

Habitat use pattern of tidal mud and sand flats by shorebirds (charadriiformes) wintering in southern India

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Abstract Habitat use pattern and status of shorebirds in southern India were investigated in six tidal flats comprising three mudflats and three sand flats on the east coast of southern India. Totally, 7757 shorebirds belonging to 21 species were recorded during September 2000–March 2002. The birds preferred mudflats over sand flats. Density, diversity and richness of shorebirds were relatively higher in tidal flats, especially in mudflats. The shorebirds preferred mudflats over sand flats as stopover sites and sites for refueling the required energy during migration. Rhythmic changes in tidal pattern also influenced the allochthonous nutrients and prey species, which also attracted the migratory shorebirds. However, the abundance of shorebirds with reference to tidal flats *season*tide and habitats*seasons * tide had strong variations ($P < 0.001$). During migratory season, bird density, diversity and species richness were observed higher than in other seasons.

Keywords Coastal wetlands · Tidal flats · Shorebirds · Charadriiformes · Habitat interactions · Conservation

Introduction

Intertidal habitat is one of the most productive ecosystems in the world (Piersma et al. 2005, Pandiyan et al. 2006) and is of great importance for shorebirds (van de Kam et al. 2004). However, the use of wetlands, particularly inter-tidal flats by

shore birds in the Indian sub-continent, has hardly been investigated. Though the east coast of India, especially the Tamil Nadu region, plays a significant role for the shorebirds as it has extensive wetlands including the Pichavaram mangroves and the swamps at Point Calimere (a Ramsar Site), very few studies have been reported so far (Sampath and Krishnamurthy 1989, 1990).

Shorebirds utilise different tidal mudflats during breeding and non-breeding seasons (Hale 1980; Lane 1987; Piersma 1997). Their primary need for the wintering grounds is to fuel up in recovery and preparation for long-distance migration (Dann 1987; Piersma 1997; Battley et al. 2003, 2004; Kvist and Lindstro 2003). Several mud and sand flats or inland wetlands satisfy all the requirements and are used for stopover and refueling during the journey (Morrison 1984; Alexander et al. 1996; Iverson et al. 1996). Trophic structure (Schoener 1965), food partition (Davis and Smith 2001), prey availability (McNeil et al. 1995; Hubbard and Dugan 2003) and selectivity (Kalejta 1993; Backwell et al. 1998), predation risk (Cresswell 1994; Ydenberg et al. 2002) and abiotic factors (Burger 1984) are the parameters that determine the habitat use pattern of the shorebirds. Thus, the availability of food resources for migrant shorebirds plays a major role in the use, distribution and timing of their use of the habitat (Wilson 1990; Botton et al. 1994; Tsipoura et al. 1999; Davis and Smith 2001; Sandilyan and Kathiresan 2015).

The migratory shorebirds currently face a steady decline in the level of global populations (e.g., Birdlife International and European Bird Census Council 2000; Stroud et al. 2004) owing to rapid degradation of wetland, habitat fragmentation and loss of quality of the habitats in term of spatial, temporal and trophic regimes. Therefore, environmentalists in the recent past are concerned about conservation and correct management of estuarine wetlands (mudflat). This task requires information about the number of stages of the birds or the stopover

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sites in the area and their distribution in the intertidal feeding areas. In fact, many species of shorebirds' assemblage in a restricted number of feeding sites, and the carrying capacity of the estuaries decreased due to local (but persistent) impacts. Hence, a good knowledge on the bird distribution is of major importance for conservation planning of estuarine wetlands, both at local and regional scales. Though this information is available only for a few areas (e.g., Musgrove et al. 2001), information on the potential feeding sites, breeding grounds and other foraging grounds is still missing for majority of the estuarine areas, and studies on such aspects have often been emphasized. This paper deals with the habitat use pattern of tidal flats including mud and sand flats by shorebirds with reference to unprotected wetlands (estuarine tidal flats) and in relation to months, seasons, inter-annual and tidal variations; conservation implication has also been suggested.

Methods

Study area

The present study was carried out in six tidal flats on the east coast of Tamilnadu and Karaikal, S. India. Of these, three were mudflats (Pazhaiyar 79° 49' 11 " E; 11° 21' 22" N, Thirumullaivasal 79° 49' 11 " E; 11° 18' 23" N and Niravi 79° 51' 02" E; 10° 53' 25" N) and three sand flats (Chinnangudi 79° 51' 19" E; 11° 05' 33" N, Tharangambadi 79° 51' 19" E; 11° 01' 35" N, and Karaikal 79° 50' 03" E; 10° 57' 07" N). For results and discussion the following abbreviations were used for the six stations, i.e., Pazhaiyar (PA), Thirumullaivasal (TH), Niravi (NI), Chinnangudi (CH), Tharangambadi (TR) and Karaikal (KA). These wetlands are located on the east coast of India between two important waterbird wintering areas: the Pichavaram mangroves and Point Calimere Wildlife Sanctuary (Fig. 1). The mudflats comprise primarily of clay substrate and are covered with sparse vegetation dominated by *Suaeda* spp. and sporadic distribution of mangrove plants such as *Avicennia* and *Rhizophora*.

The sand flats have coarse sand with submerged marine algae and are devoid of vegetation. These wetlands are used by various species of waterbirds as stopover sites during migration. Hunting of birds is prohibited in all of the wetlands. Commonly available shorebird prey in these flats includes polychaetes (*Neries* spp.), gammarid amphipods, isopods (*Apseudes*), bivalves, gastropods, prawn larvae, crabs and fish fry (Pandiyan 2002). Chironomid larvae occur seasonally during October–March. They form the staple food for the shorebirds. This region receives rain during the Northeast Monsoon (October–December). However, in the past decade, rainfall had declined markedly and in recent years, most of the rain fall occurred over a period of 2–3 weeks. Therefore, the periodic freshwater run-off has declined over the years and the

intertidal flats have become more saline, but these flats are formed with freshwater and salt water. In fact, the study areas are important as they act as stopover sties for the migratory birds during migration (Sampath and Krishnamurthy 1989; Pandiyan 1999; 2000).

