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Original article

The costs of migration: Injuries in migratory waterbirds along the west coast of India

K.M. Aarif [a], Aymen Nefla [b,*], T.R. Athira [c], P.K. Prasadan [d], Sabir Bin Muzaffar [e,*]

[a] Terrestrial Ecology, Centre for Environment and Marine Studies, King Fahad University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia
[b] Department of Biology, University of Sciences of Tunis, El Manar II, 2092 Tunis, Tunisia
[c] Post Graduate and Research Department of Zoology, Govt College Madappally, Kozhikode, Kerala, India
[d] Department of Zoology, Mananthavady Campus, Kannur University, Edavaka 670 645, Kerala, India
[e] Department of Biology, United Arab Emirates University, PO Box 15551, Al Ain, United Arab Emirates

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ABSTRACT

The long distant, transcontinental migration of shorebirds entails many well identified costs in terms of time, energy, and direct mortality risk. Injuries from debris or from human structures and activities were observed as the major reasons for the direct mortality of shorebirds during migration worldwide. We recorded injured birds in major coastal wetlands of Kerala, for a period of 15 years from 2005 to 2019. The injured birds were observed in 9 different sites in various districts of Kerala. The highest instances of injuries were observed in Kadalundi-Vallikunnu Community Reserve, the major wintering and stop over site of migrant shorebirds in the west coast of India. During the study period, fifty-eight individuals of shorebirds belonging to four families were found to be injured. The highest proportion of injuries was recorded among the families Scolopacidae and Charadriidae comprising long distance migrant shorebird species and the lowest among Laridae and Ardeidae. We recommend that environmental authorities pay special attention to minimize anthropogenic debris along the flyways used by migratory birds thereby reducing the risk of injuries to some of these species. Proactive measures such as removal of discarded fishing gear or plastic debris from wintering areas as well as stopover areas could greatly reduce injuries in migratory birds arising from anthropogenic sources.

1. Introduction

Migration is considered to have evolved as an adaptation to exploit seasonal peaks in resource abundance while avoiding seasonal resource depletion during the non-breeding periods. Thousands of diverse populations of waterbirds and other migratory birds travel back and forth along migratory flyways (Boere and Stroud, 2006). Flyways are broadly defined areas over which birds migrate on a regular basis between breeding and non-breeding areas, including all areas used in between as staging areas and stop-over sites (Boere and Stroud 2006). The Central Asian Flyway (CAF) is the smallest flyway (Aarif et al., 2014), in terms of area of coverage (Boere and Stroud, 2006), and least studied among the world's flyways with 80% of its population being unknown (Balachandran, 2006; Aarif et al., 2014). The CAF encompasses primarily the Indian subcontinent in the south and extends to the central portion of Russia and its surrounding areas (Davidson, 2003; IWSG, 2003). A high diversity of wader species uses the CAF during the course of their lives(Davidson, 2003; IWSG, 2003). The Indian coastlines cover wintering and stop-over grounds for shorebirds and other waterbirds in the CAF (Aarif et al.,2011; Aarif et al., 2014; Aarif et al., 2020; Aarif et al 2021). There is much variation in migration patterns (Lok et al., 2015). Most shorebirds migrate and some are long-distance, transoceanic and transcontinental migrants (Warnock, 2010), that require high-quality staging sites, where they refuel before continuing their journey (Choi et al., 2009; Warnock, 2010;Battley et al., 2012;Hua et al., 2013).

Shorebirds worldwide have been suffering alarming recent declines (Pandiyan and Ashokan, 2016). Migratory shorebirds, particularly, are of conservation concern owing to their low reproductive rate, long migrations, and dependence on a wide variety of wetland

* Corresponding authors.
E-mail addresses: aymennefla2007@yahoo.fr (A. Nefla), s_muzaffar@uaeu.ac.ae (S.B. Muzaffar).

