasts, in particular. The aim of this review is to address this research gap of intensive studies, by compiling available data and literature on shorebird status and distribution in Indian agroecosystems with an emphasis on the peninsular region, to help identify areas of future research. To this end, we analyzed published literature on the natural wetlands, mudflats and mangroves of KVCR and Puthuvypu sand beach (west coast of India), and adjacent agroecosystems, Sanketham Wetlands, Manthalakkadavu, Vazhakkad, Elamaram, Kodinhi, and Kooriyad, which are intensively studied on the west coast. On the east coast, only Valinokkam mudflats, Point Calimere, and Pichavaram mangroves are the intensively studied natural wetland habitats. Also, selected inland agroecosystems where shorebirds are spotted and are potential sites for the wintering shorebirds in Jammu and Kashmir, Punjab, Rajasthan, Uttar Pradesh, Tamil Nadu, and Kerala were also included (Figure 1). The objective of our study was to investigate the utilization of agroecosystems by shorebirds in India. This research underpins the importance of and need for more comprehensive systematic surveys to facilitate accurate evaluations of shorebird species and their populations utilizing diverse agroecosystems as alternate foraging and roosting grounds for winter migrants and resident species.

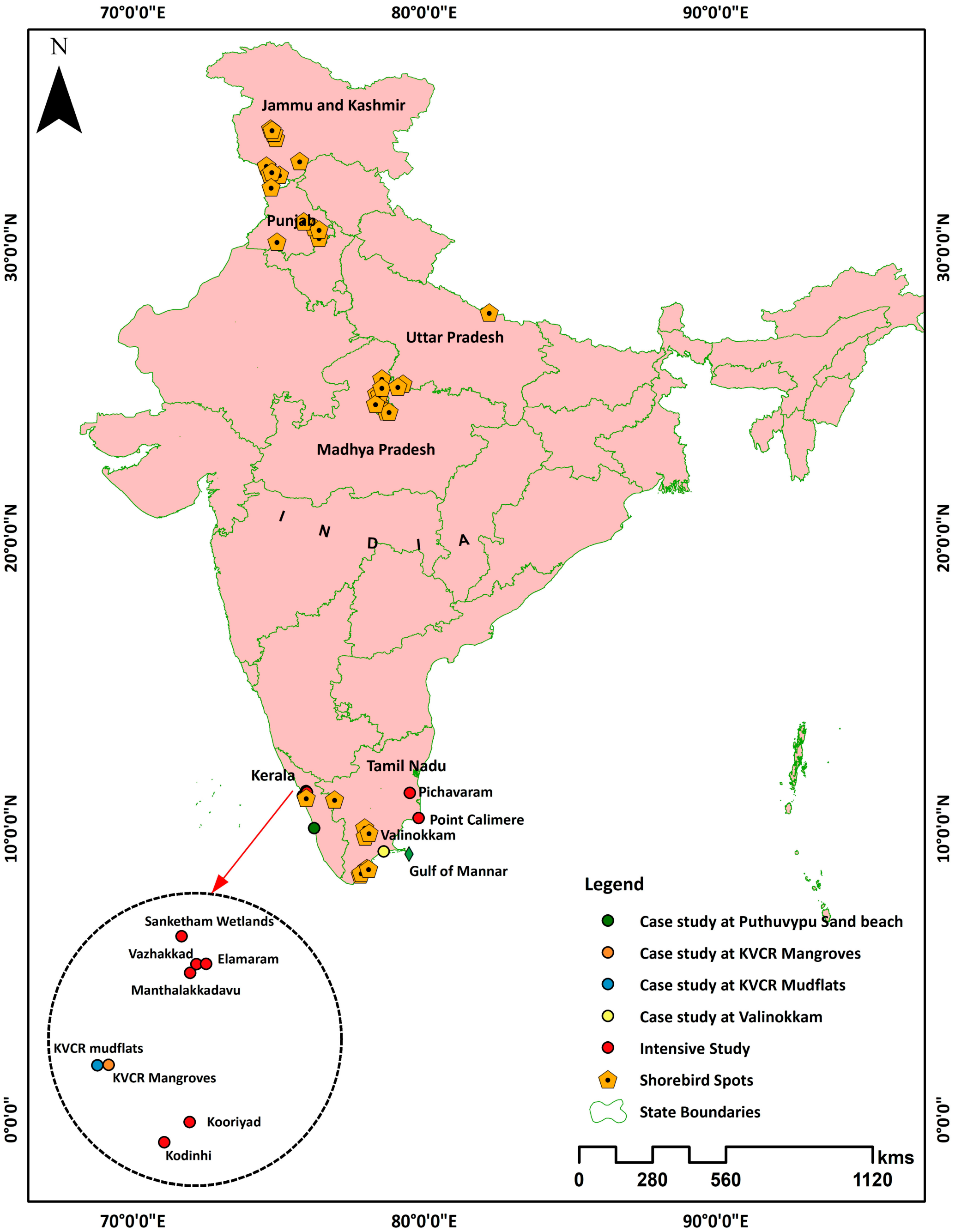

Figure 1. Map showing case studies, intensive studies, and observations at various regions in the Indian Peninsula.

2. Methodology

2.1. Literature Search Strategy

We defined the scope of our article by outlining the specific aspects of shorebird abundance in coastal habitats and their occurrence in agricultural fields in the Indian Peninsula. We compiled a list of keywords related to our concept for the ease of literature search. Databases including PubMed and Web of Science were utilized to find relevant articles, reviews, and studies. The most recent articles were prioritized. Abstracts of potential articles were reviewed to determine their relevance to our research. Additional sources identified in examining the citations of the selected papers helped us to build a comprehensive understanding of the topic. We organized key findings from each study including the limitations. Data collected on personal field observations were also considered to substantiate our concept. The gathered information was analyzed and synthesized, which helped us in formulating our own research questions [52].

