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Bird Density and Distribution Patterns in Relation to Anthropogenic Habitat Modification around an East African estuary

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Abstract—The effects of human-induced activities were examined on habitat quality, bird density and distribution at the Sabaki River mouth, an Important Bird Area along Kenya's coastline. The avifauna were surveyed along transects in tidal and supra-littoral sub-habitats using the DISTANCE protocol, and along the river by encounter rates to determine abundance and species richness. Anthropogenic activity and habitat structure, including ground cover, plant density, species richness and habitat heterogeneity, were also determined to assess their influence on bird assemblage. Water transparency and pH were measured along the river and crustaceans were sampled to evaluate their spatial abundance and distribution relative to bird dispersal. Four main forms of human activity were delineated, randomly dispersed across the habitat strata. Overall, bird density and diversity diminished with an increase in anthropogenic activity but increased with vertical habitat heterogeneity. In the river, human activity and water quality had no clear effect on the avifauna. However, crustacean abundance along the river attracted more shorebirds with a greater species richness but appeared to be limited by water pH, especially in the dry season. Regulating human access to the estuary would secure the medium-term ecological integrity of its avifauna.

INTRODUCTION

Birds inhabiting tropical coastal wetlands, just like other wild species, select their habitats based on various spatial, temporal and functional attributes (Cody, 1985). Worldwide, coastal birds are currently faced with increasing threats from anthropogenic activities in their natural habitat such as degradation pollution; prey over-harvesting; loss of foraging, roosting and breeding sites and general disturbance (Korschgen & Dahlgren, 1992; Fasola & Bidau, 2003; Burger at al., 2004). In most developing countries, water-bird habitats are among the most extensively exploited for various resources. The unregulated access by humans and livestock to such habitats exposes shorebird nesting sites to egg damage, nestling death or disruption of incubation, and may lead to breeding failure

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(Burger *et al*., 2004). Disturbance may also reduce bird reproductive fitness resulting from diversion of energy towards constant movement, vigilance and defense of young (Korschgen & Dahlgren, 1992). If prolonged, disturbance might result in nest desertion and, eventually, lower recruitment rate from fewer breeding pairs. Over-harvesting of shorebird prey may also cause alteration of the birds' dispersal patterns and habitat use as a result of which trophic relations might be altered and community structures destabilized (Becker & Bessinger, 2006).

Anthropogenic effects on birds are best elaborated by qualitative and quantitative studies of their responses to such purtabations. Patterns of such responses are particularly important for species that play key-stone roles in tropical coastal ecosystems, yet have been little studied (Tews *et al*., 2004). This is because birds are particularly useful as biotic tools in tracking such habitat effects (Bennun & Howell, 2002; Sekercioglu, 2002) since they are sensitive to environmental changes and at the same time form a keystone trophic group in coastal shoreline habitats.

Our study aimed to determine forms and intensities of human-induced activities in the Sakabi Estuary and establish how these relate to density and distribution of birds that occur there. The estuary is one of most significant bird sanctuaries along the East African coast and a source of resources to local communities. The study was deemed particularly important in light of unregulated exploitation of the estuary's rich natural resources in the absence of any formal protection (BirdLife International, 2012; Valle *et al*., 2012).

MATERIAL and METHODS

Sabaki River estuary lies at 03°09' S; 40°08' E, about 5 km north of Malindi on the coast of Kenya (Bennun & Njoroge, 1999; Fig. 1).