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habitats (Fernandez and Lank, 2008). Migration entails several well-identified costs in terms of time, energy and direct mortality risk (Conklin et al., 2017). The costs of migration increase with the distance of migration and long-distance migrants are likely to encounter a greater diversity of hazards across the flyway (Reneerkens et al., 2019). Shorebirds tend to choose the same stopover sites, which can provide constant and reliable food resources with less energy costs every year (Ranalli and Ritchison, 2012; Latifa et al., 2019). However, migratory birds suffer a high mortality rate during the migratory periods (Klaassen et al., 2013; Loss et al. 2015). It has been estimated that 23 million migratory birds die in USA and 26 million in Canada due to collisions with power lines and a further 6.6 million from collisions with communication towers (Loss et al., 2015). When considering the time and energy costs, human disturbances have comparatively larger impact on the mortality rate of shorebirds (West et al., 2002). Anthropogenic activities are the major reason for injuries among shorebirds (Aarif and Prasadan, 2014). Newton (2007) collated information on bird mortality caused by injuries from human artefacts such as power lines and wind turbines, while Crighton (2016) and Wang et al.(2018) have noted that human activities such as different trapping methods, entanglement in fishing nets cause bird mortality.

Injuries have been recorded on various types of migrant birds in the CAF, including the larger migrants that are often seriously injured through collision with man-made structures such as power lines (Burnside et al., 2015). Furthermore, poorly designed medium-voltage lines pose a significant risk of serious injuries and could lead to mass mortalities for large perching species like raptors (Birdlife International, 2012, Loss et al. 2015). Waterbirds also exhibit high mortality as a result of oil spills (Leighton, 2011; Jessica et al., 2012, Loss et al. 2015), chronic oil discharge in bilge water (Camphuysen, 2010), excessive discharge of detergents and hazardous material (Camphuysen, 2010). Injuries can lead directly to mortality or have indirect effects through reduced foraging abilities and ultimately reduced reproductive success (Wang et al., 2018).

Heavy use of pesticides in the agro-ecosystems at the wintering grounds in the CAF can cause organ deformities or injuries to waterbirds and the oil disposed, can cause serious injuries to birds (Hampton et al., 2003; Varagiya et al., 2016). It has been estimated that over 4 million birds die from pesticide related health affects in Canada (Loss et al. 2015). Entanglement in fishing nets is another critical reason for some of the serious injuries reported in waterbirds from Indian coasts (Kannan and Pandiyan, 2012; Aarif and Prasadan, 2014). Since fishing nets are used widely across the Indian subcontinent, fishing net-related mortality needs to be better characterized. For example, birds that have escaped from a fishing net may die in the coastal zone without being observed (Loss et al. 2015). This makes it difficult to quantify injuries related to entrapment in fishing lines and deaths associated with it (Loss et al. 2015). Although migrants may avoid damage behaviourally or may use efficient biochemical and physiological defences against muscle injury, the overall mortality rate arising from injuries is likely to be high (Palacin et al., 2017).

We conducted this study with the following objectives: 1) to describe the various injuries in migrant shorebirds and other waterbirds, and (2) to determine if these injuries in shorebirds and waterbirds vary between years, seasons and habitats.

2. Materials and methods

2.1. Study area

The present study was part of a long-term monitoring program assessing the abundance of waterbirds in relation to environmental variables in southwestern India (Aarif et al. 2014, Aarif et al. 2020, Aarif et al 2021). We recorded observations of injuries during the entire period to better understand patterns of injuries in migrants. We conducted our observations of injured birds from i) Shrimp farm (11.84 N 75.4055 E), Kannur district, ii) Muzhappilangadu beach (11°47′34.4″ N 75°26′38.3″E), Kannur district iii) Thikkodi beach (11°29′39.3″ N 75°36′53.4″ E), iv) Korappuzha estuary and beach (11°21′06.5″ N 75°44′07.7″ E), v) Kappad beach (11°23′40.0″ N 75°42′47.2″ E), vi) Kadalundi Community Reserve (mudflats 11°07′37.5″N 75°49′48.6″E), and (mangroves 11°07′43.2'' N 75°49′50.7″E) Kozhikode district vii) Ariyallur beach(11°06′01.4″N 75°50′07.3″E),Malappuram district viii) Vellanathuruthu beach (9°01′48.5″N 76°30′40.9″E),Kollam district and ix) Veli estuary (8°30′31.0″N 76°53′11.5″E), Trivandrum district (Fig. 1). The general patterns of arrival time are in between mid of August to November and departure time ranges between February and May. The monitoring seasons were divided into three: Pre-migration (February, March, April), Post-migration (August, September, October) and Non-breeding (November, December, January). The breeding season of birds in our area (May, June, and July) was not included since it is a wintering ground (Aarif et al., 2011; Aarif et al., 2020) for the studied species.

