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Original article

Variation of avifaunal diversity in relation to land-use modifications around a tropical estuary, the Negombo estuary in Sri Lanka

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ABSTRACT

We assessed variation in avifaunal diversity at some selected habitats around the Negombo estuary in Sri Lanka in relation to land-use modifications. During the study period, we observed 48 bird species of which 47 species are residents to Sri Lanka. The avian species richness, evenness, and heterogeneity were found to be the highest at undisturbed habitats. Further, these diversity measures were negatively correlated with the intensity of anthropogenic land-use activities. Total abundance of birds increased at highly disturbed habitats due to the presence of the house crow, as it is the most abundant of all birds observed at these habitats. This study highlights the need for habitat management around estuaries, giving due consideration to existing ecological theories to conserve avifaunal diversity. It also highlights the negative impacts of the house crow on diversity of other resident avian fauna in these habitats.

Introduction

Coastal ecosystems, including estuaries and associated habitats, have been increasingly altered and developed for human settlement (DeLuca et al 2008) and for commercial and recreational use. These anthropogenic disturbances have severely affected the long-term viability, health (Kennish 2002), and the biota including birds inhabiting these sensitive habitats.

Due to the high productivity, estuaries and coastal regions around the world have been the focal points of human settlement and marine resource use, and such use has strong negative impacts on plant and animal communities (Hilbert 2006; Lotze et al 2006). In many parts of the world human activities around estuaries significantly affect bird communities, their behavior, and existence. For example, DeLuca et al (2008) found that coastal urbanization, even at low levels, significantly affects the integrity of aquatic bird communities in the Chesapeake Bay, USA. Similarly, the abundance and richness of shorebirds and other aquatic birds were low in Southern California, where human activities were high (Lafferty et al 2013). It has also been found that human influences at intertidal mud flats of Queule River estuary in Chile have affected the distribution of both migratory and resident birds there (Suazo et al 2012). However, prominent features or characteristics of urbanization and human habitations around estuarine land-use patterns that govern the avifaunal distributions are yet to be assessed.

Sri Lanka is a small island in the Indian Ocean and together with Western Ghats of India, is recognized as one of the 34 biodiversity hotspots of the world (Gunatilleke et al 2008). In spite of the small size, Sri Lanka is known to harbor 426 avian species including residents and winter migrants (Harrison 2011). The island has its unique specialties as well, with more than 20 species and over 70 subspecies being endemic to Sri Lanka (Harrison 2011). A few studies that assess estuarine avian communities have already been carried out in Sri Lanka. For example, Bellio and Kingsford (2013) studied the alteration of wetland hydrology and its implications on shorebird conservation in Bundala National Park (a Ramsar site), and Embilikele lagoons and found that human activities such as pollution had detrimental effects on bird communities. Kaluthota et al (2008) also conducted studies in Bundala on migratory wading bird communities. Chandana et al (2008) studied the factors affecting avifaunal distribution in three lagoons, namely, Malala, Embillikele, and Bundala and showed that salinity, water depth, and abundance of aquatic macrophytes were the key determinants of bird diversity there. However, the direct impacts of urbanization on estuarine avian diversity in Sri Lanka have not yet been addressed. This gap has been identified throughout the world too, as the conservation biologists focus predominantly on the protection of natural ecosystems and have placed little importance on

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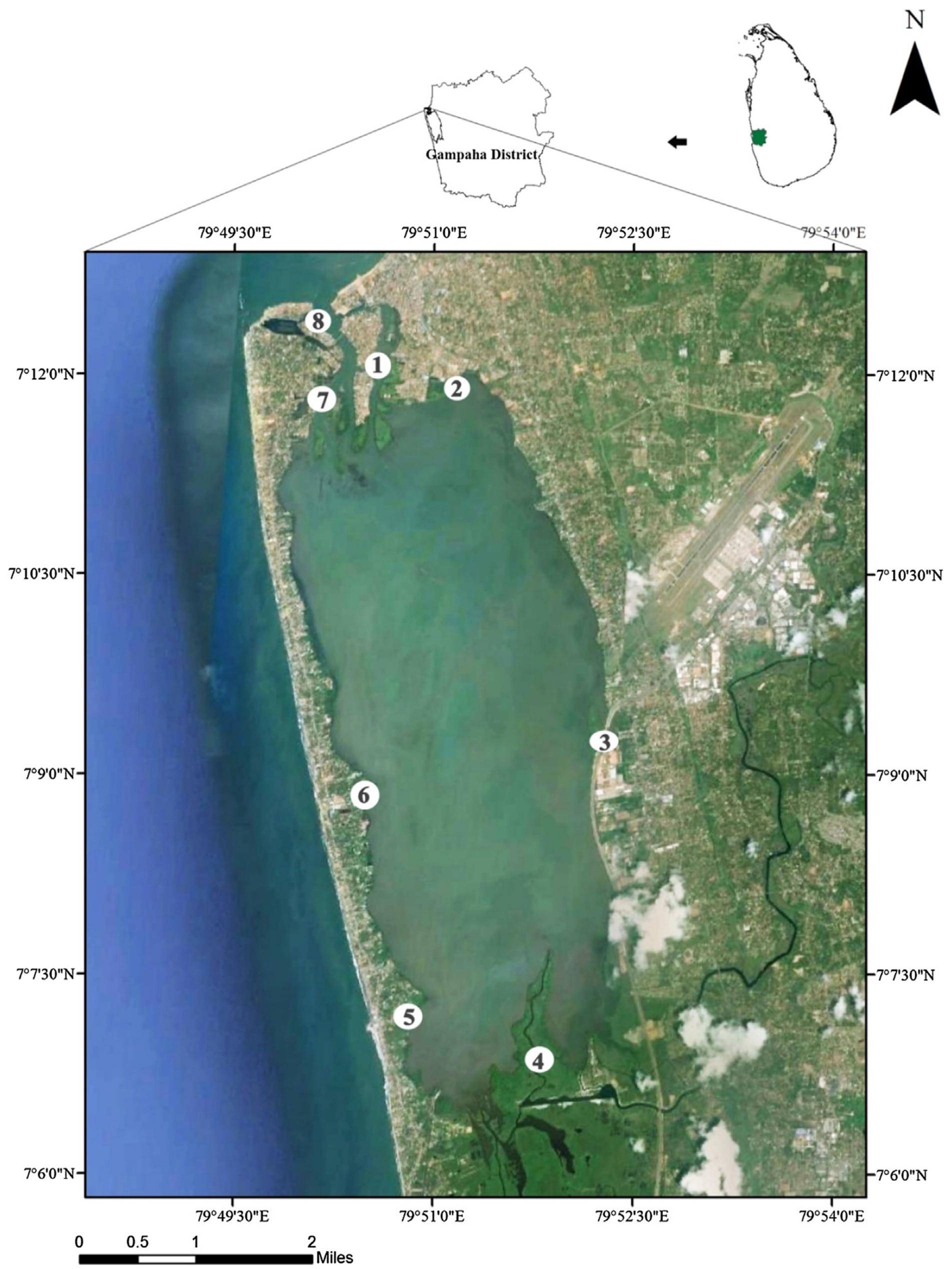

Figure 1. Satellite images of the Negombo estuary showing the eight study sites: Site 1 - Munnakkara (a highly populated village), Site 2 - Kadolkele (a pristine mangrove forest), Site 3 - Seeduwa (marsh lands adjacent to the Colombo-Katunayake expressway), Site 4 - Kindigoda (an undisturbed marsh and mangrove forest area near the head of the estuary), Site 5 - Kepungoda (a village with coconut plantations), Site 6 - Dungalpitiya (a village with a low human population density), Site 7 - Pitipana (an area with aquaculture grow-out ponds), Site 8 - Duwa (a fishing harbor/boating area). Image source: Google Earth Pro Software (Google Inc., 2013). Location of Negombo estuary in Sri Lanka is also shown.

urban biodiversity overall (Melles et al 2003). Therefore, it is important to focus on this particular aspect with regard to estuaries with varying degrees of urbanization among different land-use patterns associated with them.