2.2. Shorebird Abundance

Shorebird abundance was assessed monthly at KVCR mudflats, mangroves (data from 2010 to 2019 are published by Aarif et al. [3] and the data of 2020 are unpublished, Aarif), and Puthuvypu sand beach (Jasmine, Unpublished data) on the west coast and the Valinokkam mudflats (Byju, Unpublished data) on the east coast of India between 2010 and 2020, once a month at 7:00 to 11:00 during low tide by direct observation method in a fixed scanning point using 10 × 50 binocular and DSLR Nikon D500 camera with 200–500 mm telephoto lens to document the shorebirds that prefer agroecosystem. The standard error in the figure was calculated from the mean and standard deviation of yearly abundance.

2.3. Species Diversity

Species diversity was assessed during January, October, November, and December, from 2018 to 2022 at Vazhakkad, Manthalakkadavu, Kooriyad, Elamaram, Kodinhi and Sanketham Wetlands on the west coast of India. The survey was carried out from 7:00 to 11:00 by direct observation method in a fixed scanning point using 10 × 50 binocular and DSLR Nikon D500 camera with 200–500 mm telephoto lens to document the shorebirds that prefer agroecosystem. The diversity of shorebirds is expressed as the Shannon–Weiner index using Statistica 12.0 software [53]. Shannon–Weiner index of shorebird diversity was calculated for each month for preparing the figure.

2.4. Nighttime Light Data

Freely accessible data in ArcMap were employed for the mapping process. We utilized VIIRS nighttime light annual band composites integrated into the Google Earth Engine platform, which was made available by the Earth Observation Group. The resolution of the data is 463.83 m and was employed for the evaluation of night-time light patterns.

3. Declining Trends of Shorebirds Species Abundance and Diversity at Mudflats, Mangroves, Sand Beaches, and Salt Pans, on the East and West Coast of India

The Indian east coast has diverse habitats such as coral islands, sandy beaches, intertidal zones, mangroves, saltpans, mudflats, and lagoons near the shoreline and has a rich shorebird diversity and abundance facilitated by peculiar features, including the availability of invertebrate prey, favorable moisture levels, and vegetative structure [54–56]. Shorebirds have been found to be more diverse and abundant in tidal flats, particularly exposed mudflats [2,3,57,58].

The east coast of India hosts up to 48 species of shorebirds [6]. The main wintering site of migratory shorebirds is Sundarbans, the largest tidal mangrove track and mudflats, from where 17 shorebird species were recorded; while from other parts of West Bengal, a total of 37 species were recorded [59]. Then Chilika Lake, a brackish-water wetland with marshes and mudflats, provided a wintering area for various migratory shorebirds, such as Kentish Plover (*Charadrius alexandrinus*), Black-tailed Godwit (*Limosa limosa*), and Asian Dowitcher (*Limnodromus semipalmatus*) [60,61]. The marine biosphere reserve of the Gulf of Mannar hosted sandflat preferring shorebirds species like the near-threatened Eurasian Oystercatcher (*Haematopus ostralegus*), Bar-tailed Godwit (*Limosa lapponica*), Eurasian Curlew (*Numenius arquata*) and species of Least Concern Grey Plover (*Pluvialis squatorola*), Lesser Sand Plover (*Charadius mongolus*), and Crab Plover (*Dromas ardeola*) [62,63]. The Valinokkam Lagoon and Karangadu mangroves near the Gulf of Mannar regions were recently documented as significant wintering sites for 47 species of shorebirds on the south-east coast [64], with a significant congregation of shorebirds. Point Calimere, also known as the Great Vedaranyam Swamp, hosted 47 shorebird species [65], while in Pichavaram, 27 shorebird species were reported, with Little Stint (*Calidris minuta*) being the dominant and Bar-tailed Godwit being the smallest population [65,66]. In Pulicat Lake, a brackish to saline lagoon on India's east coast, Kannan and Pandiyan [67] recorded 34 shorebird species.

In contrast, the west coast of India hosts relatively fewer species of shorebirds, despite having numerous significant wintering grounds [2,4,6,18,58,68]. Gujarat's Byet Dwaraka Island [69], Thane Creek [70] and Sindhudurg coast of Maharashtra [58], Goa [71,72], and Kadalundi Vallikkunnu Community Reserve (KVCR) [2,3,18] are major vital wintering and stopover grounds along the west coast of India. The migratory shorebirds reported from Sindhudurg, Maharashtra [58] and KVCR [2,3,18] include the endangered Great Knot (*Calidris tenuirostris*) and near-threatened species including Eurasian Oystercatcher, Eurasian Curlew, Curlew Sandpiper (*Calidris ferruginea*), Black-tailed Godwit, and Bar-tailed Godwit, while those from Goa include Great Knot, Great Thick-knee (*Esacus recurvirostris*), Eurasian Oystercatcher, Eurasian Curlew, etc. [71,72].

Shorebirds serve as ecological indicators in wetland ecosystems [73,74]. Despite having several natural wetlands that provide diverse habitats on the east and west coasts of India, shorebird abundance is declining on both coasts (Figure 2), and this can be attributed to habitat degradation and loss due to increasing human population, climatic changes, and other regional causes, such as frequent cyclones, floods, and tsunamis [6]. According to recent observations in the Gulf of Mannar [75] on the east coast, shorebird congregation is only found at the tip of the Dhanushkodi Lagoon [6]. Recent prey shortages at KVCR and adjoining areas, a significant wintering site on the west coast, have had an impact on the abundance of shorebirds [3]. The abundance of shorebirds using mangroves and mudflats habitats in KVCR decreased over the past two decades with major shifts in habitat use patterns [2,3]. Predation pressure caused shorebirds to alternate between mudflats, mangroves, and sandy beaches, which were less profitable with respect to benthic prey availability [3]. Switching between habitat types could also be energetically expensive to shorebirds that actively build up fat reserves for their post-winter endurance flight to the northern breeding grounds [76].