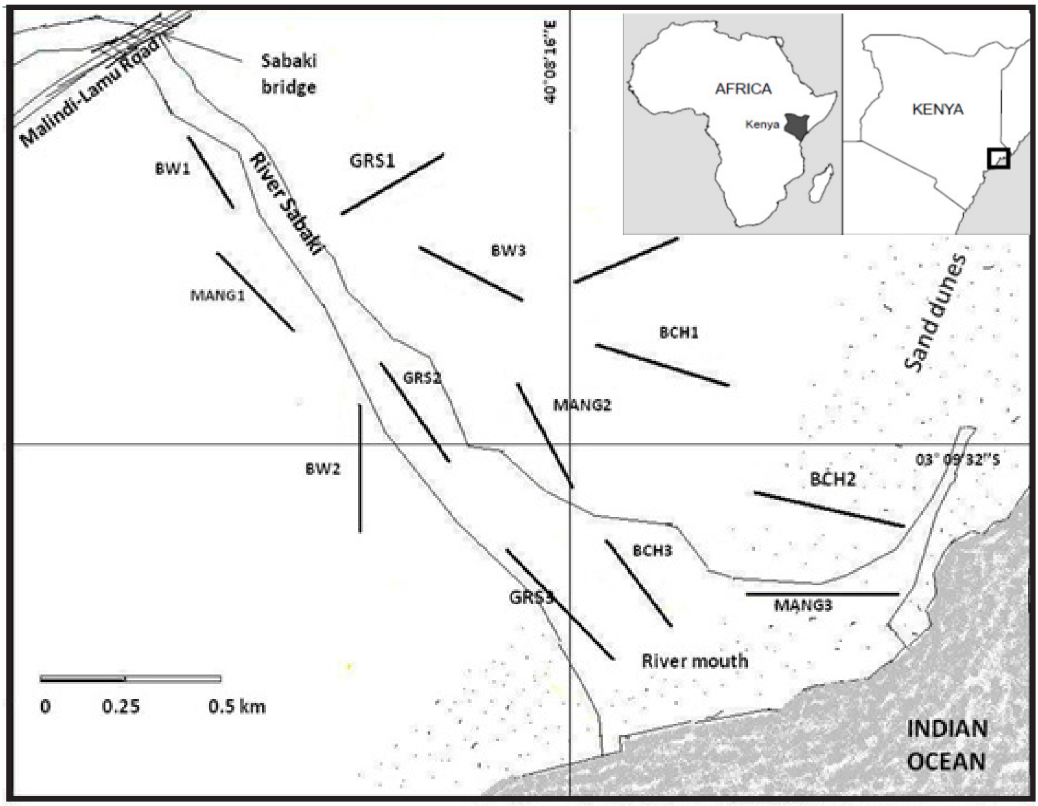

Figure 1. Map of Sabaki River estuary showing transect locations in the tidal zone (BCH = open beach, mudflat and tidal pools; GRS = grass/marsh-flat; MANG = mangrove) and supra-littoral zone (BW = bush/woodland).

The estuary forms one of Kenya's network of 61 Important Bird Areas (IBAs; BirdLife International, 2012) due to its large populations of resident and wintering palaearctic water-birds, the presence of the near-threatened *Anthus melindae*, and the regionally-threatened *Casmerodus albus* and *Rynchops flavirostris* (BirdLife International, 2012). The estuary is characterized by sandbanks and intertidal mudflats, which represent important roosting and feeding grounds for waders, gulls and terns (Bennun & Njoroge, 1999). Upstream, a narrow strip of reeds is found on the river banks on the northern side and mangroves on the southern side (Valle *et al*., 2012). Woody vegetation, including the invasive *Prosopis juliflora*, forms short brush on the Sabaki River's flanks and on beaches in the sub-tidal zone. Thin fringes of mangrove woodland are scattered in the tidal area. This study covered the inter- and sub-tidal area, including the IBA as well as the portion of River Sabaki from the Sabaki Bridge to the river mouth. Much of the downstream portion of the site is influenced by the tidal regime. The growing local human population increasingly depends upon the site for resources such as fish, fibre in the form of grass for domestic use, livestock grazing, construction timber as well as domestic water. However, the estuary enjoys no formal protection or regulation in its use.

Habitat stratification and sampling

The study area was considered in terms of the intertidal zone comprising the beach, mudflats and tidal pools (BCH), mangrove (MANG) and grassy marsh-flat (GRS); the supra-littoral fringing bush (BW) comprising mainly low, scattered, woody vegetation; and the river (River Sabaki) with 10 m of its banks from the Sabaki Bridge to the sea (Fig. 1). Sampling was conducted during low-tides in four field trips of three weeks each, at bi-monthly intervals, covering the broad regional periods of short rains (September/October), the dry season (January/February), the wet season (March/April) and the cool but dry period in July.