The Muthurajawela marsh and Negombo estuary have received widespread interest and attention and, when considered together, are designated as a protected area for biodiversity conservation (Devendra 2002). As these two wetland ecosystems occur in one of the most populated regions of the west coast of the country, they are threatened by a variety of anthropogenic user patterns including fishery, agriculture, shipping, and habitation. This region has undergone a considerable land-use change over the past few decades (Sellamuttu et al 2011), particularly towards the northern side in the Negombo estuary. Although only a few studies have been carried out to investigate the effects of these land-use changes on the floral and faunal communities around the Negombo estuary in general, their impacts on the avian diversity have never been addressed. Therefore, the present study was carried out to assess the changes of the avifaunal diversity in relation to land-use patterns around this estuary in Sri Lanka.

Materials and methods

Study area and sampling sites

The Negombo estuary (7° 6′–7° 12′ N; 79° 49′–79° 53′ E) is situated on the west coast of Sri Lanka (Figure 1). It is a shallow basin type estuary with a surface area of approximately 35 km^2. The southern part of this estuary extends further south to form the Muthurajawela marsh, a designated Ramsar site in the country. The estuary together with the Muthurajawela marsh have been recognized as important feeding and breeding habitats for resident birds and feeding and resting habitats for migratory birds as well (Bambaradeniya et al 2002). Since the present investigation was carried out during June to September 2013, and the migratory birds are only present in these habitats from September to February each year, the study focusses on the resident birds of these habitats.

Upon consultation of the satellite images of the Negombo estuary in the Google Earth Pro Software (Google Inc. 2013) and maps of the area produced by the Central Environmental Authority, areas with different anthropogenic activities and land-use patterns were identified from around the Negombo estuary, and principal terrestrial and semiterrestrial study sites were selected for the study from within these areas (Figure 1). These eight sites are Munnakkara (Site 1), Kadolkele (Site 2), Seeduwa (Site 3), Kindigoda (Site 4), Kepungoda (Site 5), Dungalpitiya (Site 6), Pitipana (Site 7), and Duwa (Site 8). It was assumed that the birds found in these sites would serve as indicator species to the anthropogenic activities there.

Sampling and analysis protocols

The present study included observation, identification and enumeration of different bird species and assessment of land use patterns of the eight sites selected for the study. For this, the fixed-radius point count method as described by Sutherland (1996) was followed where 10 circular point count stations, each with a 50 m radius, were established at random ground locations at each study site. The total area of each point count station is 7857 m^2. The birds occurring at each one of these point count stations were observed, identified, and counted *in situ* between 6:00 AM and 9:00 AM when the bird activity is considered to be the highest. Counting was carried out for a period of 10 minutes at each point count station while standing at its center. Bird observations were made using a COMET (8×40 DPSI) binocular (Kunyang Zhicheng Optical Co., Ltd. Yunnan, China (Mainland)). Birds were identified using bird guides for Sri Lanka by Harrison (2011) and Kotagama and Wijayasinghe (2011). A Nikon D5200 digital camera (Nikon Inc., NY, USA) combined with a 55–300 mm Nikkor lens (Nikon Inc., NY, USA) was used in capturing bird photographs whenever possible. These digital images were used later when birds could not be identified *in situ* or when identification was doubtful. Birds flying over the point count stations and those that were not observed to have taken off from there were not counted, due to the reasons proposed by Buckland et al (1993) and Barraclough (2000). No counts were made during steady hard rain or when the wind speed was detected to be higher than normal.

Seventeen attributes of the study sites that have been recognized as factors affecting the bird distribution in similar studies carried out elsewhere were considered in order to assess the anthropogenic activities at each point count station at each site. These included the *in situ* counting of: (1) the number of people; (2) vehicles (Melles et al 2003); (3) boats (Whelan 2003); (4) cattle (Kumar and Kumara 2011); (5) dogs (Silva-rodríguez and Sieving 2011); (6) cats (Medina et al 2011); (7) garbage dumps; (8) homesteads; (9) telephone poles; (10) electricity poles; (11) antenna poles (Armendariz et al 2011); and (12) trees taller than 4 m. It also included the measurement of: (13) the sound level (Anderson 2009) (13); (14) area of cleared areas and roads; (15) area of stagnant and flowing water bodies; (16) area of vegetation cover taken by trees taller than 4 m; and (17) the area of total vegetation cover.

The numeric values relevant to the attributes 1–8 were recorded simultaneously by a helper while the birds were being counted. The sound level (8) was measured in decibels using a sound meter (MetalMed dB version 1.2, developed by Metallurgica Medolago (Madone BG, Italy)) and the average sound level for a period of 2 minutes was recorded for each point count station. The area of cleared areas (14) was determined by measuring the area with no vegetation cover, buildings, or roads within each point count station. The areas of stagnant and flowing water bodies (15) were also measured in a similar manner. The number of trees with a height greater than 4 m (12) was counted and the diameter of the canopy of each tree was measured by visual approximation. These data were later used to calculate the area of vegetation cover taken by trees that were taller than 4 m (16). The area of total vegetation cover (17) in each point count station was calculated using Google Earth Pro software and the aerial photographs provided there, while polygons were drawn to a scale over the green space on the aerial photographs (Melles et al 2003) to determine the area occupied by the vegetation cover. Data pertinent to attributes 9–17 were collected after bird counting was performed. Kindigoda, the 4th site, was accessed by a nonmotorized canoe, while all the other sites were covered on foot. Due to logistic reasons, we could not collect data from all the 10 point count stations at each site in a single day, so each site was visited twice within a 1 week interval during the study period.