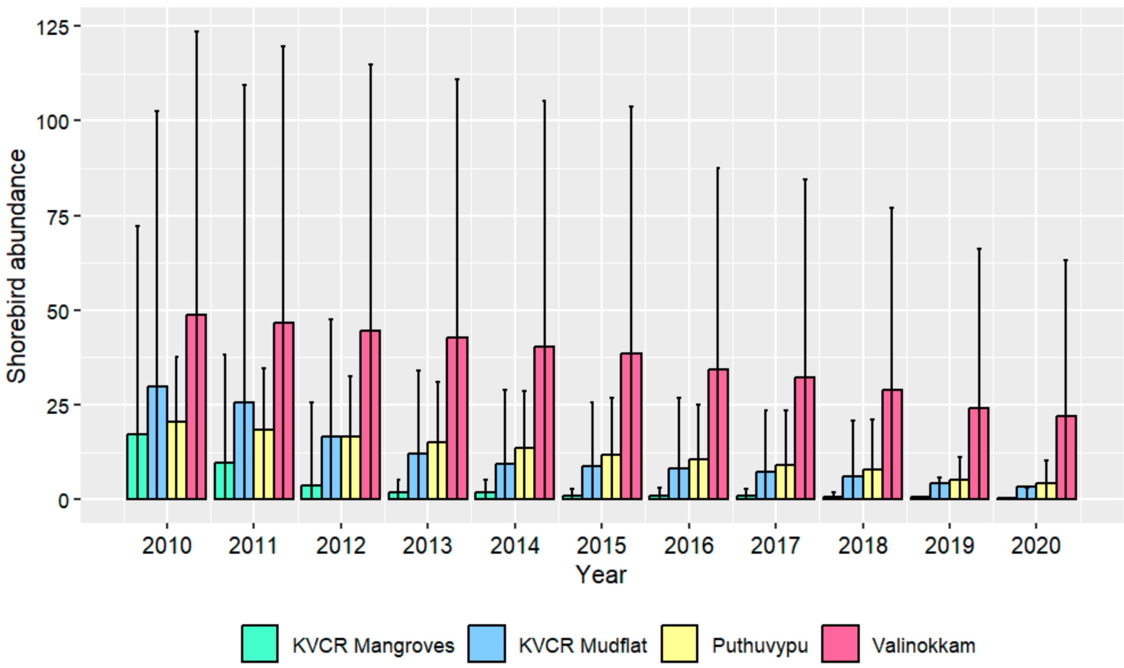

Figure 2. Declining shorebird abundance on east and west coast comparative trends, a case study performed at Kadalundi Vallikkunnu Community Reserve mudflats and mangroves, Puthuvypu Sand beach, west coast of India, and Valinokkam, Gulf of Mannar, east coast of India.

4. Slow Switching Trends of Shorebird Species to Agroecosystems on the East and West Coast

The west coast of India, which is highly productive in terms of nutritional resources, suitable cover, and favorable environmental conditions, provides multiple wintering grounds for shorebirds. In contrast, the east coast of India, which has lower nutritional resources, a high number of natural calamities, and erratic climatic variations, suggests that environmental conditions are unfavorable for shorebirds. Contrary to expectation, evidence suggests that there is a paradox in shorebird distribution, with the east coast hosting more diverse and abundant shorebirds than the west [6]. Anthropogenic pressure, especially development activities, has caused catastrophic declines in shorebird populations on both coasts [6,77] (Figure 2). For example, predation pressure and waste dumping at the mangroves [78] and sediment hardening and mangrove extension towards the mudflats [17,75] had caused habitat use shifts (from mangroves and mudflats to sand beaches) and reduced shorebird populations on the west coast [2,3,6]. Subsequent wall construction, waste dumping, and other adverse conditions [18,79] have resulted in dwindling beach areas, causing a gradual switching of foraging/roosting grounds to nearby agroecosystems [80–82]. There appears to be an increasing trend of shorebird diversity at agricultural lands (Figure 3) pointing towards the suitability of these as alternate habitats [83].