Birds were surveyed between 07:00-10:00 to capture peak bird activity and aggregation in each sampling season using the DISTANCE procedure (Buckland *et al*., 1993). Surveys were conducted at low tide (when the mud-flats were fully exposed) along three replicate, variable-width transects (Bibby *et al*., 1998), except along the river. Here surveys were conducted in terms of encounter rate at four stations ~1 km apart, from the bridge to sea, dividing the river into four 200 m sections. These were patrolled by observers who counted and recorded the birds (Bibby *et al*., 1998). In all habitats, birds in large flocks were counted using the block estimation technique (Bibby *et al*., 1998).

Human activities were recorded weekly in 100 m sections along transects between the sampling stations along the river. Metre-square quadrats were laid at 20 m intervals on alternate sides of each transect within which crustaceans were counted and recorded to genus level (Richmond, 2002). In the river, a d-frame net was used to capture crustaceans at three levels of the water column 0, 5 and 10 m from the bank (Sutherland, 1996). To characterize the vegetation of the habitat, 10 x 10 m quadrats were marked out at alternate 20 m intervals along the transects and total plant species, total live woody stems, dominant plant form and percentage ground cover were determined and recorded to the nearest 5%. To determine the vertical habitat heterogeneity, estimates were made of vegetation cover at ground level, 1, 2 and 3 m (Otieno et al., 2011; Sekercioglu, 2002) within a 2 m radius. Water temperature was measured weekly at the surface and bottom of the river, a secchi disc was used to determine water transparency and a weighted string to measure river depth. Water pH was determined colorimetrically on samples collected in 250 ml stoppered bottles at the bottom, mid-depth and water surface.

Statistical analyses

Statistical analyses were conducted using STATISTICA 6.0 (Statsoft Inc 2000). Bird densities were determined per hectare for non-riverine habitats using DISTANCE software (Buckland *et al*., 1993; Thomas *et al*., 2010). The data were analysed in terms of 1) inter-tidal birds (beach, grass mud-flat and mangrove), mainly crustacean invertebrate feeders, and 2) sub-tidal birds (bushed area), mainly insectivorous and granivorous passerines. Due to the difference in sampling methods, riverine bird abundance was analysed separately from that in the other habitats and determined as encounter rates (individuals of each species/km of river). Bird densities were analysed for resident and migrant species according to the Bird Committee of *Nature* Kenya (2009). While bird species richness constituted the cumulative total of species observed in each habitat, species diversity was determined using the reciprocal of Simpson's Diversity Index 1/D, where D is Simpson's Diversity Index in the form: $D = {}^{\Sigma}(n / N)^2$, n the number of individuals of each species and N the total number of all individuals in all species (Ludwig & Reynolds, 1988). Human activity intensity indices were derived from the relationship: $I_A = (\Sigma(n/S_T))/3$ where I_A= mean intensity of human activities per season; n = total number of activities in a 100 m section in a transect; S_T = number of 100 m sections in transect; 3 = number of replicates per season. Crustacean density was determined per m^2 for each habitat and by catch per unit effort at each sampling station along the river. Woody plant density was extrapolated per hectare, while percentage ground cover and vertical vegetation stratification were analysed using the Shannon diversity index H′ to obtain a horizontal heterogeneity index (HHI) and vertical heterogeneity index (VHI; Sekercioglu, 2002). Principal Component Analysis was conducted to delineate key drivers of bird density and distribution across the study area (Zar, 1996) and reduce data noise. To accomplish this, independent variables were reduced to four for non-riverine (human activity intensity, crustacean invertebrate density, VHI and percentage ground cover) and riverine habitats (human activity intensity, crustacean catch effort, water transparency and pH). Consequently, Canonical Correspondence Analysis was used to determine correlations between the respective independent and response variables.