The total abundance (N) and the relative abundance of birds at each study site were calculated separately. The avifaunal diversity in terms of species richness (SR), N, Pielou's species evenness index (J′), and Shannon-Weiner species heterogeneity (H′) at each site were determined following Magurran (1988). The mean values of the most common bird species and the physical attributes of the land-use patterns between the eight sites were analyzed separately separately using Principal Component Analysis (PCA) in Primer (Version 5.2.9 for Windows, PRIMER-E Ltd., Plymouth, UK). The variation of the bird abundance and variation of the physical attributes between the eight sites each were analyzed using one-way analysis of variance (ANOVA), respectively, using the statistical software package Minitab (Version 14 for Windows, Minitab Ltd., Coventry, UK) as appropriate at $\alpha = 0.05$ level of significance. When the ANOVA yielded a significant result, Tukey's pairwise comparison tests were performed for significant differences between the sites. Only the common birds with $N > 1\%$ each and those that were present at two or more study sites, were considered for the above PCA and one-way ANOVA analyses following Melles et al (2003). Further, the relationship between the PC 1 scores of PCA and SR, N, J′, and H′ were determined separately using regression analysis.

Results

Land-use patterns in Negombo estuary

The 17 physical and biological attributes used to assess the land-use patterns varied between the eight study sites (Table 1). PCA revealed that Munnakkara (Site 1) which is the highly populated, polluted, and disturbed site situated near Negombo City, is characterized by a large number of people, vehicles, garbage dumps, homesteads, stray dogs, and telephone, electricity, and antenna poles (Figure 2; Table 2).

Kepungoda (Site 5), the village with large coconut plantations is characterized by a large canopy area contributed by the largest number of tall (4 m < height) coconut trees and cattle. Duwa (Site 8), the fishing harbor/boating area is characterized by a large number of boats, cats, garbage dumps, and electricity poles. Kindigoda (Site 4), the undisturbed pristine marsh area situated near the head of the estuary is characterized by the presence of a large number of stagnant and flowing water bodies, while Kadolkele

Table 1. Physical and biological attributes of the eight study sites in Negombo estuary.

Physical Attributes	Site 1 (Munnakkara)	Site 2 (Kadolkele)	Site 3 (Seeduwa)	Site 4 (Kindigoda)	Site 5 (Kepungoda)	Site 6 (Dungalpitiya)	Site 7 (Pitipana)	Site 8 (Duwa)
1. No. of people*	11.40 ± 2.38^{a} (4–30)	0^{b}	2.40 ± 1.21^{b} (0–11)	0^{b}	2.20 ± 0.55^{b} (0–5)	4.20 ± 0.51^{b} (2–7)	1.50 ± 0.31^{b} (0–3)	10.40 ± 1.54^{a} (3–20)
2. No. of vehicles*	8.20 ± 1.18^{a} (3–15)	0^{b}	0.80 ± 0.36^{b} (0–3)	0^{b}	0.20 ± 0.13^{b} (0–1)	1.40 ± 0.34^{b} (0–3)	0.20 ± 0.20^{b} (0–2)	6.20 ± 1.23^{a} (0–11)
3. No. of boats*	0^{a}	0^{a}	0^{a}	0^{a}	0.10 ± 0.10^{a} (0–1)	0^{a}	0^{a}	16.30 ± 2.62^{b} (9–36)
4. No. of cattle*	0^{a}	0^{a}	0^{a}	0^{a}	$0.20 \pm 0.13^{a,b}$ (0–1)	1.30 ± 0.75^{b} (0–7)	0^{a}	0^{a}
5. No. of dogs*	2.30 ± 0.50^{a} (1–6)	0^{b}	$0.70 \pm 0.33^{a,b}$ (0–3)	0^{b}	0.70 ± 0.33^{b} (0–3)	1.10 ± 0.28^{b} (0–2)	0.80 ± 0.33^{b} (0–3)	1.50 ± 0.70^{b} (0–5)
6. No. of cats	0.40 ± 0.22 (0–2)	0	0	0	0.10 ± 0.10 (0–1)	0	0	0.40 ± 0.31 (0–3)
7. No. of garbage dumps*	1.30 ± 0.67^{a} (0–6)	0^{b}	$0.50 \pm 0.22^{a,b}$ (0–2)	0^{b}	$0.10 \pm 0.10^{a,b}$ (0–1)	$0.30 \pm 0.15^{a,b}$ (0–1)	$0.20 \pm 0.13^{a,b}$ (0–1)	$1.10 \pm 0.31^{a,b}$ (0–3)
8. No. of homesteads*	21.20 ± 2.82^{a} (9–35)	0^{b}	0^{b}	0^{b}	$2.30 \pm 0.47^{b,c}$ (0–5)	$5.10 \pm 0.43^{c,d}$ (3–7)	$0.90 \pm 0.48^{b,c}$ (0–)	7.60 ± 1.34^{d} (2–14)
9. No. of telephone poles*	4.30 ± 0.47^{a} (2–7)	0^{b}	0^{b}	0^{b}	$0.60 \pm 0.31^{b,c}$ (0–2)	$3.00 \pm 0.65^{a,d}$ (0–7)	$0.60 \pm 0.27^{b,c}$ (0–2)	$2.1 \pm 0.81^{c,d}$ (0–7)
10. No. of electricity poles*	4.10 ± 0.55^{a} (2–6)	0	$2.70 \pm 0.50^{a,b}$ (2–5)	0	1.10 ± 0.41^{b} (0–3)	3.90 ± 0.46^{a} (2–6)	$2.80 \pm 0.57^{a,b}$ (0–6)	4.30 ± 0.99^{a} (1–12)
11. No. of antenna poles*	8.50 ± 1.38^{a} (2–14)	0^{b}	0^{b}	0^{b}	0.40 ± 0.31^{b} (0–3)	0.60 ± 0.22^{b} (0–2)	0.80 ± 0.47^{b} (0–4)	3.90 ± 1.04^{c} (1–11)
12. No. of tall trees (4 m <)*	10.10 ± 1.96^{a} (2–21)	131.8 ± 15.1^{b} (66–196)	5.80 ± 3.55^{a} (0–35)	4.10 ± 0.95^{a} (0–10)	96.20 ± 11.08^{c} (22–150)	28.50 ± 4.42^{a} (11–50)	2.40 ± 1.27^{a} (0–11)	3.50 ± 0.90^{a} (0–8)
13. Sound level*	73.00 ± 2.05^{a} (64–82)	51.80 ± 2.18^{b} (44–62)	63.30 ± 1.43^{c} (56–70)	40.70 ± 0.33^{d} (39–42)	63.80 ± 1.23^{c} (58–68)	64.60 ± 0.97^{c} (61–71)	54.80 ± 2.12^{e} (46–63)	$57.1 \pm 3.15^{b,c,e}$ (50–82)
14. Area of cleared areas and roads*	4.59 ± 0.56^{a} (2.23–7.64)	0.06 ± 0.06^{a} (0–0.58)	11.91 ± 3.12^{b} (2.54–31.82)	0^{a}	0^{a}	4.03 ± 1.61^{a} (1.59–18.45)	0.97 ± 0.63^{a} (0–6.36)	1.33 ± 0.39^{a} (0–2.04)
15. Area of stagnant and flowing water bodies*	1.95 ± 1.37^{a} (0–12.73)	0.59 ± 0.32^{a} (0–2.54)	10.18 ± 5.31^{a} (0–53.39)	42.8 ± 7.97^{b} (24.74–99.0)	3.35 ± 3.23^{a} (0–32.45)	0.03 ± 0.02^{a} (0–0.19)	40.63 ± 10.05^{b} (0–83.27)	38.63 ± 3.31^{b} (21.06–48.15)
16. Area of trees > 4m*	1.80 ± 0.49^{a} (0.18–5.13)	7.61 ± 1.32^{b} (3–14.89)	0.41 ± 0.24^{a} (0–2.12)	0.94 ± 0.28^{a} (0–1.58)	8.92 ± 0.97^{b} (2.09–11.4)	2.22 ± 0.29^{a} (0.84–3.73)	0.44 ± 0.28^{a} (0–2.75)	0.66 ± 0.17^{a} (0–1.76)
17. Area of total vegetation*	20.59 ± 3.16^{a} (2.38–35.48)	97.21 ± 1.64^{b} (83.48–100)	44.97 ± 7.75^{c} (5.92–75.28)	53.79 ± 8.72^{c} (1.67–74.25)	91.53 ± 2.86^{b} (69.08–99.99)	79.64 ± 2.90^{b} (64.65–94.55)	16.99 ± 5.40^{a} (0–41.88)	7.10 ± 1.77^{a} (0–18.64)