2.2. Data collection

We collected data on injuries between January 2005 to April 2019 (15 years). Each study area was visited once a week throughout the period with trained volunteers and each injury case was photographed and the individual birds were identified to species. The year, season, habitat, and body part injured was recorded. The study was carried out using direct observation method between 6.00 and 12.00 hrs. In addition to the above, secondary information such as incident reports and photographs were also considered from the trained volunteers and PhD candidates. From Kannur shrimp farm we captured two species entangled in nets Common Redshank (*Tringa totanus*) and Common Snipe (*Gallinago gallinago*). Observations were made with the help of Nikon binocular (10 × 50 mm) and three sets of video cameras (CX 130 E Video; Sony VG 30 interchangeable lens; Nikon Coolpix p1000) during low tide in early hours of the day (6.00 to 12.00 a.m.), as it was the ideal time to observe the migrant waterbirds. The taxonomic designation of species was confirmed with the help of resource materials (Grimmet et al., 1999; Message and Tylor, 2005).

2.3. Statistical analysis

All cases of injuries were expressed as injury rate. This variable was calculated as the ratio of number of injured individuals per species/total number of individuals per species. Since the normality of the dependent variable (injury rate) was not verified, we used the Kruskal-Wallis test to evaluate the variation of injury rate over species, families, year, season, and habitat.

Spearman's rank correlation coefficient was performed to check for the relationship between annual injury rate (calculated as the ratio of annual number of injured individuals (all species combined)/overall abundance of waterbirds) and both waterbird species richness, and waterbird diversity (measured as Shannon–Weiner index of diversity, *H*).

We assessed whether the frequency of injury in each species matched its abundance in the study area, using the Ivlev's electivity index: $E = (r_i – p_i)/ (r_i + p_i)$, where $r_i$is the relative abundance of injured individuals of species *i* in the subset of all species injury cases, while p_i denotes the relative abundance of this bird species (*i*) among all observed species (showed at least one injured individual) (Ivlev, 1961). Values of E range from −1 to + 1, with negative values indicating injuries avoidance (invulnerability of

Fig. 1. Map of study area: i) Kannur Shrimp farm ii) Muzhappilangadu beach, iii) Thikkodi beach iv) Kappad beach, v) Korappuzha estuary and vi) Kadalundi Community Reserve (mudflats and mangroves), vii) Ariyallur beach, viii) Vellanithuruthu beach and ix) Veli beach.

species to injury), positive values suggesting the vulnerability of species to (Ivlev, 1961) injury, and values close to zero indicating the occurrence of random injuries.

To examine the degree of independence between body parts of shorebirds (leg or wing) injured counts and the two bird families (Scolopacidae and Charadriidae), and at the two different habitat categories (sand beach and rest of habitats combined) we used the Chi-square (χ^2) test. Significance was set at alpha < 0.05. Statistical analysis were carried out in Statistica 12.0 software (StatSoftInc, 2013).

Fig. 2. A and 2B – 2A: above Black-headed Gull and 2B: below Common Greenshank.

3. Results

3.1. Injury rate variability

From 2005 to 2019, 58 injured individual shorebirds belonging to 12 species and four families were observed (Table 1). Scolopacidae showed the highest species richness (five species) including Common Greenshank (*Tringa nebularia*), Common Redshank (*Tringa totanus*), Little Stint (*Calidris minuta*), Ruddy Turnstone (*Arenaria interpres*) and Whimbrel (*Numenius phaeopus*). The Charadriidae contained four species: Greater Sand Plover (*Charadrius leschenaultia*), Grey (*Pluvialiss quatarola*) Plover, Kentish Plover (*Charadrius alexandrines*) and Lesser Sand Plover (Charadrius mongolus). Laridae and Ardeidae were represented respectively by two (Black headed Gull *Chroicocephalus ridibundus*, Saunder's Tern *Sternula saundersi*) and a (Reef Heron *Egretta*

Table 1
Yearly details on recorded injuries cases of birds (L: leg; W: wing; B: bill). The Shannon index express the diversity of shorebird populations among which at least one injured bird was observed.