RESULTS

A total of 129 bird species in 42 families were identified in the study area. Of these, 93 (72.1%) were resident species while 36 (27.9%) were migrants (28 or 21.7% palaearctic; 6 or 4.7% afro-tropical and 2 or 1.6% Malagasy). In the inter-tidal zone, the highest bird species richness (98) was recorded in the dry period while, in the bushed area, the highest species richness (33) was recorded in the wet period (Table 1). Bird species richness in the river was higher in the dry period (35; Table 1):

Bird density was, overall, higher in the wet than the dry season (with an overall AIC =66.9, χ^2=0.44). The mean overall density of resident terrestrial birds was 586±11.3/ha and

Table 1. Densities and species richness of birds recorded in various habitats in the Sabaki River estuary. **Tidal zone** = beach, mudflats and tidal pools; grass marsh-flat; mangrove; **Supra-littoral zone** = riparian bush and woodland; **River** = Sabaki River, including 10 m of banks; **RES** – resident bird species; **MIG** – migratory bird species including palaearctic, Madagascan and intra-African migrants which move sporadically across the continent.

Habitat		Wet season				Dry Season				N
	Parameter	RES	MIG	Total	Mean	RES	MIG	Total	Mean	
Tidal zone	Density/ha	674.6	1294.4	1969.0	985.0±95.7	496.0	1114.0	161.0	805.5 ±59.4	36
	Species	55.0	21.0	76.0	-	58.0	40.0	98.0	-	36
Supra-littoral zone	Density/ha	104.9	15.9	120.0	60.4±3.8	60.5	31.8	92.0	46.2±6.4	36
	Species	29.0	4.0	33.0	-	17.0	3.0	20.0	-	36
River	Density/ha	292.6	346.9	639.0	319.8±17.1	63.6	68.5	132.0	66.1±2.6	24
	Species	18.0	11.0	29.0	-	22.0	13.0	35.0	-	24

that of migrants 1204.8±11.3/ha (N=3) in the wet period, while for resident species it was 82.7±5.6/ha and for migrants 23.9±3.4 (N=3) in the dry period. In the river alone, 319.8±4.6 birds/km were encountered in the wet season and 60.8±6.2/km in the dry season (N=2). This also constituted an overall mean encounter rate of 178.1±12.7/km and 207.7±13.9/km for resident and migrant birds respectively (N=2; Tables 1 & 2). However, there was no significant variation in bird encounter rates along the river (R=0.1007, p=0.2350, df=6). The four most prevalent anthropogenic activities recorded were cattle grazing, solid waste disposal, development of paths or tracks, and wood collection. Cattle grazing was associated with reduced ground cover (R=-0.5958, p= .0409, df=11) and lower vertical habitat heterogeneity (R=-0.6896, p = 0.0131, df=11), while the other three human activities

Table 2. Overall densities (per hectare) of birds by family in habitats in the Sabaki River and estuary (N = 36). Riverine counts are in encounters per km.

Family	Beach and mudflat	Grass and marsh	Mangrove	Bush/woodland	River
Phasianidae	0	0.3	0	5.89	0
Anatidae	0	0	0	0	4.65
Phoenicopteridae	191.61	19.35	0	0	0
Ciconiidae	3.44	2.98	0	0	2.44
Threskiornithidae	13.69	11.9	4.63	0	2.65
Ardeidae	2.06	3.88	4.63	0	8.68
Pelecanidae	0	0	0	0	6.53
Phalacrocoracidae	0	0	0	0	5.54
Accipitridae	0.34	0	0.31	2.94	1.44
Burhinidae	0	0.3	0.93	0.59	0
Dromadidae	7.91	0	1.85	0	1.22
Charadriidae	27.19	16.09	18.54	10.59	0.99
Scolopacidae	365.66	38.11	108.64	2.35	32.1
Glareolidae	0	0	0	0	9.19
Laridae	251.42	10.14	0	0	127.5
Columbidae	2.75	1.19	5.26	7.06	0.33
Cuculidae	0	0.6	1.54	2.35	0
Apodidae	0	0.89	0	34.71	8.19
Coliidae	1.72	1.48	3.08	16.47	0
Coraciidae	0	0	1.23	1.76	0
Alcedinidae	0.34	0.89	3.09	0.59	0.33
Meropidae	0.34	0	0.93	0.59	0
Capitonidae	0	0	0.32	0	0
Malaconotidae	0.68	0.89	4.02	6.47	1
Laniidae	0.34	0	0	2.3	0
Dicruridae	0.34	0	2.47	4.12	0
Corvidae	1.38	0	2.16	0	0
Paridae	0	0.3	0	1.76	0
Cisticolidae	0	0.597	0	3.53	0
Pycnonotidae	3.78	1.19	5.25	12.94	0
Sylviidae	0	2.38	0.62	3.53	1.44
Sturnidae	0	1.19	0	0	0
Muscicapidae	0	0.89	0.31	2.36	0
Ploceidae	2.42	3.88	5.25	28.81	2.21
Estrildidae	10.32	2.97	10.19	12.94	0
Motacillidae	2.05	1.49	0.64	1.18	0
Total	**890±77.9**	**124±7.5**	**186±18.1**	**166±7.9**	**216±21.6**