Mean ± standard error (SE) for each attribute is given ($n = 10$). Note: Values represent Mean ± SE and range in parentheses.
* Significant p values detected by one-way ANOVA. Different superscript letters in a row show significant differences ($p < 0.05$) indicated by Tukey's pairwise comparisons after ANOVA.

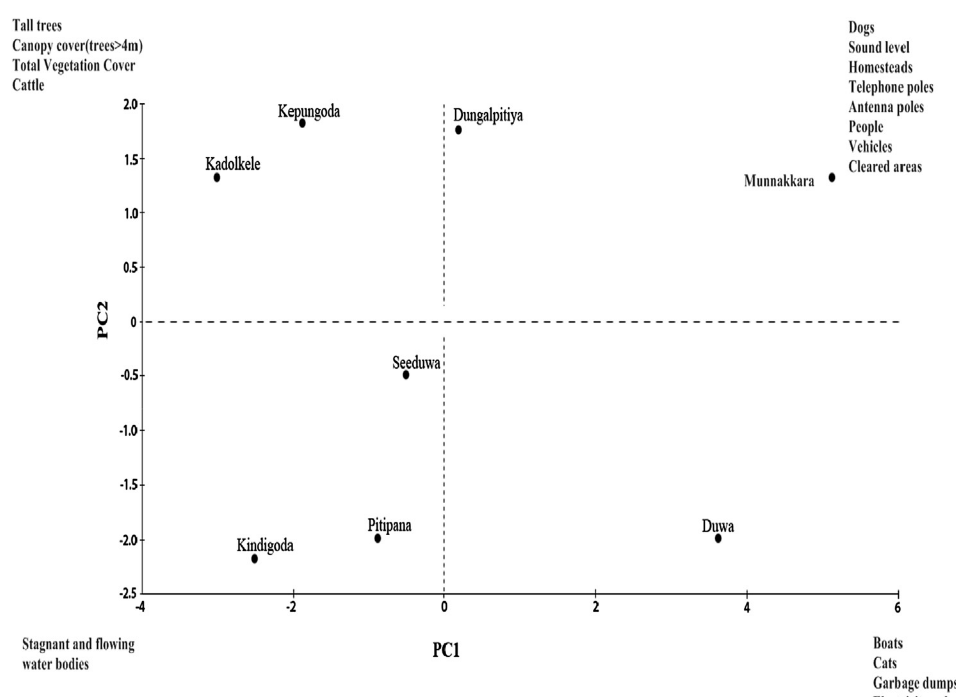

Figure 2. Principal component analysis (PCA) ordination based on PC 1 and PC 2 scores between the physical and biological attributes of the eight sites around the Negombo estuary. Physical and biological attributes that are characteristic to Kepungoda and Kadolkele, Munnakkara, Kindigoda, and Duwa are also summarized in this ordination.

Table 2. Abundance of individual species and results of one-way ANOVA for the 12 most common bird species across the eight study sites in Negombo estuary ($n = 10$).

Bird species (common name)	Site 1 (Munnakkara)	Site 2 (Kadolkele)	Site 3 (Seeduwa)	Site 4 (Kindigoda)	Site 5 (Kepungoda)	Site 6 (Dungalpitiya)	Site 7 (Pitipana)	Site 8 (Duwa)	Relative abundance
*Corvus splendens** (house crow)	23.90 ± 2.22^{a} (13–36)	7.90 ± 1.25^{a} (3–15)	8.40 ± 1.92^{a} (1–21)	9.50 ± 1.74^{a} (3–15)	6.60 ± 1.14^{a} (1–13)	11.90 ± 1.15^{a} (6–18)	17.20 ± 4.70^{a} (3–49)	45.80 ± 10.59^{b} (15–102)	60.41%
*Egretta garzetta** (little egret)	0^{a}	$1.60 \pm 0.45^{a,b}$ (0–3)	0^{a}	0^{a}	0.20 ± 0.20^{a} (0–2)	0^{a}	$4.60 \pm 1.85^{b,c}$ (0–19)	7.70 ± 1.58^{c} (0–17)	6.49%
Orthotomus sutorius sutorius (common tailorbird)	0.70 ± 0.30 (0–2)	1.90 ± 0.46 (0–5)	2.00 ± 0.42 (0–4)	1.70 ± 0.76 (0–6)	1.40 ± 0.52 (0–4)	1.70 ± 0.42 (0–4)	0.60 ± 0.31 (0–2)	0.20 ± 0.20 (0–2)	4.7%
*Phalacrocorax niger** (little cormorant)	0^{a}	0.40 ± 0.31^{a} (0–3)	0.30 ± 0.21^{a} (0–2)	$1.40 \pm 0.31^{a,b}$ (0–3)	$1.20 \pm 1.09^{a,b}$ (0–11)	0^{a}	3.00 ± 0.76^{b} (0–8)	0.40 ± 0.22^{a} (0–2)	3.08%
Acridotheres tristis melanosturnus (common myna)	0.30 ± 0.21 (0–2)	1.50 ± 1.50 (0–15)	1.30 ± 0.99 (0–10)	0.90 ± 0.35 (0–3)	0.30 ± 0.21 (0–2)	1.30 ± 0.42 (0–4)	0.10 ± 0.10 (0–1)	0.10 ± 0.10 (0–1)	2.67%
*Amaurornis phoenicurus** (white-breasted waterhen)	0^{a}	$1.90 \pm 0.77^{b,c}$ (0–6)	$0.50 \pm 0.27^{a,b}$ (0–2)	2.40 ± 0.58^{c} (0–5)	0^{a}	$0.50 \pm 0.27^{a,b}$ (0–2)	0.10 ± 0.10^{a} (0–1)	0^{a}	2.49%
*Psittacula krameri** (rose-ringed parakeet)	0^{a}	$0.40 \pm 0.31^{a,b}$ (0–3)	$0.20 \pm 0.20^{a,b}$ (0–2)	2.20 ± 0.98^{b} (0–7)	$1.50 \pm 0.81^{a,b}$ (0–8)	$0.70 \pm 0.26^{a,b}$ (0–2)	0^{a}	$0.30 \pm 0.30^{a,b}$ (0–3)	2.44%
Nectarinia asiatica (purple sunbird)	0.30 ± 0.30 (0–3)	1.00 ± 0.37 (0–3)	1.20 ± 0.51 (0–5)	0.40 ± 0.27 (0–2)	0.40 ± 0.27 (0–2)	1.30 ± 0.37 (0–3)	0.50 ± 0.34 (0–3)	0	2.35%
*Dendrocygna javanica** (lesser whistling-duck)	0^{a}	0^{a}	0.10 ± 0.10^{a} (0–1)	3.30 ± 1.18^{b} (0–11)	0^{a}	0^{a}	0^{a}	0^{a}	1.57%
*Ardeola grayii** (Indian pond heron)	0^{a}	2.40 ± 0.96^{b} (0–9)	0.50 ± 0.27^{a} (0–2)	0.20 ± 0.13^{a} 0–1)	0^{a}	0.20 ± 0.13^{a} (0–1)	0^{a}	0^{a}	1.52%
*Vanellus indicus** (Red-wattled Lapwing)	0^{a}	0^{a}	0.70 ± 0.42^{a} (0–4)	1.80 ± 0.51^{b} (0–5)	0^{a}	0.20 ± 0.20^{a} (0–2)	0^{a}	0^{a}	1.24%
*Mesophoyx intermedia** (intermediate egret)	0^{a}	0.40 ± 0.22^{a} (0–2)	0.40 ± 0.27^{a} (0–2)	0^{a}	0^{a}	0.10 ± 0.10^{a} (0–1)	1.50 ± 0.43^{b} (0–4)	0.10 ± 0.10^{a} (0–1)	1.15%