Study period and data collection

The study was undertaken during September 2000 and March 2002, and the study period was grouped into year I (September 2000–March 2001) and year II (September 2001–March 2002). Between April and August of both the years data were not collected owing to summer season when the flats mostly dry up and birds do not use them.

Habitats

The six tidal flats were grouped into two major habitats, namely, mudflats and sand flats. Tidal flats of Pazhaiyar (mudflat-1), Thirumullaivasal (mudflat-2), and Niravi (mudflat-3) are considered as mudflats and of Chinnangudi (Sandflat-1), Tharangambadi (Sandflat-2), and Karaikal (Sandflat-3) as sand flats. The mudflats have sparse vegetation of mangrove plants and the sand flats are devoid of vegetation.

Seasons

The study period is divided into three seasons, viz., pre-migratory, migratory and post-migratory based on the season of migration chronology of shorebirds. The pre-migratory season included September–October when birds arrive or pass these flats for wintering. Migratory season included November–January when the bird population was almost stable due to completion of inward migration to the wintering grounds. Post-migratory season included February and March when birds start to depart for breeding grounds.

Shorebird counts

Since the tidal flats appeared relatively homogenous, a study area of one hectare was chosen at random. Birds were counted with the help of 7 × 50 mm binocular and 20 × 60 mm spotting scope from vantage points on the coast. Total counts of the shorebirds were made each of 1 ha. study area every fortnight covering low and high tides following the 'direct count' method. The birds were always counted individually (Yates and Goss-Custard 1991) and two counts a day for a duration of 3.00 h were made. Usually, counts were made during clear, sunny days to avoid bias arising out of variation in weather conditions. Since all study areas were relatively open and had little vegetation there was no problem in the visibility of the birds. Birds that flew in and out of the study plots during the census were also recorded to avoid double counting. Care was

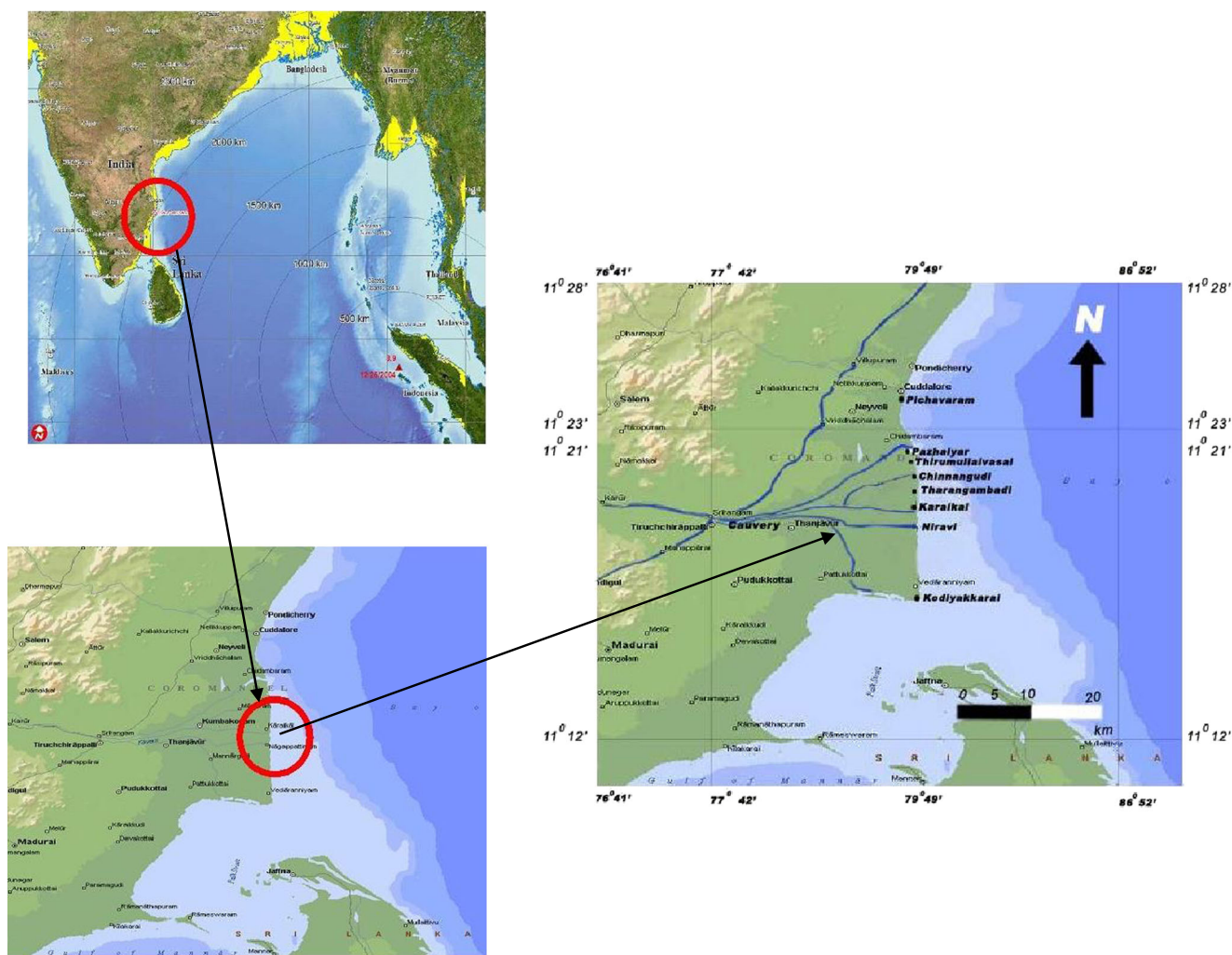


Fig. 1 Map of the study area showing the six tidal flats studied at the east coast of southern India

taken to see the birds were not deliberately disturbed, and the arrival or departure of flocks of birds in the areas was counted carefully and recorded without omission.