had little effect on birds. The human activity intensity index differed across the terrestrial habitats (mangrove 0.0838±0.01; grass/ marsh-flat 0.0762±0.01; bush 0.0680±0.02; beach 0.0422±0.01, F=3.0774, p=0.051, df=23). Overall, reduced bird density in the intertidal zone (R=0.643, p=0.043, df=7) and in the sub-tidal (bushed) habitat (R=-0.794, p=0.030, df.=5) corresponded with human activity (Fig. 2). The distribution of human activities was random across each habitat (Dispersion Index=1.58, df=8), though relative intensities of certain forms of human activity were significantly associated with each habitat ($\chi^2_{(36,0.05)}$=64.23). Cattle activity was found in all habitats associated with solid waste disposal and tracks on open beaches; grass collection on the grassy marsh-flat; tracks in the mangrove; wood collection in the bush zone area and fishing along the river.

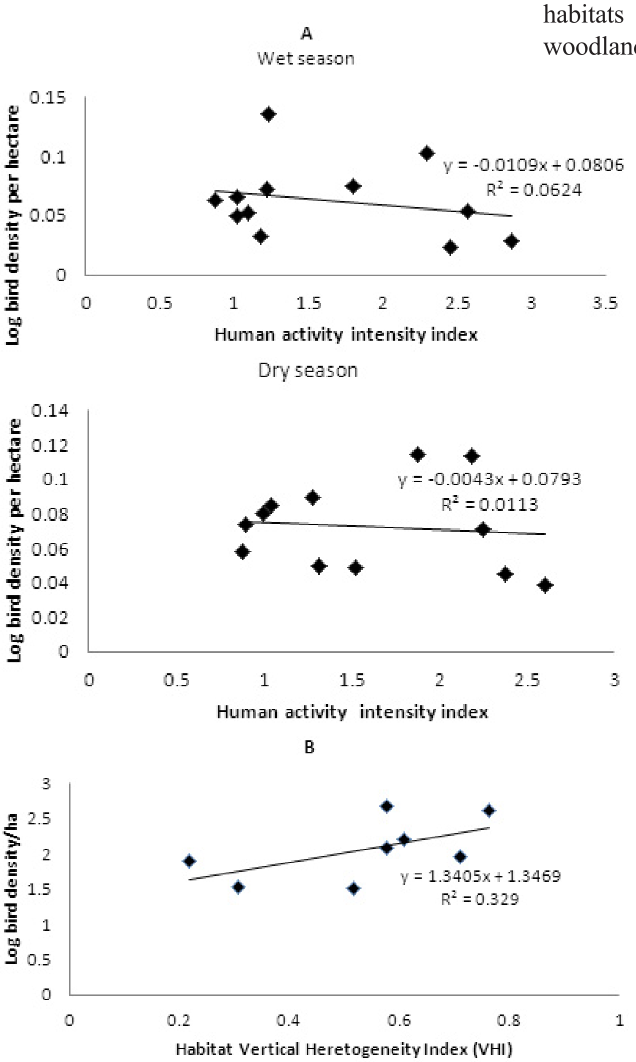

Figure 2. Relationship between bird density and A) the human activity index in non-riverine habitat in the wet (top) and dry (bottom) seasons, and B) the habitat heterogeneity index. Human activity and heterogeneity indices are arcsines of indices ranging between 0 and 1.