Year	Species	Family	Shannon index H'	Total abundance	Individuals injured	Injury rate%	Injured part
2005	**Lesser Sand Plover**	Charadriidae	0.18	764	1	0.13	L
	Ruddy Turnstone	Scolopacidae		19	2	10.53	L
	Whimbrel	Scolopacidae		2	1	50.00	L
2006	**Greater Sand Plover**	Charadriidae	1.26	126	1	0.79	L
	Lesser Sand Plover	Charadriidae		184	1	0.54	L
	Whimbrel	Scolopacidae		22	1	4.55	L
2007	**Lesser Sand Plover**	Charadriidae	1.29	14	1	7.14	L
	Ruddy Turnstone	Scolopacidae		2	2	100.00	L
	Whimbrel	Scolopacidae		11	1	9.09	L
2008	**Black headed Gull**	Laridae	0.6	76	1	1.32	W
	Lesser Sand Plover	Charadriidae		464	1	0.22	L
	Whimbrel	Scolopacidae		1	1	100.00	L
2009	**Black headed Gull**	Laridae	1.3	20	1	5.00	W
	Ruddy Turnstone	Scolopacidae		4	2	50.00	L
	Whimbrel	Scolopacidae		8	1	12.50	L
2010	**Common Redshank**	Scolopacidae	0.07	3	1	33.33	W
	Lesser Sand Plover	Charadriidae		864	3	0.35	L
	Whimbrel	Scolopacidae		2	2	100.00	L
	Whimbrel	Scolopacidae		2	1	50.00	W
2011	**Black headed Gull**	Laridae	1.01	80	1	1.25	W
	Little Stint	Scolopacidae		16	1	6.25	W
	Whimbrel	Scolopacidae		9	1	11.11	L
2012	**Common Redshank**	Scolopacidae	1,06	17	1	5.88	W
	Grey Plover	Charadriidae		2	1	50.00	W
	Whimbrel	Scolopacidae		4	1	25.00	L
2013	**Common Redshank**	Scolopacidae	0.66	1	1	100.00	W
	Greater Sand Plover	Charadriidae		64	1	1.56	L
	Saunders Little Tern	Laridae		10	1	10.00	W
2014	**Common Redshank**	Scolopacidae	1.57	1	1	100.00	W
	Kentish Plover	Charadriidae		186	1	0.54	W
	Lesser Sand Plover	Charadriidae		244	1	0.41	L
	Lesser Sand Plover	Charadriidae		156	1	0.64	L
2015	**Common Redshank**	Scolopacidae	1.28	4	1	25.00	W
	Ruddy Turnstone	Scolopacidae		22	1	4.55	L
	Whimbrel	Scolopacidae		9	1	11.11	L
2016	**Common Greenshank**	Scolopacidae	1.02	176	1	0.57	L
	Lesser Sand Plover	Charadriidae		123	2	1.63	B
	Whimbrel	Scolopacidae		2	1	50.00	L
2017	**Common Redshank**	Scolopacidae	0.29	4	1	25.00	L
	Lesser Sand Plover	Charadriidae		156	1	0.64	B
	Reef Heron	Ardeidae		3	1	33.00	L
2018	**Common Greenshank**	Scolopacidae	1.46	25	1	4.00	L
	Lesser Sand Plover	Charadriidae		153	1	0.65	L
	Lesser Sand Plover	Charadriidae		106	1	0.94	L
	Ruddy Turnstone	Scolopacidae		8	1	12.50	L
2019	**Common Greenshank**	Scolopacidae	1.8	112	1	0.89	L
	Common Greenshank	Scolopacidae		66	1	1.52	L
	Common Redshank	Scolopacidae		21	1	4.76	L
	Lesser Sand Plover	Charadriidae		139	2	1.44	L
	Reef Heron	Ardeidae		2	1	50.00	L

gularis) species respectively. Scolopacidae exhibited 55.17% cases followed by Charadriidae (34.48%), Laridae (6.90%) and Ardeidae (3.45%). The injury rate varied significantly over species ($H = 36.57$; $df = 11$; $P < 0.001$) being the highest in Ruddy Turnstone (0.65 ± 0.19), Whimbrel (0.47 ± 0.13) and Common Redshank (0.41 ± 0.16). The injury rate of Ardeidae (0.41 ± 0.30) and Scolopacidae (0.41 ± 0.08) was significantly higher than recorded in Charadriidae (0.04 ± 0.10) and Laridae (0.04 ± 0.21) ($H = 23.02$; $df = 3$; $P < 0.001$) (Fig. 3). The injury rate of observed birds did not vary significantly over years (Fig. 4a) ($H = 10.93$; $df = 14$; $P = 0.69$), seasons (Fig. 4b) ($H = 1.30$; $df = 2$; $P = 0.51$) and habitats (Fig. 4c) ($H = 5.43$; $df = 2$; $P = 0.06$). Furthermore, no relationship was found between the annual injury rate and waterbird diversity (Shannon index) ($r = -0.28$; $P = 0.31$).