Data analysis

Shorebird densities were calculated as number per hectare for each tidal flat. Species richness was the number of shorebird species recorded from each tidal flat in a month (Verner 1985), and species diversity was calculated by using the Shannon–Wiener Index (H' : Shannon and Wiener 1949). Individual bird density was calculated as number per hectare for each tidal flat for each month. Pearson Correlation was used to determine the relationship between the shorebird density and shorebird species richness. Analysis of Variance (ANOVA) was used to determine the impact of individual shorebirds and shorebird population characteristics in relation to variations within the months, seasons, years, tidal flats and between the

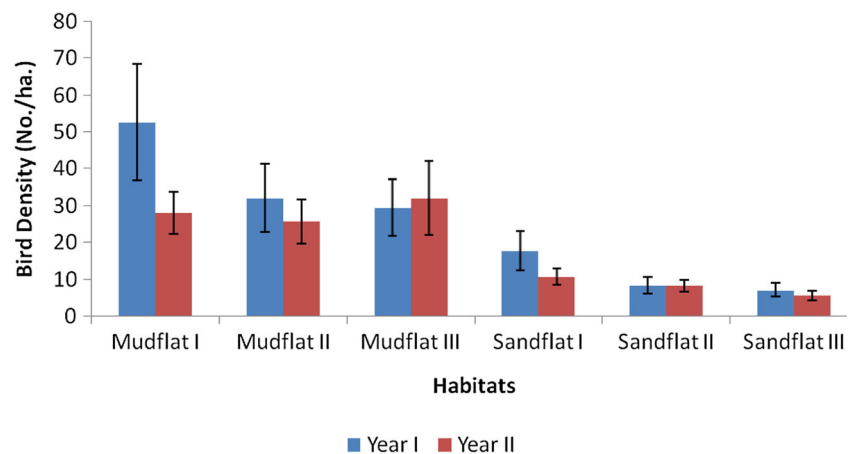
habitats (mud and sand flats). General Linear Model (GLM) was used to assess the interactions of season*tides tidal flats*tides and seasons*habitat*tides with the shorebird density. All the statistics were run by using Minitab 17.0 and SPSS 21.0. software packages. Results of the analyses are interpreted using standard statistical procedures (Sokal and Rohlf 1995).

Results

Seasonal variations

A total of 7757 individual shorebirds belonging to 21 species were recorded from the six tidal flats (Table1). Shorebirds were observed at all levels, including dry sand, in and around muddy and sandy flats, in pools, and on the exposed mudflats. The maximum turnover of mean shorebird density, 42.4 and

Fig. 2 Mean shorebird density (No./Ha.) recorded in the six different stations during three different seasons for the period of two years (Where Year I = September 2000-March 2001 and Year II = September 2001-March 2002). Bars represent the mean values and lines represent the standard error values



27.4/ha., was recorded during the migratory season for the year I and year II, respectively (Fig. 2). In addition, bird diversity and species richness were also the highest during the migratory season (Table 1). The density of shorebirds differed significantly among the months and seasons ($F = 9.77$, $df = 6$, $P < 0.001$).

However, the species richness of shorebirds also differed significantly between months ($F = 16.51$, $df = 6$, $P < 0.001$) and seasons ($F = 22.37$, $df = 2$, $P < 0.001$). Although the shorebird diversity differed significantly among the months and seasons ($F = 1.40$, $df = 6$, $P < 0.001$; $P < 0.005$; $F = 24.62$, $df = 1$, $P < 0.001$) seasonal variations of the Pectoral sandpiper, Sharp tailed sandpiper, Common snipe, Little curlew, Yellow wattled lapwing and Whimbrel did not show significant variation (Table 1). The present results show a strong relationship between seasonality and bird's population attributes such as density, richness and diversity of shorebirds of the exposed tidal flats.

Habitat variations

The shorebird density, species richness and diversity were greater in mudflats than in sand flats (Fig. 3). Similarly, overall shorebird density varied between habitats and among stations ($F = 32.42$, $df = 6$, $P < 0.001$; $F = 9.07$, $df = 6$, $P < 0.005$). The species richness of both habitats (mud and sand flats) ($F = 46.28$, $df = 1$, $P < 0.001$) and among the individual tidal flats differed significantly ($F = 12.83$, $df = 5$, $P < 0.001$) (Table 2).

Shorebird diversity varied significantly between habitats and among the stations $F = 35.19$, $df = 1$, $P < 0.001$; $F = 9.78$, $df = 5$, $P < 0.001$. Maximum diversity was observed in mudflats when compared to sand flats (Table 2). The shorebird richness was also higher in mudflats than in sand flats. In mudflats, maximum mean bird richness was 7.5 during year I, and 6.5 in year II. On the contrary, habitat wise, the Common sandpiper did not show any variation in either mud or sand flats ($P > 0.05$). But station-wise the shorebird species showed significant variations ($P < 0.001$). In addition, shorebird

density and species richness showed significant relationship ($r = 0.686$; $P < 0.001$). Thus, the present study indicates that the availability of the prey species in the habitat, nature of habitat and other environmental factors are important for the sustenance and regulation of the migration of shorebirds.