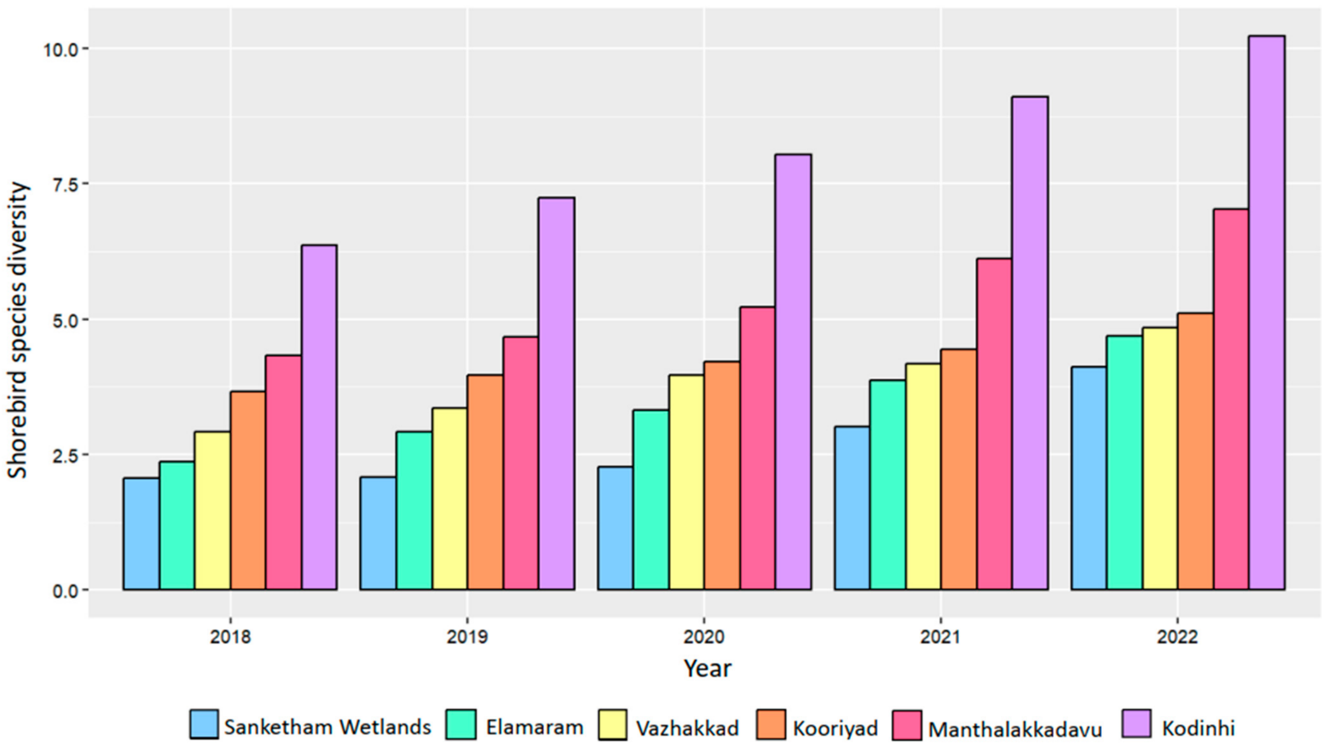

Figure 3. Increasing trends of shorebird diversity (measured as a total number of species) in six agricultural lands at Sanketham Wetlands, Elamaram, Vazhakkad, Kooriyad, Manthalakkadavu, and Kodinhi, west coast of India.

Studies on the use of agroecosystems by shorebirds on the east coast of India are limited to a few sites. Most of the major wintering sites on the east coast have vast areas of paddy fields adjacent to them. One example is the paddy fields near Pichavaram mangroves, which reported a higher density of shorebirds along with other waterbirds [84]. Sandilyan [85] recorded 25 waterbird species, of which 15 were shorebirds, in the agricultural land near Pichavaram wetlands during the monsoon as well as post-monsoon seasons. Other wintering sites on the east coast, like Chilika Lake, the Great Vedaranyam Swamp of Point Calimere, and the Gulf of Mannar, also have vast agroecosystems near the shorebird wintering sites. The shorebird population in the Gulf of Mannar region has been adversely affected by recent infrastructure developments in the Dhanushkodi Lagoon [6], leading to changes in the mudflat substratum, which might have compelled the shorebirds to slowly shift their foraging activities to adjacent agricultural lands. In Point Calimere, the extent of *Prosopis juliflora*, a wide-ranging hyperaccumulator plant species from various locales, caused the shrinkage of the edges of mudflats as well as the dried salt pans, and marked siltation phenomenon at the Pulicat Lake ecosystem has jeopardized the ecological homeostasis endangering shorebird populations [67]. This led to the slow switching of some shorebird species to the nearest agroecosystem (Table 1).

Our personal field observations in Point Calimere and the Gulf of Mannar divulged the presence of over-summering shorebirds, including Common Sandpiper (*Actitis hypoleucos*), Marsh Sandpiper (*Tringa stagnatilis*), Eurasian Curlew, and Black-tailed Godwit, utilizing adjacent agroecosystems, mainly paddy fields, indicating that these agroecosystems can serve as over-summering sites for selected migratory shorebirds. We have recorded 19 species of shorebirds, out of which, 14 were winter visitors, that used agroecosystems in these regions along the east coast. This included near-threatened species, Eurasian Curlews, which highlighted the conservation significance of these agroecosystems. The diversity of these shorebird species could be indicative of the availability of suitable resources such as food, water, and nesting sites in these areas and valuable ecosystem services [86]. The predominance of Least Concern species among the recorded shorebirds is a positive sign in terms of the overall health, stability, and adaptability of the avian community in these agroecosystems.

KVCR plays a significant role as a critical stopover and wintering habitat for shorebirds along the western coast. However, a concerning trend of diminishing shorebird diversity has been observed over the years [2,3]. This decline can be attributed to several pivotal factors that have altered the ecological dynamics of the area. Multiple factors such as alterations in sediment and water quality [17], depletion of primary and secondary productivity [15], sediment hardening [17], depletion of key prey items such as polychaetes and crabs [3], habitat fragmentation [18], incursion of mangroves [74], changes in shorebirds' intake rate due to predation pressures (Aarif, unpublished data), biomagnification of heavy metals in trophic transfer [87], microplastic contamination [88], and possible artificial light intensity from development activities (Supplementary Figure S1) may be linked with shorebird declines at natural wetlands. Meanwhile, their population exhibited an increasing trend in the agroecosystem, which is an artificial wetland (Figure 3).

Field surveys conducted at six distinct agroecosystems near KVCR on the periphery of the west coast—Sanketham Wetlands, Manthalakkadavu, Vazhakkad, Elamaram, Kodinhi, and Kooriyad—reported 21 shorebird species including migrants, and the species diversity exhibited an increasing trend over years [89] (Figure 3). This distinct assemblage still differs from that of the east coast. Among these, 14 were winter migrants (Table 1).

Table 1. List of shorebirds documented from agroecosystems of the east and west coast of peninsular India.