Note: Values represent Mean ± standard error (SE) and range in parenthesis.
* Significant p value detected by one-way ANOVA. Different superscript letters in a row show significant differences ($p < 0.05$) indicated by Tukey's pairwise comparisons after ANOVA.

(Site 2), the pristine mangrove forest near Negombo town is characterized by a large canopy area contributed by a large number of tall mangrove trees (4 m < height) and the largest area of total vegetation cover (Figure 2; Table 2).

Results of the one-way ANOVA were consistent with the above PCA results. For example, the number of people, vehicles, stray dogs, homesteads, telephone poles, antenna poles, and the sound level were significantly higher in Munnakkara (Site 1) (Table 1) ($p < 0.05$; Tukey's pairwise test after one-way ANOVA) than the other sites. Similarly, the number of tall trees, area of tree cover contributed by tall trees and the area of total vegetation cover were significantly high both at Kadolkele (Site 2) and Kepungoda (Site 5). Seeduwa (Site 3), the site near the Colombo-Katunayake expressway had significantly large areas of cleared areas and roads ($p < 0.05$; Tukey's pairwise test after one-way ANOVA) than in all the remaining sites. Further, the area for stagnant and flowing water bodies was significantly high in Kindigoda (Site 4), Pitipana (Site 7), and Duwa (Site 8) compared to the other sites, while the number of boats was significantly high in Duwa (Site 8) (Table 1) ($p < 0.05$; Tukey's pairwise test after one-way ANOVA).

Avifaunal community

Altogether 48 bird species belonging to 26 different families were observed at the eight study sites. The N of these birds varied within a range of 1–1312 and the relative abundance was 0.05%–60.41%.

The most common of all the 48 bird species was *Corvus splendens* (house crow). It dominated the avifaunal community at all of the eight study sites with a total of 1312 observations and a highest relative abundance of 60.41%.

Although not as common as the house crow, 11 other bird species were also found to be common. They were, *Egretta garzetta* (little egret) (6.49%), *Orthotomus sutorius sutorius* (common tailorbird) (4.70%), *Phalacrocorax niger* (little cormorant) (3.08%), *Acridotheres tristis melanosturnus* (common myna) (2.67%), *Amaurornis phoenicurus* (white-breasted waterhen) (2.49%), *Psittacula krameri* (rose-ringed parakeet) (2.44%), *Nectarinia asiatica* (purple sunbird) (2.35%), *Dendrocygna javanica* (lesser whistling-duck) (1.57%), *Ardeola grayii* (Indian pond heron) (1.52%), *Vanellus indicus* (red-wattled lapwing) (1.24%), and *Mesophoyx intermedia* (intermediate

Table 3. Variation of the avifaunal diversity at the eight study sites in Negombo Estuary.

Site	Measure of the avifaunal diversity			
	Species richness (SR)	Total abundance (N)	Pielou's evenness index (J')	Shannon- Weiner heterogeneity index (H')
Site 1 - Munnakkara	11	266	0.221	0.531
Site 2 - Kadolkele	21	232	0.774	2.355
Site 3 - Seeduwa	25	182	0.668	2.151
Site 4 - Kindigoda	28	293	0.747	2.489
Site 5 - Kepungoda	10	122	0.667	1.535
Site 6 - Dungalpitiya	19	207	0.578	1.702
Site 7 - Pitipana	19	313	0.570	1.679
Site 8 - Duwa	12	557	0.261	0.648

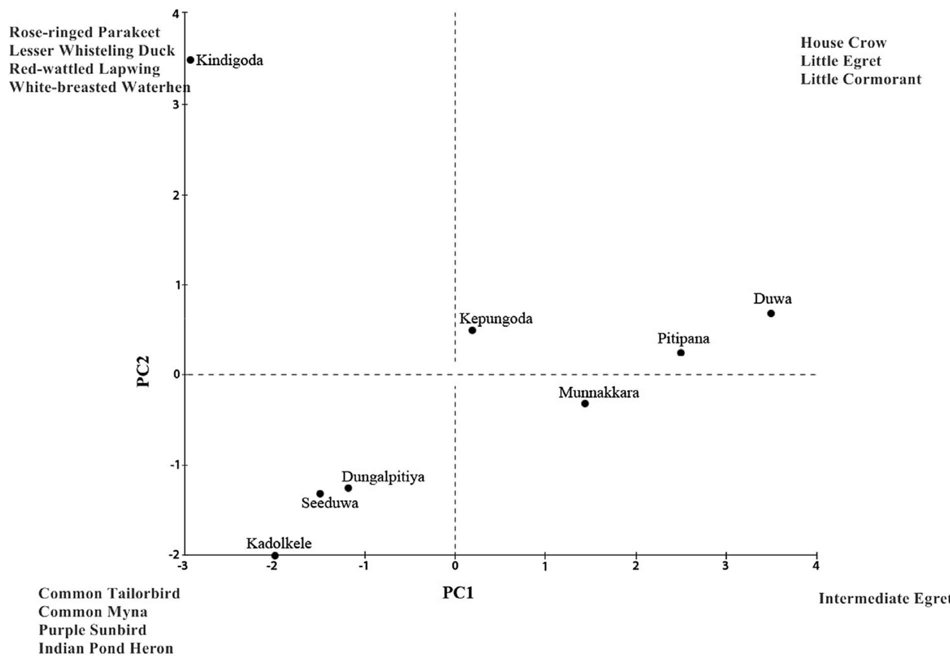

Figure 3. Principal component analysis (PCA) ordination based on PC 1 and PC 2 scores between the 12 most common bird species observed at the eight study sites in Negombo estuary. Duwa (Site 8), and Pitipana (Site 7) are dominated by the house crow and little egret. Kadolkele (Site 2) is dominated mainly by the common tailorbird, common myna, purple sunbird, and Indian pond heron. Kindigoda is dominated by the rose-ringed parakeet, lesser whistling-duck, red-wattled lapwing, and white-breasted waterhen.

egret) (1.15%). The relative abundance of the above 11 bird species was > 1% (Table 2).