On the basis of assemblage of shorebirds in mudflats, two major groups were identified. The first group consisted of Kentish plover and Little stint and the remaining 19 species of shore birds formed another group (Fig. 4). In the sand flats also two patterns of assemblage were recorded. But the Little stint and the Little ringed plover were recorded along with Kentish plover in this group. The other group consisted of 18 species (Fig. 5).

Tidal variation

The overall results showed that the assemblage of the shorebirds was relatively more during the low tide in the mudflats than in the high tide. Shorebird density, richness and diversity differed significantly among the tides, i.e., $F = 42.43$, $df = 6$, $P < 0.001$; $F = 51.14$, $df = 1$, $P < 0.001$; and $F = 48.42$, $df = 1$, $P < 0.001$, respectively (Table 2). The results of the tidal variation showed that shorebird density, richness and diversity are closely associated with the tidal rhythm of the coastal ecosystem. The General Linear analysis Model (GLM) showed significant difference ($P < 0.001$) between shorebird density and among tidal flats, seasons, habitats and between tides. However, shorebird density in relation to Tidal flats *Season*Tide and Habitats *Seasons * Tide showed strong interactions, which implies that there was a close association between shorebird density and factors such as nature of tidal flats, seasons, tides and habitats.

Discussion

This present study reveals the distribution patterns and variations of shorebirds in the intertidal mud and sand flats of the

Table 1 Seasonal variations of shorebird density (No./ha.) recorded in the six tidal flats from I Year: September 2000-March 2001, II Year: September 2001-March 2002 (the six different tidal flats of two years of data were pooled into three different seasons and years (Year I and Year II) and the values are Mean and Standard Errors)

S. No.	Shorebirds name	Seasons ^a						Overall
		Pre-migratory		Migratory		Post-Migratory		
		Year I (N = 14)	Year II (N = 14)	Year I (N = 14)	Year II (N = 14)	Year I (N = 14)	Year II (N = 14)	
1	Great sand plover <i>Charadrius leschenaultia</i>	0.5 ± 0.19	0.6 ± 0.22	2.4 ± 0.44	1.4 ± 0.49	0.1 ± 0.11	0.07 ± 0.07	1.1 ± 0.17
2	Kentish plover <i>Charadrius alexandrinus</i>	0.7 ± 0.17	1.3 ± 0.60	6.8 ± 1.62	4.6 ± 1.04	1.9 ± 0.79	0.4 ± 0.19	3.2 ± 0.49
3	Little ringed plover <i>Charadrius dubius</i>	0.7 ± 0.19	1.3 ± 0.60	5.9 ± 0.91	3.1 ± 0.83	1.7 ± 0.62	0.2 ± 0.14	2.6 ± 0.33
4	Long-billed plover <i>Charadrius placidus</i>	0.9 ± 0.27	0.4 ± 0.13	3.7 ± 0.64	1.5 ± 0.46	1.1 ± 0.56	0.3 ± 0.21	1.6 ± 0.21
5	Common ringed plover <i>Charadrius hiaticula</i>	1.5 ± 0.50	0.6 ± 0.17	3.8 ± 0.61	2.2 ± 0.67	0.9 ± 0.53	0.3 ± 0.24	1.9 ± 0.25
6	Small pratincole <i>Glareola lactea</i>	0.7 ± 0.28	0.3 ± 0.13	1.4 ± 0.43	0.8 ± 0.33	0	0	0.7 ± 0.14
7	Common Sandpiper <i>Actitis hypoleucos</i>	0.6 ± 0.25	0.8 ± 0.24	1.8 ± 0.41	1.1 ± 0.28	1.5 ± 0.74	0	1.0 ± 0.14
8	Pectoral sandpiper <i>Calidris melanotos</i>	0.2 ± 0.08	0.4 ± 0.18	0.3 ± 0.13	0.47 ± 0.12	0	0	0.3 ± 0.05
9	Sharp-tailed sandpiper <i>Calidris acuminata</i>	0.03 ± 0.02	0.1 ± 0.09	0.08 ± 0.04	0.2 ± 0.11	0	0	0.1 ± 0.03
10	Marsh sandpiper <i>Tringa stagnatilis</i>	0.1 ± 0.08	0.2 ± 0.12	0.4 ± 0.16	1.1 ± 0.25	0	0	0.4 ± 0.07
11	Common redshank <i>Tringa totanus</i>	0.1 ± 0.11	0.2 ± 0.12	1.5 ± 0.52	1.2 ± 0.23	0	0	0.7 ± 0.14
12	Common snipe <i>Gallinago gallinago</i>	0.2 ± 0.10	0.1 ± 0.07	0.2 ± 0.08	0.5 ± 0.18	0.2 ± 0.16	0	0.2 ± 0.05
13	Dunlin <i>Calidris alpina</i>	0.8 ± 0.29	2.0 ± 0.40	5.3 ± 1.22	2.2 ± 0.40	0.1 ± 0.11	0.1 ± 0.14	2.3 ± 0.34
14	Little curlew <i>Numenius minutus</i>	0.2 ± 0.14	0.4 ± 0.25	0.4 ± 0.22	0.3 ± 0.19	0	0	0.3 ± 0.08
15	Little stint <i>Calidris minuta</i>	0.7 ± 0.42	1.3 ± 0.34	6.0 ± 1.45	2.7 ± 0.47	0.4 ± 0.47	0	2.5 ± 0.40
16	Red knot <i>Calidris canutus</i>	0	0.7 ± 0.19	1.7 ± 0.34	1.6 ± 0.41	0	0	0.9 ± 0.13
17	Great Knot <i>Calidris tenuirostris</i>	0.2 ± 0.09	0.3 ± 0.11	0.9 ± 0.29	0.3 ± 0.12	0	0	0.4 ± 0.08
18	Ruddy turn stone <i>Arenaria interpres</i>	0.2 ± 0.07	0.9 ± 0.21	1.7 ± 0.43	1.5 ± 0.25	0	0.4 ± 0.16	1.0 ± 0.13
19	Red wattled lapwing <i>Vanellus indicus</i>	0.5 ± 0.17	2.5 ± 0.34	0.7 ± 0.18	3.0 ± 0.33	0.4 ± 0.19	0.7 ± 0.23	1.5 ± 0.12
20	Yellow wattled lapwing <i>Vanellus malabaricus</i>	0.3 ± 0.19	0.4 ± 0.23	0.3 ± 0.14	0.5 ± 0.19	0.5 ± 0.36	0	0.3 ± 0.08
21	Whimbrel <i>Numenius phaeopus</i>	0.1 ± 0.06	0.09 ± 0.05	0.3 ± 0.14	0.1 ± 0.07	0	0	0.1 ± 0.04
	Overall bird density/(No./Ha.)	9.2 ± 2.82	2.8 ± 0.75	42.4 ± 7.05	27.4 ± 4.55	8.6 ± 1.60	13.8 ± 1.80	21.4 ± 2.19
	Bird diversity (H')	0.4 ± 0.08	0.2 ± 0.06	0.2 ± 0.02	0.3 ± 0.02	0.2 ± 0.03	0.2 ± 0.02	0.3 ± 0.01
	Bird species richness	2.4 ± 0.47	1.1 ± 0.25	5.4 ± 0.59	5.2 ± 0.56	2.5 ± 0.41	3.1 ± 0.30	3.9 ± 0.24