In terms of ground cover, the vegetation significantly differed across terrestrial habitats (grassy marsh-flat = 56±9.8; bush/ woodland=43±4.4; mangrove=18±1.8; and beach 8.7±4.8, ANOVA, F=71.6, p<0.01, df=23) but not between seasons. Vertical heterogeneity differed only slightly (ANOVA, F=5.31, p=0.07, df=23) but was significantly higher in the wetter periods (t=7.72, p<0.001, df=6) reflecting new foliage growth. A higher vertical heterogeneity index corresponded significantly with higher bird densities in the supra-littoral habitat (R=0.755, p=0.015; Fig 2).

Crustacean density differed significantly across the non-riverine habitats (F=15.92 p=0.0190, df=6) with the highest value in the mangroves (32±1.5), but did not seem to elicit any significant response in the bird assemblage. In the river, however, despite a lack of variation in human activity intensity, crustacean abundance in terms of catch per unit effort was higher in the wet season (1.11±0.37) than the dry season (0.88±0.31, t=3.863, p=0.0181, df=4). Crustaceans also declined downstream (Fig 3). River transparency and pH were both negatively correlated with crustacean abundance (R=-0.9429, p=0.0048 and R=-0.9239, p=0.0138; Fig. 3), though the water was less clear in the wet (6±0.38 cm) than the dry season (15.1±0.38, t=4.723, p=0.0032, df=6). On the other hand, river pH was higher in the dry season (t=3.536, p=0.0123, df=7) and generally increased with transparency (R=0.8857, p=0.0188; Fig. 3). Both bird encounter rate and species richness were positively correlated with crustacean abundance in the river (R=0.8095, p=0.0149, df=3 and R=0.6429, p=0.0856, df=3 respectively)

DISCUSSION and CONCLUSION

From the results, Sabaki River estuary forms an important resource for the local community and a significant bird habitat. Together with the river system and the diverse associated habitat structure, the estuary offers excellent foraging opportunities for large populations of aquatic and passerine birds. Although the large majority of the birds recorded were waders that feed on a variety of crustaceans, other macro-invertebrates and amphibians, many piscivores may be attracted by the high diversity of fish species for which this coastal belt is known (Oyugi, 2005). Furthermore, despite most of the birds encountered being waders, a considerable number of passerine species were observed in the more heterogeneous wooded riparian zone invaded by *Prosopis juliflora*, and in the bushy habitat (Table 2). This adds to the estuary's importance as a bird habitat.

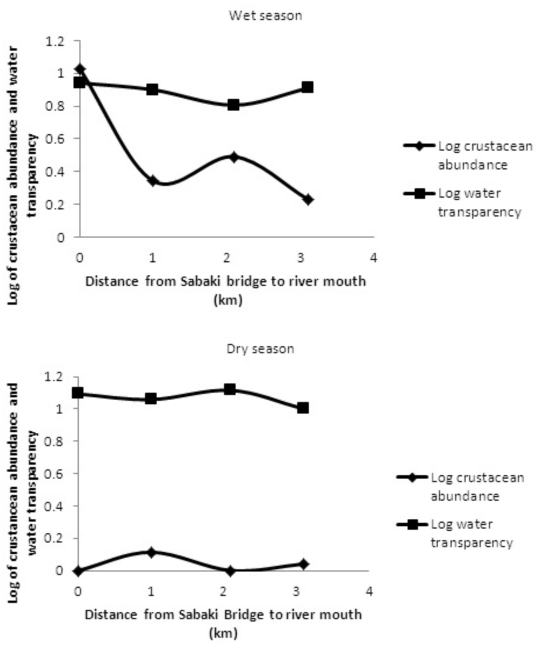

Figure 3. Relationship between abundance of crustaceans (catch per unit effort) in the Sabaki River estuary with water transparency (secchi depth in cm) at various sampling points along the river in the wet (top) and dry (bottom) seasons.