Injury cases were mainly recorded on Lesser Sand Plover (16 cases; 27.5% of all injury cases) corresponding to a negative Ivlev index value since it is the most abundant species in the area (74.6%) indicating an invulnerability of species to injury. The same trend was revealed on Kentish Plover showing a negative Ivlev index (Fig. 5). Other species were Black-headed Gull (Fig. 2a) (3; 5.2%), Common Greenshank (Fig. 2b) (4; 6.9%) and Greater Sand Plover (2; 3.4%). Together, these species accounted for 16.5% of overall bird abundance in the area. Each one these species corresponded to an Ivlev index value close to zero and suggesting the occurrence of random injuries (Fig. 5). The rest of the species found injured are Common Redshank (7; 12%), Grey Plover (1; 1.7%), Little Stint (1; 1.7%), Reef Heron (2; 3.4%), Ruddy Turnstone (8; 13.8%), Saunders Little Tern (1; 1.7%) and Whimbrel (12; 20.7%).

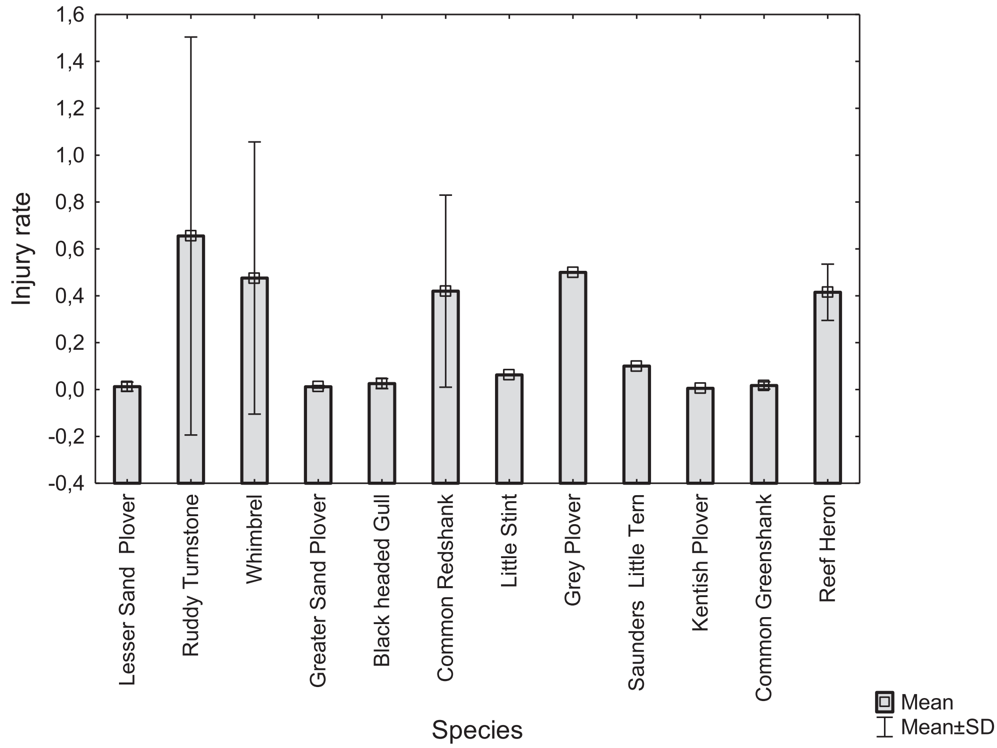


Fig. 3. Injury rate variability of waterbird species.

These species are the least abundant forming together 4.7% of counted birds. They were considered the most vulnerable to injury since they showed a positive Ivlev index values (Fig. 5).