Pre-migratory = (September -October); Migratory = (November- January);

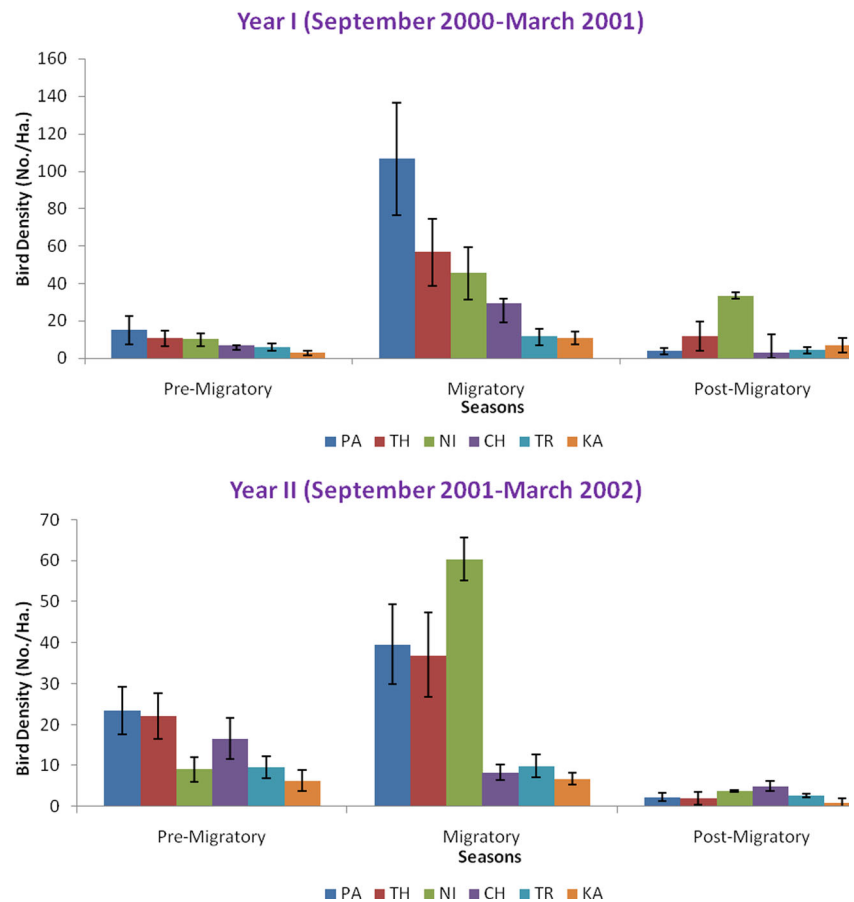
Post-migratory = (February – March)

^a Indicates the further information regarding the months within the season

Coromandel coasts of Tamilnadu, southern India. Totally, 21 species of shorebirds were recorded and analysed with

associated factors such as months, seasons, years, habitats (mudflats and sand flats) as well as different stations. The

Fig. 3 Mean shorebird density (No./Ha.) recorded in the six different stations during the study periods. (Bars represent the mean values and Lines represent the standard error values). (Where the Mudflat I = Pazhaiyar, Mudflat II = Thirumullaivasal, Mudflat III = Niravi, Sandflats I = Chinnangudi, Sandflats II = Tranqubar and Sandflats III = Karaikkal)



Pazaiyar, Thirumullaivasal and Niravi were classified into mudflats and the Chinnangudi, Tharangambadi and Karaikal into sand flats. Totally, 7757 shorebirds were counted during the entire study period from September 2000 to March 2001 and September 2001 to March 2002.

The shorebird density, species richness and diversity were relatively higher in the mudflats than in the sand flats. It is well established that the shorebirds are specific in their choice of habitats and show spatial distribution based on the availability of habitat dynamics (Frederickshon and Reid 1990; Skagen and Knopf 1993). The spatial pattern is often strongly associated with prey species' diversity, prey distribution and abundance (Kelsey and Hassall 1989). Shorebirds feed mainly on benthic invertebrates (van de Kam et al. 2004), which show wide variation in density and diversity between mud and sand flats. Goss-Custard (1970, 1980) reported that adequate food supply attracted the shorebirds to the habitats. Even within habitats, either mud or sand flats, there was patchy distribution (Piersma et al. 2005), and this might have led to some differences in prey abundance (Pandiyan 2002; Pandiyan et al. 2006). Moreover, the shorebirds' characteristics such as bird density, species richness and diversity were observed more turn over in the mudflats than in the sand flats (Table 2).