S.No	Common Name	Scientific Name	IUCN Status	Migration Status	Gujarat [29]	Vazhakkad	Elamaram	Manthalakkadavu	Sanketham Wetlands	Kodinhi	Kooriyad	Pichavaram [34,84,90]	Gulf of Mannar (Byju 2017–2022)	Point Calimere (Raveendran 2018–2019)
					West Coast							East Coast		
1	Greater Sand Plover	*Charadrius leschenaultii*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
2	Lesser Sand Plover	*Charadius mongolus*	LC	WV	-	-	-	-	-	-	-	Yes	-	-
3	Kentish Plover	*Charadrius alexandrinus*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4	Little Ringed Plover	*Charadrius dubius*	LC	R/LM	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5	Common Ringed Plover	*Calidris hiaticula*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-
6	Pacific Golden Plover	*Pluvialis fulva*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	Yes
7	Grey Plover	*Pluvialis squatarola*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-
8	Caspian Plover	*Charadrius asiaticus*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
9	Grey headed Lapwing	*Vanellus cinereus*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-
10	Red-wattled Lapwing	*Vanellus indicus*	LC	R	Yes	Yes	-	Yes	Yes	-	-	Yes	Yes	Yes
11	Yellow-wattled Lapwing	*Vanellus malabaricus*	LC	R	Yes	-	-	-	-	-	-	-	Yes	Yes
12	Northern Lapwing	*Vanellus vanellus*	NT	WV	Yes	-	-	-	-	-	-	-	-	-
13	River Lapwing	*Vanellus duvaucelii*	NT	R	Yes	-	-	-	-	-	-	-	-	-
14	White-tailed Lapwing	*Vanellus leucurus*	LC	R	Yes	-	-	-	-	-	-	-	-	-
15	Black-winged Stilt	*Himantopus himantopus*	LC	R	Yes	Yes	-	Yes	-	-	-	Yes	Yes	Yes
16	Pied Avocet	*Recurvirostra avosetta*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
17	Common Sandpiper	*Actitis hypoleucos*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
18	Wood Sandpiper	*Tringa glareola*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19	Marsh Sandpiper	*Tringa stagnatilis*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
20	Green Sandpiper	*Tringa ochropus*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
21	Curlew Sandpiper	*Calidris ferruginea*	NT	WV	Yes	-	-	-	-	-	Yes	Yes	-	Yes
22	Broad-billed Sandpiper	*Limicola falcinellus*	LC	WV	Yes	-	-	-	-	-	Yes	-	-	-
23	Terek Sandpiper	*Xenus cinereus*	LC	WV	Yes	-	-	-	-	-	-	Yes	-	-
24	Little Stint	*Calidris minuta*	LC	WV	Yes	-	-	-	-	-	Yes	Yes	-	Yes
25	Temminck's Stint	*Calidris temminckii*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
26	Long-toed Stint	*Calidris subminuta*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
27	Dunlin	*Calidris alpina*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-
28	Sanderling	*Calidris alba*	LC	WV	Yes	-	-	-	-	-	-	Yes	-	-

Table 1. *Cont.*

S.No	Common Name	Scientific Name	IUCN Status	Migration Status	Gujarat [29]	Vazhakkad	Elamaram	Manthalakkadavu	Sanketham Wetlands	Kodinhi	Kooriyad	Pichavaram [34,84,90]	Gulf of Mannar (Byju 2017–2022)	Point Calimere (Raveendran 2018–2019)
29	Common Redshank	*Tringa totanus*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
30	Spotted Redshank	*Tringa erythropus*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
31	Common Greenshank	*Tringa nebularia*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
32	Nordmann’s Greenshank	*Tringa guttifer*	EN	WV	Yes	-	-	-	-	-	-	-	-	-
33	Common Snipe	*Gallinago gallinago*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
34	Greater Painted Snipe	*Rostratula benghalensis*	LC	WV	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-	-	-
35	Pin-tailed Snipe	*Gallinago stenura*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
36	Solitary Snipe	*Gallinago solitaria*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
37	Swinhoe’s Snipe	*Gallinago megala*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
38	Jack Snipe	*Lymnocryptes minimus*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
39	Eurasian Curlew	*Numenius arquata*	NT	WV	Yes	-	-	-	-	-	-	Yes	Yes	Yes
40	Eastern curlew	*Numenius madagascariensis*	EN	WV	Yes	-	-	-	-	-	-	-	-	-
41	Black-tailed Godwit	*Limosa limosa*	NT	WV	Yes	-	-	-	-	-	-	Yes	Yes	Yes
42	Bar-tailed Godwit	*Limosa lapponica*	NT	WV	Yes	-	-	-	-	-	-	-	-	-
43	Whimbrel	*Numenius phaeopus*	LC	WV	Yes	-	-	-	-	-	-	Yes	Yes	Yes
44	Great Knot	*Calidris tenuirostris*	EN	WV	Yes	-	-	-	-	-	-	-	-	-
45	Ruff	*Philomachus pugnax*	LC	WV	Yes	-	-	-	-	-	Yes	-	-	-
46	Collared Pratincole	*Glareola pratincola*	LC	WV	Yes	-	-	-	-	-	-	-	-	-
47	Oriental Pratincole	*Glareola maldivarum*	LC	R/WV	Yes	-	-	-	-		-	-	-	-
48	Small Pratincole	*Glareola lactea*	LC	R	Yes	-		-	-		-	-	-	Yes

LC, least concern; NT, near threatened; WV, winter visitor; LM/R, locally migrant or resident; R, resident.

In a previous study, Aarif and Basheer [91] recorded nine different shorebird species in the Mavoor wetland, which included Manthalakkadvu, one of the agroecosystems under investigation in the present study. We recorded 17 species of shorebirds from both Manthalakkadavu and Vazhakkad agroecosystems. Paddy fields at Elamaram and Kodinhi supported 15 species each; while Sanketham Wetlands upheld 16 shorebird species. Nineteen species of shorebirds including Ruff (*Calidris pugnax*), an uncommon visitor to South India, were documented from the paddy fields at Kooriyad, west coast of Kerala (Figure 4) (Table 1). Furthermore, 20 shorebird species were reported from the Kole wetlands in Kerala [92], which serve as important wintering and stopover sites for long-distance migrants. The paddy cultivation here provided ideal foraging habitats for many shorebird populations to reach their peak counts and survive after low rainfall periods [2]. Thirty-eight shorebird species, including 33 migrant species, were documented from the Changaram wetland on the west coast of Kerala [68], where the pokkali farming system is employed. Pokkali farming involves paddy cultivation from May to October and shrimp and fish culture from November to April alternately in the same wetlands. We speculate that this type of farming increases the invertebrate, amphibian, and small fish diversity of this agroecosystem [93], possibly making it attractive for shorebirds.