3.2. Origin of injuries and organs affected

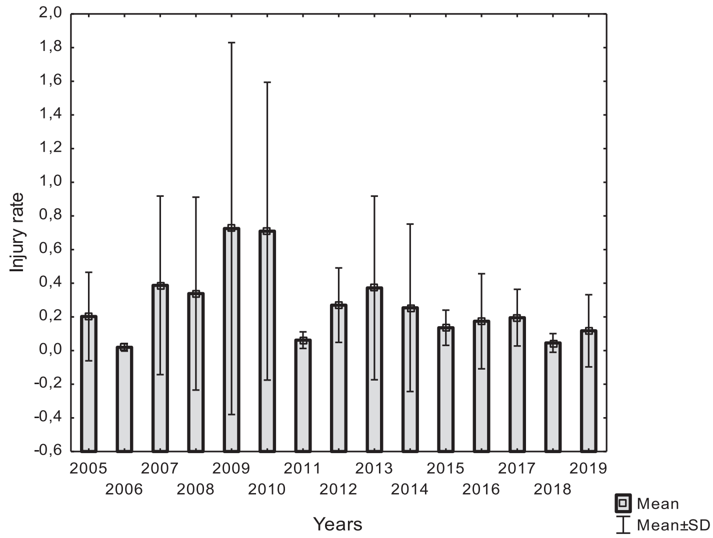
Most of shorebirds were observed with leg injuries (72.41%) followed by wings (22.42%) and bills (5.17%) injured cases (Table 2). Ardeidae (two individuals) and Laridae (four individuals) were exclusively injured, respectively, on legs and wings. In Scolopacidae (32 individuals) and Charadriidae (20 individuals) most specimens had leg injury (Table 2). These injury types were not linked to habitat type ($X2 = 0.95$; $df = 1$; $p = 0.32$) nor to corresponding bird family ($X2 = 0.07$; $df = 1$; $p = 0.79$) (Table 3). The causes of 24.1% of all recorded injuries were known. These injuries were caused by human-associated activities including entrapment in fishing nets (78.6%) and oil related feather damage (21.4%).

4. Discussion

The long distance, transoceanic and transcontinental migrant shorebirds, require high-quality stop-over sites where they refuel before continuing their journeys (Choi et al., 2009; Warnock, 2010; Battley et al., 2012, Hua et al., 2013). Along the CAF, migratory shorebirds have a broad distribution in their non-breeding areas, but a much narrower range during their stopovers in South Asia. The bird species with injuries were mostly from the Scolopacidae and Charadriidae. During the study period, the shorebirds gradually shifted from using the mudflats and mangroves to the sand beaches at Kadalundi-Vallikkunnu Community reserve (Aarif et al., 2014). Our observed proportion of injuries at sand beaches was significantly higher than that recorded at mangroves and mudflats. This is an interesting finding, although we are unclear as to whether the injuries occurred en-route to these wintering sites or they injured themselves after arrival.

Migration is inherently dangerous mostly because the migratory periods may be associated with stochastic mortality (Conklin et al., 2017). The impacts of cost of migration on fitness have been inferred in a wide range of avian taxa including shorebirds (Baker et al., 2004). Migratory bird species face many threats worldwide, and long distant migrants are declining faster than residents and short distant migrants (Bairlein, 2016). Hundreds of millions of long-distance migrants are either injured or suffer fatalities due to collisions with power lines, communication towers, wind turbines, marine debris, marine oil pollution and agricultural pesticide exposure in Canada and the USA (Loss et al. 2015). Data from Asia is relatively scanty and in our study we observed a negligible proportion of resident species being affected by injuries. The highest proportions of injuries on shorebirds were observed during the non-breeding season and pre-migratory season and it was very low during the post-migratory season. Migration may expose individuals to unfamiliar and unpredictable conditions (Newton 2006), and thus result in high mortality during migratory periods (Klaassen et al., 2013; Loss et al. 2015, Conklin et al., 2017).