The prey species belonged to benthic forms were qualitatively and quantitatively greater in the mudflats compared to the

sand flats (Pandiyan 2002; Pandiyan and Asokan 2008a, b). Qualitatively, the benthic prey species such as polychaete, chironomid, amphipods, molluscan and crustaceans represented high biomass in the mudflats rather than the sand flats. Pandiyan (2002) also reported of a low level of productivity in benthic forms. However, the competition for the available quantity of prey was very high in the sand flats compared to the mudflats.

However, shorebird characteristics differed significantly between the habitats ($P < 0.001$) (mud and sand flats) and the birds used to feed frequently on the mudflats (Eybert et al. 2003, Pandiyan et al. 2006) as they provide more feed than the sand flats and the risk of predation is also less when compared to the other habitats (Zwarts 1978). Besides, the water-holding capacity of the mudflats is more which facilitates the enrichment of prey. It has also been reported that the sand flats have low productivity and high feeding competition when compared to mudflats (Pandiyan 2002). Obviously, the density of birds depends on prey base (Goss-Custard et al. 1977a, b, c). The present results also indicate that the shorebirds use different habitats at stopover sites to seek different food resources in different tidal flats to overcome competition in their migration process. Thus, their different habitat use patterns at stopover sites allow the shorebirds to get the required energy rapidly and hence ensure their successful migration.

Table 2 Habitat variations of shorebirds density (No./ha.) recorded in the six tidal flats from September 2000 – March 2001 and September 2001–March 2002. (Two years of six different tidal flats data were pooled into two major habitats i.e. mudflats and sand flats for further information please see the method section and values of Mean and Standard Errors)

S. No.	Shorebirds name	Mudflats ^a Year I (N = 28)		Sandflats ^a Year I (N = 28)		Mudflats ^a Year II (N = 28)		Sandflats ^a Year II (N = 28)		Overall
		LT	HT	LT	HT	LT	HT	LT	HT	
1	Great sand plover <i>Charadrius leschenaultia</i>	3.8 ± 0.59	0.3 ± 0.09	0	0	2.8 ± 0.88	0.2 ± 0.16	0.6 ± 0.24	0	1.1 ± 0.17
2	Kentish plover <i>Charadrius alexandrinus</i>	9.2 ± 2.20	0.7 ± 0.22	1.9 ± 0.44	0.2 ± 0.22	9.0 ± 1.86	0.7 ± 0.22	1.2 ± 0.39	0	3.2 ± 0.49
3	Little ringed plover <i>Charadrius dubius</i>	7.2 ± 1.21	0.7 ± 0.22	3.0 ± 0.55	0.7 ± 0.50	5.9 ± 1.46	0.5 ± 0.21	1.6 ± 0.83	0	2.6 ± 0.33
4	Long-billed plover <i>Charadrius placidus</i>	5.3 ± 0.85	0.6 ± 0.24	1.2 ± 3.16	0.2 ± 0.21	3.0 ± 0.83	0.3 ± 0.13	0.5 ± 0.17	0	1.6 ± 0.21
5	Common ringed plover <i>Charadrius hiaticula</i>	5.6 ± 0.92	0.5 ± 0.20	2.3 ± 0.49	0.5 ± 0.41	4.5 ± 1.19	0.2 ± 0.10	0.7 ± 0.23	0	1.9 ± 0.25
6	Small pratincole <i>Glareola lactea</i>	2.3 ± 0.64	0.2 ± 0.14	0.8 ± 0.35	0.07 ± 0.07	1.7 ± 0.60	0.1 ± 0.08	0.03 ± 0.18	0	0.7 ± 0.14
7	Common Sandpiper <i>Actitis hypoleucos</i>	2.0 ± 0.56	0.8 ± 0.32	1.4 ± 0.39	0.7 ± 0.42	1.6 ± 0.28	0.5 ± 0.32	1.1 ± 0.42	0	1.0 ± 0.14
8	Pectoral sandpiper <i>Calidris melanotos</i>	0.4 ± 0.19	0.2 ± 0.08	0.07 ± 0.07	0	0.3 ± 0.14	1.2 ± 0.30	0	0	0.3 ± 0.05
9	Sharp-tailed sandpiper <i>Calidris acuminata</i>	0.1 ± 0.06	0	0	0	0.3 ± 0.17	0.4 ± 0.19	0	0	0.1 ± 0.03
10	Marsh sandpiper <i>Tringa stagnatilis</i>	0.7 ± 0.22	0.04 ± 0.03	0.1 ± 0.17	0	1.5 ± 0.36	0.4 ± 0.23	0	0.5 ± 0.25	0.4 ± 0.07
11	Common redshank <i>Tringa totanus</i>	1.2 ± 0.59	0.2 ± 0.18	1.4 ± 0.88	0	1.3 ± 0.34	0.8 ± 0.23	0	0.5 ± 0.25	0.7 ± 0.14
12	Common snipe <i>Gallinago gallinago</i>	0.4 ± 0.13	0.1 ± 0.07	0	0.2 ± 0.19	0.5 ± 0.21	0.7 ± 0.29	0	0	0.2 ± 0.05
13	Dunlin <i>Calidris alpina</i>	7.7 ± 1.61	0.9 ± 0.46	0.07 ± 0.07	0.07 ± 0.07	2.6 ± 0.63	1.1 ± 0.31	1.4 ± 0.43	2.1 ± 0.51	2.3 ± 0.34
14	Little curlew <i>Numenius minutus</i>	0.7 ± 0.34	0.1 ± 0.09	0	0.04 ± 0.03	0.6 ± 0.28	0.7 ± 0.44	0	0	0.3 ± 0.08
15	Little stint <i>Calidris minuta</i>	9.0 ± 1.98	0.6 ± 0.27	0	0	2.9 ± 0.78	1.6 ± 0.38	2.0 ± 0.51	0.6 ± 0.23	2.5 ± 0.40
16	Red knot <i>Calidris canutus</i>	2.1 ± 0.46	0.2 ± 0.08	0	0	2.1 ± 0.71	1.0 ± 0.26	0.4 ± 0.18	0.5 ± 0.29	0.9 ± 0.13
17	Great Knot <i>Calidris tenuirostris</i>	1.3 ± 0.40	0.1 ± 0.08	0.04 ± 0.03	0.07 ± 0.07	0.2 ± 0.13	0.8 ± 0.22	0.05 ± 0.05	0	0.4 ± 0.08
18	Ruddy turn stone <i>Arenaria interpres</i>	2.1 ± 0.57	0.3 ± 0.16	0.2 ± 0.21	0.1 ± 0.12	0.8 ± 0.22	1.7 ± 0.32	1.2 ± 0.36	0.7 ± 0.24	1.0 ± 0.13
19	Red wattled lapwing <i>Vanellus indicus</i>	1.4 ± 0.26	0.3 ± 0.16	0	0.1 ± 0.12	2.5 ± 0.40	4.0 ± 0.44	1.3 ± 0.37	2.0 ± 0.37	1.5 ± 0.12
20	Yellow wattled lapwing <i>Vanellus malabaricus</i>	0.9 ± 0.32	0.05 ± 0.05	0	0.2 ± 0.15	0.2 ± 0.18	1.3 ± 0.45	0	0	0.3 ± 0.08
21	Whimbrel <i>Numenius phaeopus</i>	0.5 ± 0.20	0.04 ± 0.03	0	0	0	0.3 ± 0.15	0	0	0.1 ± 0.04
	Bird density/(No./Ha.)	58.9 ± 9.19	7.0 ± 1.28	11.9 ± 2.12	3.5 ± 1.61	39.6 ± 8.06	17.5 ± 2.23	10.7 ± 1.75	6.0 ± 1.07	21.5 ± 2.19
	Bird diversity (H')	0.3 ± 0.03	0.2 ± 0.03	0.3 ± 0.03	0.2 ± 0.06	0.3 ± 0.04	0.3 ± 0.03	0.3 ± 0.04	0.2 ± 0.03	0.3 ± 0.01
	Bird species richness	7.5 ± 0.78	1.9 ± 0.27	3.5 ± 0.35	0.7 ± 0.26	6.5 ± 0.94	4.9 ± 0.63	3.0 ± 0.36	1.83 ± 0.27	3.9 ± 0.24