The least common bird species in the eight study sites were *Nycticorax nycticorax* (black-crowned night heron), *Mycteria leucocephala* (painted stork), *Elanus caeruleus* (black-winged kite), *Pernis ptilorhynchus* (oriental honey-buzzard), *Porphyrio porphyrio* (purple swamphen), and *Pelargopsis capensis* (stork-billed kingfisher). Each one of these species was observed only once at any one of the eight study sites during the study period and had a relative abundance of 0.05% each.

The avifaunal diversity in terms of SR, N, J′, and H′ also varied between the eight study sites (Table 3).

Avian SR varied within a range of 10–28 where high values were recorded at the undisturbed marshy area at Kindigoda (Site 4) (SR= 28), near the express way of Seeduwa (Site 3) (SR= 25), and in the pristine mangrove forest Kadolkele (Site 2) (SR= 21). Species richness was lowest at the coconut plantation at Kepungoda (Site 5) where only 10 bird species were recorded (Table 3).

The N of birds also varied within a range of 122–577. The highest numbers of birds were observed both at the fishing harbor/boating area Duwa (Site 8) (N = 557) and in Pitipana (Site 7) (N = 313) where aquaculture grow out ponds are established. Bird abundance was low at Seeduwa (Site 3) (N = 182), and it was the lowest at Kepungoda (Site 5) (N = 122) (Table 3). The remaining four sites had a moderate number of birds.

There were many bird species (i.e. high SR) at Kindigoda, Kadolkele, and Seeduwa where the abundance of each and every species was high and more or less equal to each other (i.e. high J' and high H') (Table 3).

There were few bird species (i.e. low SR) at Kepungoda, Munnakkara, and Duwa with one or a few bird species dominating (i.e. low species evenness and low species heterogeneity) at these three sites.

The most abundant bird species characteristic to each site is identified by the PCA (Figure 3). Accordingly, Duwa (Site 8) and Pitipana (Site 7) are characterized by the house crow, little cormorant, and the little egret (Figure 3). Kadolkele (Site 2) is characterized by the common tailor bird, common myna, purple sunbird, and the Indian pond heron.

Kindigoda (Site 4) is characterized by the lesser whistling-duck, rose-ringed parakeet, red-wattled lapwing, and the white-breasted waterhen. Munnakkara (Site 1) is characterized by the presence of intermediate egrets. However, both Seeduwa (Site 3) and Dungalpitiya (Site 6) had no dominant species.

A summary of the one-way ANOVA of the 12 most common bird species between the eight study sites is given in Table 2. This one-way ANOVA was consistent with most of the above PCA data interpretations. For example, the abundance of the house crow and the little egret were significantly higher in Pitipana (Site 7) and in Duwa (Site 8) than in all the other sites ($p < 0.05$ Tukey's pairwise test after one-way ANOVA).

The abundance of the lesser whistling-duck, red-wattled lapwing, and the white-breasted waterhen were significantly higher in Kindigoda (Site 4) than in all the other sites ($p < 0.05$ Tukey's pairwise test after one-way ANOVA).

The Indian pond heron was more abundant at Kadolkele (Site 2) than in other sites ($p < 0.05$ Tukey's pairwise test after one-way ANOVA).

The little cormorant and the intermediate egret were highly abundant at Pitipana (Site 7) ($p < 0.05$ Tukey's pairwise test after one-way ANOVA).

The common tailorbird, common myna, and the purple sunbird were present in almost all the eight study sites, but their abundance did not vary significantly between the sites ($0.05 < p$ one-way ANOVA).

The avifaunal diversity decreased with the increased intensity of anthropogenic activities of the eight study sites. For example, both the species evenness and species heterogeneity significantly decreased along a gradient of increasing number of people, vehicles, sound level, and garbage dumps ($p < 0.05$, regression analysis) (Figures 4 and 5).

SR also decreased with the increasing intensity of anthropogenic activities but the relationship was not significant as above ($0.05 < p$, regression analysis) (Figure 6). However, the N of birds increased

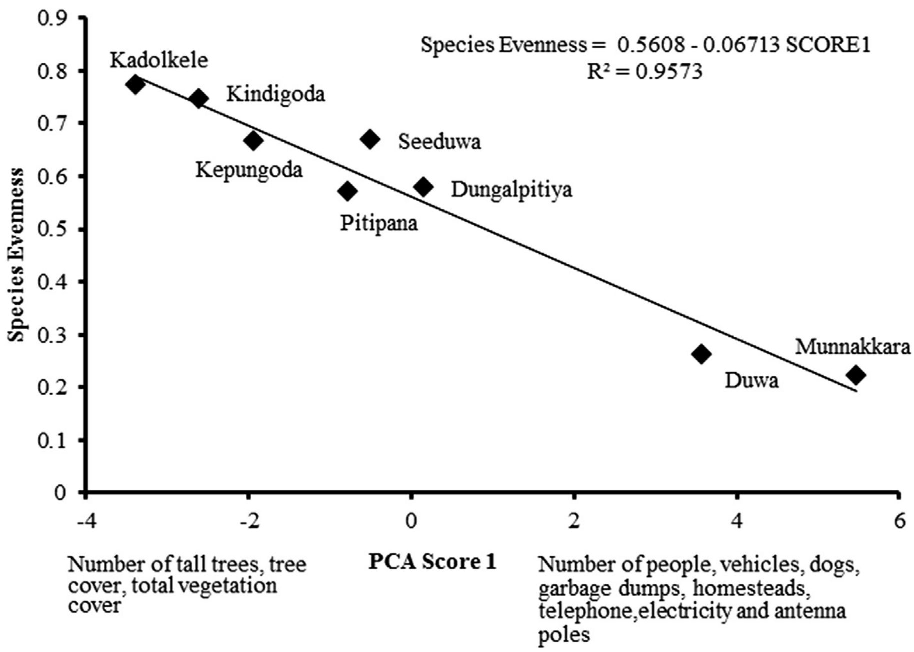

Figure 4. Linear regression of the species evenness at the eight study sites against principal component analysis (PCA) scores for physical attributes of each site.

along with the intensity of land-use patterns (Figure 7). This may be due to the presence of house crows at these sites.

Discussion

In the Negombo estuary there is a direct relationship between the intensity of anthropogenic disturbances and the loss of avifaunal diversity, suggesting that presence and absence of birds serve as indicators of land cover alterations.