Heavy use of pesticides in the agro-ecosystems at the wintering grounds in the CAF can cause organ deformities or injuries to waterbirds and the oil disposed, can cause serious injuries to birds (Hampton et al., 2003; Varagiya et al., 2016). Entanglement in fish-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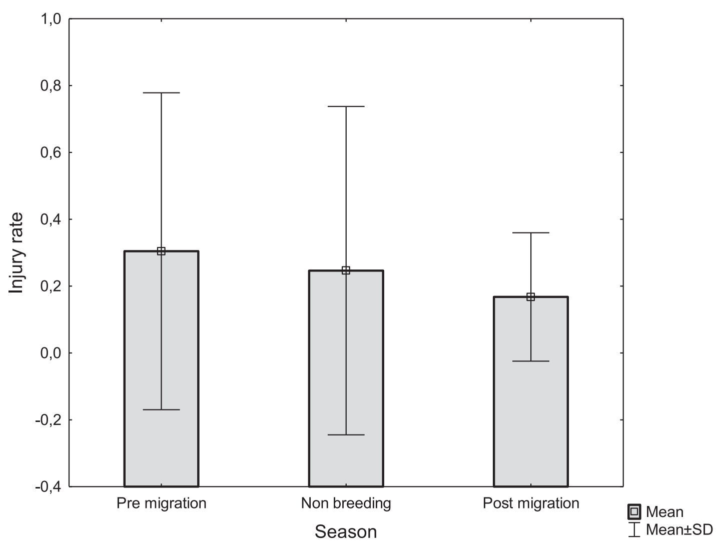
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Season
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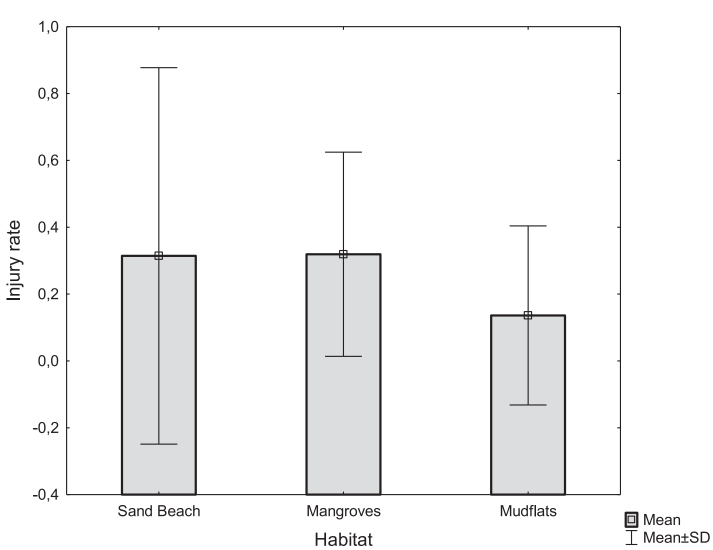
Mean±SD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Habitat
Mean
Mean±SD

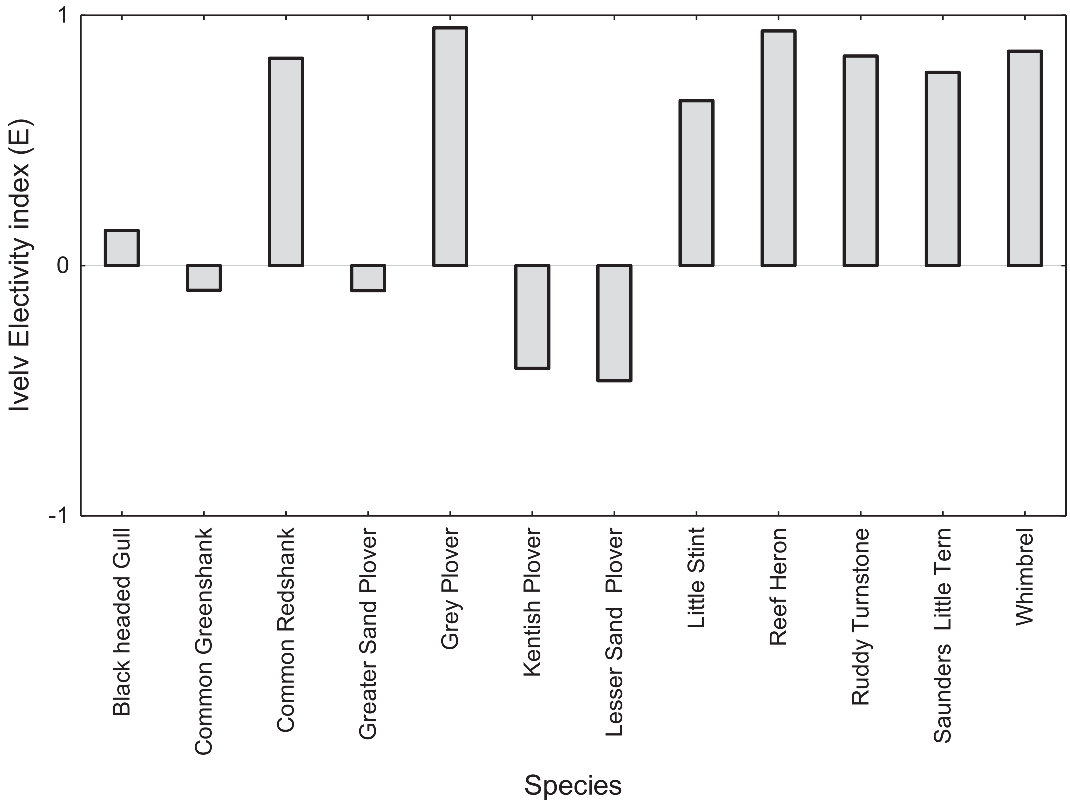

Fig. 5. Ivlev's electivity index corresponding to each waterbird species in which at least one individual was found injured.