The high density of migrant birds clearly demonstrates the estuary's crucial importance as a wintering ground or feeding site for migrants from the northern hemisphere (BirdLife International, 2012; Valle *et al*., 2012), especially in the wet periods when the Sabaki River carries large amounts of organic material (KenSea, 2006) utilized by macro-invertebrates consumed by shorebirds. The negative effect of human activity on bird densities in the study area appeared largely due to disturbance of bird feeding sites, particularly in wet periods (Fig. 2). Gill (2007) pointed out that birds may be affected by human activities either directly by disturbance or through such effects on their habitat. For example, in the present study, cattle grazing was associated with reduced vegetation cover that might provide perch sites for birds (Hinsley & Bellamy, 2004) and habitat for invertebrates (Strayer, 2007); such vegetation also prevents water evaporation by conserving soil moisture. Habitat quality was aggravated by other human activities such as unregulated access, the formation of paths and tracks as well as the exploitation of resources such as grass and timber. These further affected bird diversities across the various habitat zones through their impacts on the various bird niches (Tews *et al*., 2004). Such disturbances and habitat degradation might also affect birds by limiting their access to resources or through a reduction in the quantity or quality of the resources available (Gill, 2007). In addition, disturbance of shorebirds may result in lower bird fitness, as less food is collected and energy is used in constant movement, vigilance and protection of young; this might lead to a long-term population decline in more sensitive species (Pfister *et al*., 1992).

Cattle-grazing is associated with reduced vertical habitat heterogeneity (Tews *et al*., 2004). As cattle graze and browse on vegetation, they not only trample soil, roots and stolons of many plants but also break and remove considerable vegetation, thereby increasing soil erosion and creating a spatial vegetation mosaic through preferential defoliation (Bokdam & Gleichman, 2000; Albon *et al*., 2007). In the Sabaki Estuary, the effects of cattle grazing were accentuated by other forms of human activity, viz. vegetation clearing, the development of tracks and grass harvesting. Thus, it is noteworthy that human activity was more pronounced on the grassy marsh-flat and in the mangrove area, where the cattle spent much of their time feeding. The former habitat, which comprises grasses and sedges up to 1.6 m in height, contributes significantly to habitat heterogeneity and provides an array of niches for different bird species (Table 1). Unfortunately, it is also the habitat targeted for livestock grazing and thus one of the most impacted by livestock activity. In the wetter periods when rainfall promoted new foliage growth, pressure on the estuarine vegetation eased somewhat as cattle could obtain their food further upstream. This explained the improvement in vertical habitat heterogeneity from enhanced foliation by woody plants in the wet season which, in turn, was associated with a higher overall bird density (Fig. 2).

In the river itself, although there was a mixture of piscivorous, invertebrate- and mixed-feeding birds, overall bird encounter rates appeared predominantly linked to crustacean abundance. Avian abundance was, however, little affected by water turbidity. In the wet season when turbidity was high and the pH comparably lower, the crustacean biomass was greater, possibly due to greater allochthonous input, which in turn attracted greater bird numbers and species. Conversely, in the drier periods when freshwater input, sediment discharge and river velocity were reduced and the water more transparent, evaporation was enhanced due to elevated temperatures (Burger *et al*., 2004), leading to a rise in pH and reduced crustacean biomass with a correspondingly lower avifauna along the river. This negative influence of pH on crustaceans (Reiner, 2000) suggests that activities such as large-scale aquaculture, farming or industrialization around the estuary may affect food chains upon which birds are dependent.

In conclusion, the study revealed a general negative influence of anthropogenic activity on bird density in the Sabaki River estuary, mainly through its effect on habitat quality. This is mainly attributable to unregulated human access to the site, including intensive livestock activity. Formal protection backed by a management plan is strongly recommended to prevent the negative consequences of these activities on the integrity of the estuary as an Important Bird Area, making it a valuable resource for tourism.

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