In the present study, altogether 48 bird species were observed. Almost all of these species are residents to Sri Lanka since the study was conducted during the nonmigratory season. Of these, the more abundant species such as the house crow, little egret, and the little cormorant, etc., would serve as effective indicators to reflect the land-use alterations. For example, the house crow had an impressively high relative abundance of 60.41% of the entire avian community composition, and they were more abundant at highly disturbed sites such as Munnakkara (Site 1) and Duwa (site 8), while having less abundance at least disturbed pristine sites such as Kindigoda (Site 4).

Many features of the house crow have made them effective indicators of anthropogenic disturbances. Some of these features are their synanthropic generalist predation ability (Armendariz et al 2011), opportunistic omnivorous scavenging ability (Marzluff 2009), intelligence and adaptability (Koul and Sahi 2013), sophisticated social behavior and ability to use simple tools (Bluff et al 2010), and ability to build their nests in more open areas with high levels of disturbance (Soh et al 2002). Further, they are also well adapted to urban areas due to their ability to perch and roost in man-made structures such as telephone poles, antenna and electricity poles and associated cable structures (Armendariz et al 2011) so that all the above play a key role in increasing crow populations in urbanized areas.

The house crow can be found in every possible land-use type (Armendariz et al 2011) and this wide distribution of habitat use was also observed in the present study. They were particularly abundant at Munnakkara (Site 1) and Duwa (Site 8). Both these sites are situated near the mouth of the estuary and are perhaps the most urbanized areas with the highest population density, but with unplanned homestead constructions. These have made way to an increased level of pollution of the area as well. For example, garbage dumps are present almost everywhere and the sound level is also the highest at these sites. A large number of telephone poles, electricity poles, and antenna poles are also some prominent features of these sites. Therefore, both Duwa and Munnakkara provide the best habitat for the house crow so that it is not surprising to find them in very high numbers at these habitats where conditions are ideal for them.

It was also found that the bird SR of these two habitats is low (SR = 11 at Munnakkara and SR = 12 at Duwa) compared to the undisturbed pristine habitat Kindigoda (Site 4, SR = 28), probably due to the presence of the crow. For example, Suliman et al (2011) found that crows with their loud calls and aggressiveness are responsible for the reduction or severe depletion of other birds and small terrestrial vertebrates and can create problems to the natural biodiversity. Crows also prey on eggs of other birds (Armendariz et al 2011) which in turn may reduce their diversity. They are also the nest predators of many wading birds (Kosicki and Chylarecki 2013). Therefore, the increased abundance of the house crow, as discussed earlier, may have caused the low SR in these two areas. The species evenness and H′ were also the lowest, perhaps due to the presence of the house crow, in addition to severe habitat destruction at these sites.

One can expect a highly diverse avian community when physical attributes such as the extent of tree cover are in ideal conditions. It has been found that the extent of tree cover is an important environmental determinant for birds, as the trees provide them opportunities for foraging (Galbraith et al 2002), perching, nesting and roosting (Harvey and Villalobos 2007). In the present study it was found that the extent of tree cover was very low both at Munnakkara and Duwa. These differences too, may have caused a reduction in SR at these sites.

Kadolkele mangrove forest (Site 2) is situated close to the busy city of Negombo. In spite of its closeness to the city, Kadolkele is an undisturbed patch of pristine mangrove forest. A high avian SR and diversity with more abundant birds such as the house crow, Indian

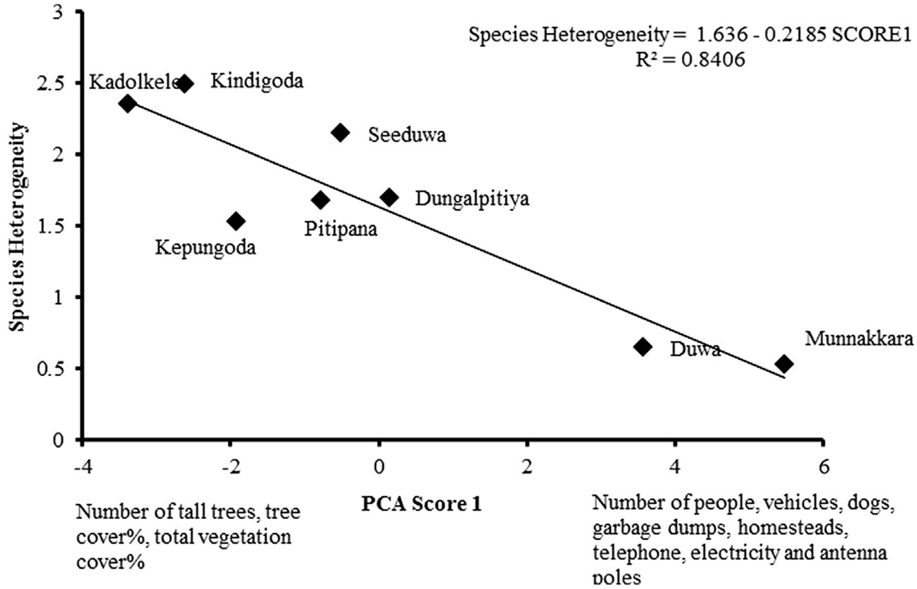

Figure 5. Linear regression of the species heterogeneity at the eight study sites against principal component analysis (PCA) scores for physical attributes of each site.

Pond heron, little egret, white-breasted water hen, Asian koel, common myna, common tailorbird, and the purple sunbird were recorded at this site. They are also the common resident birds to this area (Jayamanne and Jayamanne 2012). Kadolkele undeniably serves as a resting and roosting site for many city wandering birds including the house crow, which is also the most abundant bird at this site. A study conducted in Karnataka, India revealed that herons and egrets are the most conspicuous group of birds found within mangrove ecosystems, as they provide feeding, breeding, roosting, and resting grounds for large colonies of these birds (Kumar and Kumara 2011). Yu and Swennen (2004) also found that birds have loafing sites on mangroves.

Seeduwa (Site 3) is located adjacent to the recently constructed Colombo-Katunayake expressway. Although the highways cause significant impacts on birds in many ways, including direct and indirect mortalities, habitat fragmentation, and disturbances caused by vehicular noise (Jacobson 2005), Seeduwa recorded the second highest bird diversity in the present investigation. The house crow, common tailorbird, common myna, purple sunbird and the red-wattled lapwing, were among the commonest bird species of this site. A purple swamp hen and a common sandpiper, a migrant species that may be present as a rare summer loiterer, were also observed at this site. The high bird diversity of this site may be related to the presence of short mangroves and marshy areas of this site, the data collection was done prior to the opening of the expressway which was in October 2013, and its closeness to the Muthurajawela/lagoon transition zone, or a combination of all.