ing nets is another critical reason for some of the serious injuries reported in waterbirds from Indian coasts (Kannan and Pandiyan, 2012; Aarif and Prasadan, 2014). However, it may be mentioned that it is difficult to measure the true extent of injuries or mortality arising from agrochemicals or oil pollution based on observation. Birds that die from agrochemical exposure are often eaten by predators or are washed away by the water before they may be recorded (Loss et al. 2015). Similarly, oiled birds in coastal zones may be observed but many die or are depredated before being recorded. Thus, further work is needed to better quantify the effects of injuries or mortalities associated with these environmental contaminants.

Oil spills cause the direct, immediate mortality of birds through several pathways (Jessica et al., 2012). Oil on feathers destroys their waterproofing and insulating capabilities (Leighton and Couillard, 1993), which leads to the bird's death from hypothermia. During the survey we observed a Lesser Sand Plover, whose whole body was covered with black oil, resulting in loss of water proofing capability of feathers. Crighton (2016) and Wang et al. (2018) found that in the coastal regions of south Asia, fishnets on the mudflats impacted feeding activities of waterbirds, as well as caused some waterbird injuries which leads to mortality through drowning during high tide due to entanglement in the nets. Our study is consistent with these studies. For example, the Ruddy Turnstone and Common Redshank were seriously injured because of entanglement in fishing nets. Hunting is another significant issue for shorebirds mortality (Birdlife International, 2012, Loss et al. 2015) or injuries, some shorebirds luckily escape from the poachers with injury (Melville,1997a,b). Such injured birds were observed during the study period from Korappuzha beach. Furthermore, plastic stranded along shorelines, mudflats and mangroves can cause injuries, impede mobility, and cause mortality in many species (Derraik, 2002). Targeted research is needed to better evaluate the long-term impact of oil pollution and marine debris on shorebirds.

5. Conclusion

Anthropogenic debris contaminates aquatic and terrestrial habitats, degrading most levels of biological organization, however mechanisms linking effects on shorebirds or other coastal avifauna are poorly quantified (Browne et al., 2015). Shorebirds that use the Kerala Coasts are already facing a diverse array of threats, including habitat loss, alteration of habitat and pollution caused by human developmental activities (Aarif et al., 2014). Shorebird populations have shrunk and the species that breed in the Arctic are among the hardest hit. The crashing numbers, seen in many shorebird populations around the world, have prompted wildlife agencies and scientists to warn that, without action, some species might go extinct. We recommend that environmental authorities pay special attention to minimize anthropogenic debris along the flyways used by migratory birds thereby reducing the risk of extinction of some of these species. Proactive measures such as removal of discarded fishing gear or plastic debris from wintering as well as stopover areas could greatly reduce injuries in migratory birds arising from anthropogenic sources.

Fig. 4. Injury rate variability over years (Fig. 4a above), seasons (Fig. 4b middle) and habitats (Fig. 4c below).

Table 2
Count and proportion of body parts injured cases in families.

Scolopacidae (n = 32)						Charadriidae (n = 20)						Laridae (n = 4)						Ardeidae (n = 2)						All birds (n = 58)					
Wing		Leg		Bill		Wing		Leg		Bill		Wing		Leg		Bill		Wing		Leg		Bill		Wing		Leg		Bill	
n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
7	21.88	25	78.12	0	0.00	2	10.00	15	75.00	3	15.00	4	100	0	0.00	0	0.00	0	0.00	2	100	0	0.00	13	22.42	42	72.41	3	5.17

Table 3
Count and proportion of body parts injured; cases in habitats types.

Sand beach (n = 31)						Mangroves (n = 9)						Mudflats (n = 18)						All Habitats (n = 58)					
Wing		Leg		Bill		Wing		Leg		Bill		Wing		Leg		Bill		Wing		Leg		Bill	
n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
6	19.36	24	77.42	1	3.22	1	11.12	8	88.88	0	0.00	6	33.33	10	55.55	2	11.12	13	22.42	42	72.41	3	5.17

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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