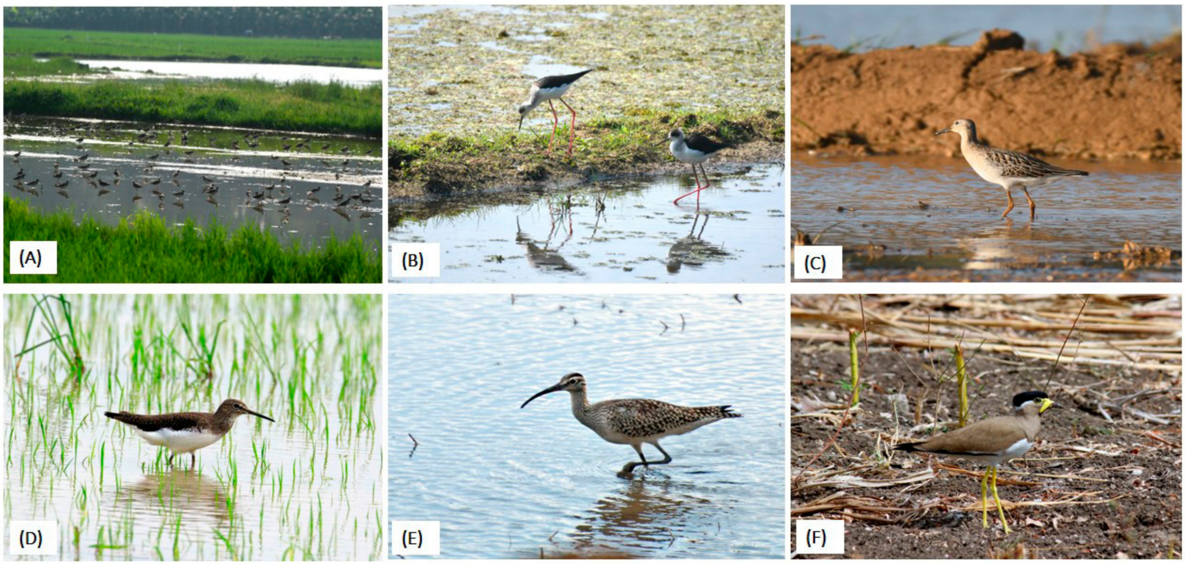

Figure 4. Habitat use of shorebirds in various agricultural lands on east and west coast of India: (**A**) mixed flocks of Wood Sandpiper (*Tringa glareola*) and Common Sandpiper (*Actitis hypoleucos*) at Vazhakkad agricultural lands (Photo credit: Shifa), (**B**) Black-winged Stilt (*Himantopus himantopus*) at Manthalakkadavu (Photo credit: Shifa), (**C**) Ruff (*Calidris pugnax*) at Kooriyad (Photo credit: Jishnu), (**D**) Common Sandpiper at Point Calimere (Photo credit: Byju), (**E**) Whimbrel (*Numenius phaeopus*) at Gulf of Mannar (Photo credit: Gajanmohanraj), and (**F**) Yellow-wattled Lapwing (*Vanellus malabaricus*) at Gulf of Mannar (Photo credit: Raveendran).

5. Agroecosystems and Shorebirds: An Indian Perspective

In India, apart from the agroecosystems adjacent to the natural wetlands on the east and west coasts, there are diverse inland agricultural fields that form wintering grounds, stop-over sites, and breeding grounds for the shorebirds. Shorebirds find northern subcontinental regions as transient stop-overs during the wintering period, while those embarking on a southern migration encounter rice fields as a consistent nutritional source throughout the duration of their stay [29]. The post-harvest remnants in the rice fields and the subsequent processes of fallowing, flooding, ploughing, etc., before the next cycle of cultivation, improve the nutritional quality of the field and facilitate the occurrence and availability of invertebrates and other prey species for the wintering and resident shorebird species [94].

Red-wattled Lapwings (*Vanellus indicus*) and the Black-winged Stilts (*Himantopus himantopus*) are resident shorebirds that are the most frequently encountered species in fields throughout Punjab year-round. Their nesting (see Figure 5) has been observed in paddy fields from April to July in waterlogged agricultural fields and in post-harvested wheat fields from April to July in dry beds of agricultural land, respectively (Figure 5). Common Greenshank (*Tringa nebularia*), Spotted Redshank (*Tringa erythropus*), Wood Sandpiper (*Tringa glareola*), Marsh Sandpiper (*Tringa stagnatilis*), Green Sandpiper (*Tringa ochropus*), Common Sandpiper (*Actitis hypoleucos*), Black-tailed Godwit (*Limosa limosa*), Pied Avocet (*Recurvirostra avosetta*), and Ruff (*Calidris pugnax*) are more frequently seen during the early migratory months of October and November in barren, waterlogged agricultural fields and during the reverse migration in the months of April and May. Shorebirds stay for a few days at each site and are observed to be foraging in the waterlogged fields preceding the planting of crops. This could be because waterlogged fields support more invertebrates, including shrimps, and small fishes [95].

Figure 5. (**A**) Mixed flock of Common Greenshank (*Tringa nebularia*), Spotted Redshank (*T. erythropus*), Wood Sandpiper (*T. glareola*), Marsh Sandpiper (*T. stagnatilis*), Green Sandpiper (*T. ochropus*), Common Sandpiper (*Actitis hypoleucos*), Black-tailed Godwit (*Limosa limosa*), Pied Avocet (*Recurvirostra avosetta*), Ruff (*Calidris pugnax*) at Patiala, Punjab (Photo credit: Jagdeep Singh); (**B**) breeding Black-winged Stilt (*Himantopus himantopus)* at Ludhiana (Photo credit: Jagdeep Singh); and (**C**) Marsh Sandpiper (*T. stagnatilis*) (Photo credit: Jagdeep Singh).

At least 53 shorebird species are utilizing the agroecosystem in various parts of India including Uttar Pradesh. Among the species listed, seven are near threatened—Black-tailed Godwit (*Limosa limosa*), Bar-tailed Godwit (*Limosa lapponica*), Eurasian Curlew (*Numenius arquata*), Northern Lapwing (*Vanellus vanellus*), River Lapwing (*Vanellus duvaucelii*), and Great Thick-knee (*Esacus recurvirostris*)—and three were endangered—Eastern Curlew (*Numenius madagascariensis*), Normann's Greenshank (*Tringa guttifer*), and Great Knot (*Calidris tenuirostris*). From the personal observations in Uttar Pradesh, we documented 22 shorebird species, with the addition of the Great Thick-knee (*Esacus recurvirostris*), which was not reported in any of the published literature for the Indian list. Further north, in Jammu and Kashmir, 4 shorebird species, Ruff, Pacific Golden Plover, Greater Painted Snipe and Black-winged Stilt, were recorded from 14 different agricultural fields. In Tamil Nadu, South India, 35 shorebirds, including Little Stint, Whimbrel (*Numenius phaeopus*), Red-wattled Lapwing, Yellow-wattled Lapwing, and Marsh Sandpiper, were reported from eight different agroecosystems (Table 2).