^a = Mudflats: Pazhiyar Estuary, Thirumullaivasal Estuary and Niravi Estuary

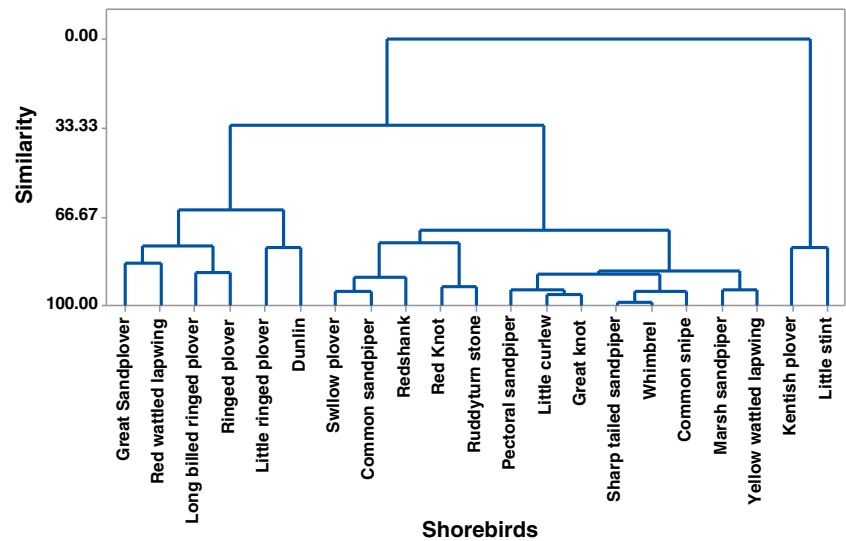
= Sandflats: Chinnangudi Estuary, Tharangambadi Estuary and Karaikal Estuary;

LT = Low Tide; HT = High tide Ist year =2000–2001 and IInd year =2001–2002

Shorebirds were the most abundant on both the tidal flats during the migratory seasons (October–December). The density, species richness and species diversity gradually increased from pre-migratory to migratory season with the arrival of the shorebirds and the onset of favourable migratory season.