Table 2. List of shorebirds documented from other inland agroecosystems of India.

S.No	Common Name	Scientific Name	IUCN Status	Migration Status	Uttar Pradesh	Punjab	Jammu and Kashmir	Inland Areas of Tamil Nadu
1	Greater Sand Plover	*Charadrius leschenaultii*	LC	WV	-	-	-	Yes
2	Lesser Sand Plover	*Charadius mongolus*	LC	WV	-	-	-	Yes
3	Kentish Plover	*Charadrius alexandrinus*	LC	WV/R	-	-	-	Yes
4	Little Ringed Plover	*Charadrius dubius*	LC	WV/R	Yes	-	-	Yes
5	Common Ringed Plover	*Charadrius hiaticula*	LC	WV	Yes	-	-	Yes
6	Pacific Golden Plover	*Pluvialis fulva*	LC	WV	-	-	Yes	Yes
7	Grey Plover	*Pluvialis squatarola*	LC	WV	-	-	-	Yes
8	Hanuman Plover	*Charadrius seebohmi*	NE	R	-	-	-	Yes
9	Grey-headed Lapwing	*Vanellus cinereus*	LC	R	Yes	-	-	-
10	Red-wattled Lapwing	*Vanellus indicus*	LC	R	Yes	-	-	Yes
11	Yellow-wattled Lapwing	*Vanellus malabaricus*	LC	R	Yes	-	-	Yes
12	Northern Lapwing	*Vanellus vanellus*	NT	WV	Yes	-	-	-
13	River Lapwing	*Vanellus duvaucelii*	NT	R	Yes	-	-	-
14	White-tailed Lapwing	*Vanellus leucurus*	LC	R	Yes	-	-	-
15	Black-winged Stilt	*Himantopus himantopus*	LC	R	Yes	Yes	Yes	Yes
16	Pied Avocet	*Recurvirostra avosetta*	LC	WV	-	Yes	-	-
17	Common Sandpiper	*Actitis hypoleucos*	LC	WV	Yes	Yes	-	Yes
18	Wood Sandpiper	*Tringa glareola*	LC	WV	Yes	Yes	-	Yes
19	Marsh Sandpiper	*Tringa stagnatilis*	LC	WV	Yes	Yes		Yes
20	Green Sandpiper	*Tringa ochropus*	LC	WV	Yes	Yes	-	Yes
21	Curlew Sandpiper	*Calidris ferruginea*	NT	WV	-	-	-	Yes
22	Terek Sandpiper	*Xenus cinereus*	LC	WV	-	-	-	Yes
23	Little Stint	*Calidris minuta*	LC	WV	Yes	-	-	Yes
24	Temminck's Stint	*Calidris temminckii*	LC	WV	Yes	-	-	Yes
25	Sanderling	*Calidris alba*	LC	WV	-	-	-	Yes
26	Common Redshank	*Tringa totanus*	LC	WV	Yes	-	-	Yes
27	Spotted Redshank	*Tringa erythropus*	LC	WV	Yes	Yes	-	-
28	Common Greenshank	*Tringa nebularia*	LC	WV	Yes	Yes	-	Yes
29	Common Snipe	*Gallinago gallinago*	LC	WV	Yes	-	-	Yes
30	Greater Painted Snipe	*Rostratula benghalensis*	LC	R	-	-	Yes	Yes
31	Pin-tailed Snipe	*Gallinago stenura*	LC	WV	-	-	-	Yes
32	Eurasian Curlew	*Numenius arquata*	NT	WV	-	-	-	Yes
33	Black-tailed Godwit	*Limosa limosa*	NT	WV	Yes	Yes	-	Yes
34	Bar-tailed Godwit	*Limosa lapponica*	NT	WV	-	-	-	Yes
35	Whimbrel	*Numenius phaeopus*	LC	WV	-	-	-	Yes
36	Ruddy Turnstone	*Arenaria interpres*	LC	WV	-	-	-	Yes
37	Ruff	*Philomachus pugnax*	LC	WV	Yes	Yes	Yes	Yes
38	Oriental Pratincole	*Glareola maldivarum*	LC	R/WV	-	-	-	Yes
39	Small Pratincole	*Glareola lactea*	LC	R	-	-	-	Yes
40	Great Thick-knee	*Esacus recurvirostris*	NT	R	Yes	-	-	-
41	Indian Stone Curlew	*Burhinus indicus*	LC	R	-	-	-	Yes
42	Indian Courser	*Cursorius coromandelicus*	LC	R	-	-	-	Yes

LC, least concern; NT, near threatened; WV, winter visitor; LM/R, locally migrant or resident; R, resident; NE, not evaluated.