During the migratory seasons more shorebirds used intertidal mudflats as the food resources are abundant during the winter period normally due to increased population dynamics and relative density of phytoplanktons (Henley and Rauscher 1978), benthic organisms (Flint and Kalke 1985) and intertidal

Fig. 4 Assemblage pattern of shorebird species studied in the mudflats from 2000 to 2002



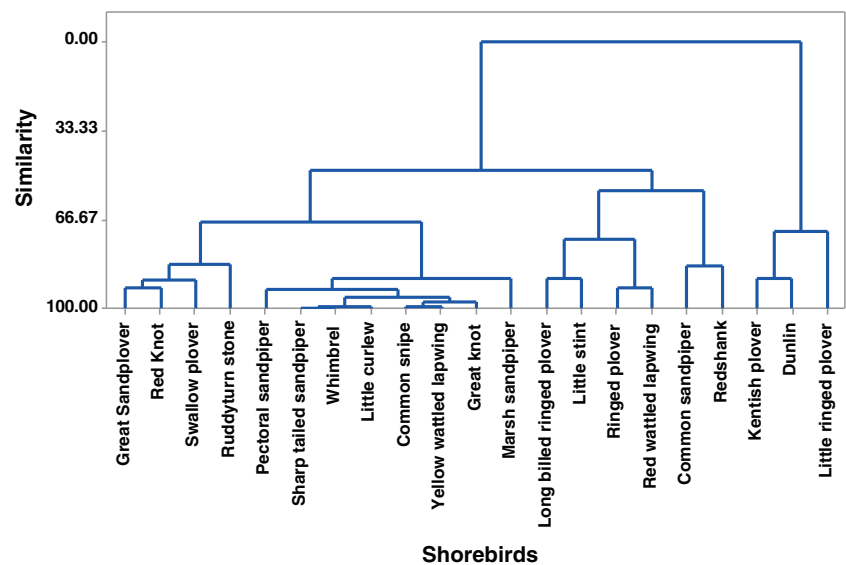
macro invertebrates (Veg 1988) (Pandiyan 2000, 2002). The present study also found that population attributes such as density, richness and diversity were directly proportional to food availability.

Similar attributes were also observed higher during low tide than the high tide (Table 2). According to Powell (1987), the tidal range is very important for foraging of waders including shorebirds and the birds must either shift to alternative foraging habitats from the area or disperse. On the contrary, the present study shows that the shorebirds returned to their feeding habitats (exposed tidal flats) immediately after high tide which increased the inward flow of allochthonous nutrients that resulted in an increase in species richness due to increase in the population of phyto and zooplankton, invertebrates, fishes, etc. (García et al. 1997; Bucher et al. 2000).

Hence, the water level or tidal rhythms are the unique features for effective feeding and survival of shorebirds.

Interestingly, no specific mechanism has so far been identified to attribute the assemblage of shorebirds in a particular habitat. Nevertheless, it has been attributed to the availability of specific type of prey species in an area or habitat. On the basis of the present study it is established that the species assemblages are obviously associated with particular feeding types or availability of prey species (Figs. 4 and 5). The shorebirds have been categorized in to two groups (Figs. 4 and 5). The Kentish plover and Little stint occurred in the mudflat in a different group among the shorebirds studied. But in the sand flats the Dunlin and Little ringed plover were associated with the Kentish plover. All the other species were associated in one group in both the habitats. These four species of

Fig. 5 Assemblage pattern of shorebird species studied in the sand flats from 2000 to 2002



shorebirds showed remarkable distribution pattern. In the mudflats, 19 species, whether the Little ringed plover and Dunlin, grouped either in small or larger groups, showed togetherness in the pattern of assemblage. The segregation of the four species and the togetherness of the Little ringed plover and Dunlin could be attributed to the prey preference and feeding mechanism of the shorebirds as the parameters of the habitat ecology. Fascinatingly, all the four species are plovers, which are social birds and hence could get mixed up with other species of shorebirds. However, they form different groups at the time of foraging. They partition the resources of the habitat to overcome competition and ensure survival by way of prey selection from varied microhabitats (spatial), seasonal parameters (temporal), availability of prey species (trophic) and the behavior of the shorebirds. Majority of shorebirds obtain their prey at or close to the surface of intertidal mudflats by pecking or shallow probing. Most of the prey species are located visually either directly or by using secondary cue such as the surface casts of polychaete worms and the movements of prawn irrigating their burrow (Smith 1975). The wading bird is limited by the beak morphology as is the range or prey they are able to capture. Of the short-legged waders such as Little stint, Dunlin, Little ringed plover, Ringed plover, Great sand plover and Kentish plover are not able to forage with ease on the exposed mudflats of the tidal flats or at the edge of the water bodies. These species are also very familiar with search and detection of their prey and consume more in the diversified habitats by exercising chemoreception and mechanoreception strategies (Heppleston 1970). The process of natural selection permits the survival of the fittest and the survival is ensured by way of success in the inter- and intra-species competition. This also permits the co-existence of different species of population of shorebirds.

Conclusion and conservation implications

The present study provides first-hand information on the shorebirds that use the tidal flat as the feeding ground while migrating from their native countries, the patterns and assemblages of several species of shorebirds in the tidal flats. Shorebird density, species richness and diversity and their migratory pattern indicates the quality of the habitat and the components of the coastal system. The availability of tidal habitat (exposed muddy flat), onset of monsoon at the right time and tidal rhythm are the more precious requirement to sustain the shorebird ecology.

Besides the practice of wetland management for providing water bird habitat, it is also necessary to develop effective tools of predicting the effects of wetland management on the dynamics of water birds and their habitats. This requires simplified decision- supporting systems on the basis of complex multidisciplinary knowledge. Socioeconomic scenario also

needs to be examined along with the systems to develop an integrated prediction of wetland management (Zhijun et al. 2010).

The overall results of the present study reveal a decrease in the number of species of shorebirds when compared to the previous observations (Pandiyana and Asokan 2008a, b). Hence, it is time to protect the tidal flats and make sea-level modifications, i.e., restoration of natural hydrology to facilitate sediment accretion and building of deltaic coastal wetlands. If the climate changes continue, the wetlands, particularly tidal flats, will disappear soon. It is not an exaggeration to say that the wetlands are at a critical stage and it is very important to protect and conserve them to ensure the global network of migratory routes of shorebirds.

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