Many shorebirds were reported to congregate in good numbers in unvegetated fields adjacent to the west coast of India [96]. This provides an unobstructed view of the approaching predators [97] and kleptoparasites [98]. The waterlogged agriculture fields near wetlands attract breeding waterbirds and migratory shorebirds [84,99]. This is because the flooded paddy fields in winter support invertebrate prey species and thus offer a suitable foraging ground for a large number of shorebirds, positively influencing shorebird diversity and species richness [100,101]. The abundance of aquatic insects, worms, snails, and tadpoles in the agricultural field ensures the availability of food for these shorebirds [102] and hence serves as potential foraging grounds when intertidal habitats are under the threat of fragmentation, degradation, and modification [103]. In the Indian subcontinent, it is reported that 27% of shorebirds, including 23 species of global conservation concern [29], are using agricultural fields as their foraging sites. From the site-specific study on peninsular India, we also documented 22 shorebird species on the east coast and 47 on the west coast that utilize agroecosystems (Table 1). Lesser Sand Plover was exclusive to the east coast, whereas the Greater Sand Plover, Common Ringed Plover, Grey Plover, Greater Painted Snipe, Temminck's Stint, Dunlin, Grey-headed Lapwing, Spotted Redshank, Pin-tailed Snipe, Solitary Snipe, Swinhoe's Snipe, Jack Snipe, Bar-tailed Godwit, Eastern Curlew, Nordmann's Greenshank, Great Knot, Long-toed stint, Broad-billed Sandpiper, Ruff, Pied Avocet, Collared Pratincole, Oriental Pratincole, Caspian Plover, Northern Lapwing, River Lapwing, and White-tailed Lapwing were unique to the west coast.

Agroecosystems near shorebird wintering sites influence the foraging of individual species [31,40,104–106] as birds move back and forth between habitats regularly [107]. The nycthemeral movement of shorebirds between natural habitats (the mangroves, mudflats, and adjoining sand beaches) in response to predation pressure and tides [18] is an energetically expensive behavior, which is not desirable for the migrants that are gathering energy reserves for their northward endurance flight at the end of winter [108]. In addition to better prey availability, predator visibility could provide a benefit that counters the effects of declining natural environments, such as mudflats and wetlands.

Limited attention has been directed toward evaluating the utility and significance of field edges, irrigation canals, and other associated water features that form integral components of rice cultivation systems [38,107,109]. Assessing the factors that attract these shorebirds to agroecosystems, such as food availability, water resources, and vegetation structure, can help to determine the nutritional quality of these habitats as compared to other natural and artificial wetlands. Furthermore, the factors that adversely affect the quality of habitat at the rice fields must be checked extensively, including pesticide and heavy metal contamination [87]. Additionally, sustainable agricultural practices like using biopesticides and carefully planning the timing of agricultural methods like water-logging to coincide with the visiting time of migrants must be encouraged [110]. Balancing conservation efforts with agricultural practices is crucial to ensuring the long-term sustainability of both shorebird populations and local livelihoods.

6. Conclusions

Declining environmental quality and shortage of adequate prey in the natural habitats combined with other anthropogenic pressures make it difficult for shorebirds to find adequate food and habitats along the west and east coasts of India. Hence, shorebirds appear to exhibit an adaptive behavior by switching their foraging grounds to less desirable habitats or to artificial habitats, such as agroecosystems (Figure 6). Agricultural activities like fallowing, flooding, and ploughing have supported the abundance and accessibility of prey for shorebirds, with the plentiful resources drawing them in increased numbers. Our findings indicate that while several shorebird locations are documented, only a handful have been studied in depth. Though limited, these studies indicate that agroecosystems, particularly paddy fields, may be of high value to wintering shorebirds across the Indian subcontinent. Systematic intensive studies on the distribution, population dynamics, habitat preferences, prey availability, food range, and nutritional resources that sustain shorebirds in these alternative habitats are of paramount importance.

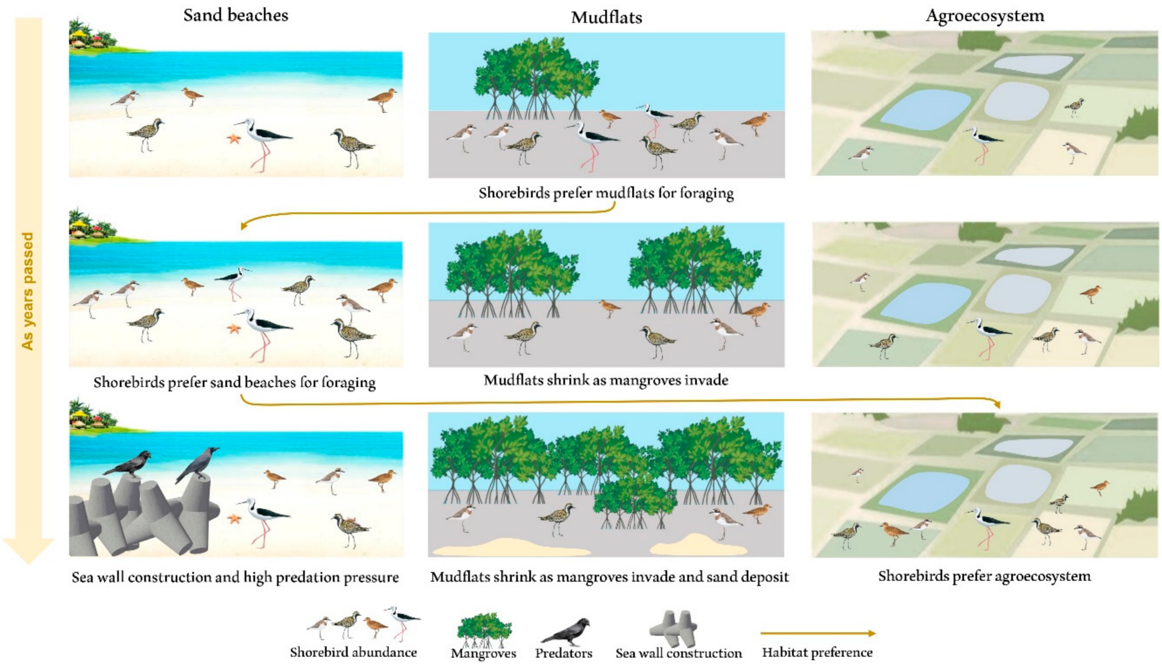

Figure 6. Pictorial representation of gradual switching of shorebirds from natural habitats to agroecosystems.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/d16010023/s1, Figure S1: Nighttime light data between 2013 and 2020 in Indian perspectives, showing that consumption of light has been increasing year after year. The unit of the DNB radiance value is nanoWatts/sr/cm^2; Table S1: Classification of shorebirds according to habitat specialization and foraging guild [18,111].

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