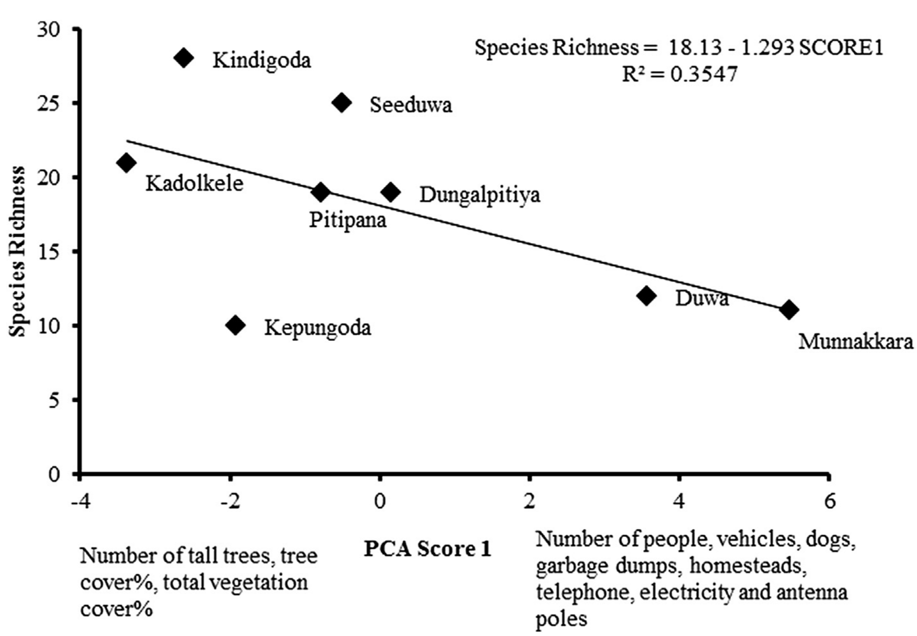

Figure 6. Linear regression of the species richness at the eight study sites against principal component analysis (PCA) scores for physical attributes of each site.

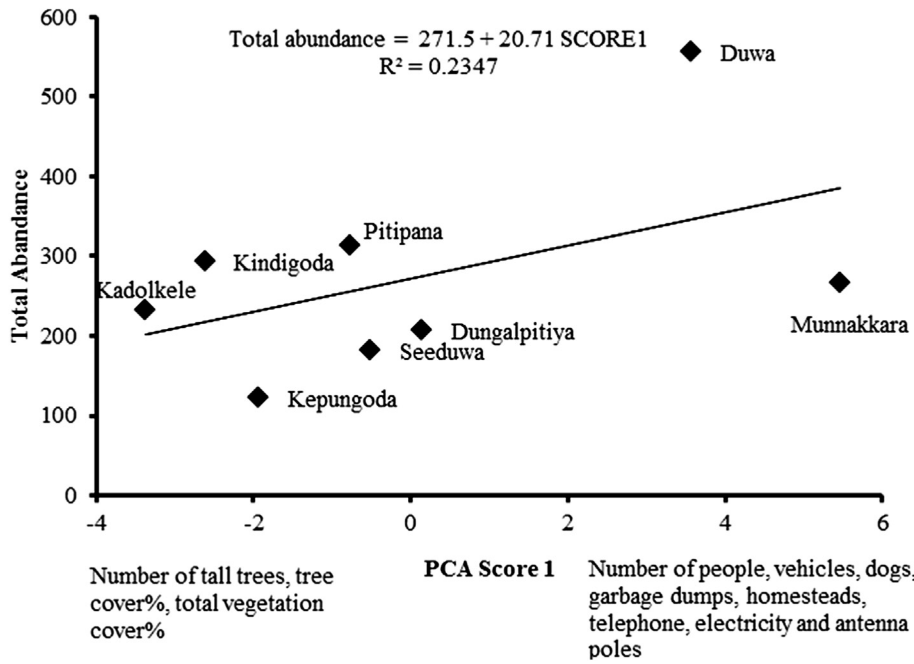

Figure 7. Linear regression of the total abundance of birds at the eight study sites against principal component analysis (PCA) scores for physical attributes of each site.

Kindigoda (Site 4) is the pristine undisturbed marsh/lagoon transition zone where the river Dandugam Oya and Muthurajawela marsh merge with the Negombo estuary. There were no people, homesteads, other manmade structures, and animals such as cats, dogs, and cattle in this area. The sound level of this site was the lowest of all the eight sites and the percentage area of stagnant and flowing water bodies were the highest. This site contributed to the highest avian SR (SR = 28) and the highest H′ (H′ = 2.489) compared with all the other sites. The presence of stagnant and flowing water bodies, low lying mangroves, and shallow marsh microhabitats of this area provide foraging and nesting habitats for many wading birds and they appear to be the most dominant group of vertebrates in this wetland ecosystem (Bambaradeniya et al 2002); also, their high mobility (Jacobson 2005) may be allowing them to be attracted to food sources in the neighboring Negombo estuary and to return for safety and roosting after foraging.

The number of tall coconut trees, extent of the tall tree cover, and the total vegetation cover are the main characteristic features of Kepungoda (Site 5). Studies on the effects of agricultural plantations on bird communities have been previously carried out. For example, Greenberg et al (2000) and Sidhu et al (2010) found bourgeoning populations of birds in cocoa and cardamom plantations, respectively, but data are sparse on coconut plantations. The present study showed the Kepungoda having the lowest SR and the lowest N of birds. The reason may be the wind, as this site is situated closer to the sea than any other site. It has been found that the high winds negatively affect bird distribution (Bibby et al 1998) and even census results can be affected. Further, a coconut plantation is not the best foraging area as no sweet fruits are available there but would offer the birds only a place to rest and roost.

Although Dungalpitiya (Site 6) is a human habitation, it is far less congested than Duwa and Munnakkara. Cattles, mostly the tall trees such as coconut and other fruit trees, and the extent of total vegetation cover are the dominant features of this site. The avian diversity in this site is high compared to the highly congested Munnakkara (Site 1) and Duwa (Site 8), and it endorses the findings of McClure (2012), where SR of birds is higher in rural landscapes than in urbanized areas.

At Pitipana (Site 7), prawns and milkfishes are farmed extensively so that this site is characterized mostly by the aquaculture grow out ponds providing excellent foraging grounds for predatory birds looking for a chance to sneak an easy meal. The commonest birds observed at this site were the little cormorant, intermediate egret, little egret, and the house crow. As predation on prawns and fish by predatory birds is a problem (Schramm et al 1987) and that there is evidence that birds are vectors of shrimp viruses (Vanpatten et al 2004), farmers have taken every possible measure to reduce the abundance of birds. For example, some farmers have even especially hired workers to chase these preying birds. Another observation was that nylon threads are drawn over the ponds to prevent birds from landing and preying on farmed animals.

Apart from the high level of urbanization, Duwa (Site 8) is also a fishing harbor characterized by the presence of a large number of fishing boats, trash fish, and fish wastes. The percentage area of stagnant and flowing water bodies is also high in this site. Surprisingly though, the N of birds was the highest (N = 557) at this site than in all the other sites, despite the low SR (SR = 12) species. The dominant species at this site is the house crow followed by the little egret and the little cormorant. It has been found that the trash fish and fish waste alter the food supply for birds living around fishing harbors (Tasker et al 2000) and this was clearly observed at the Duwa fishing harbor too. As explained earlier, a large number of crows as well as egrets and cormorants were found feeding on trash fish, fish offal, and other fish refuse. This site also has the highest number of electricity poles and the associated power lines that allow perching sites for birds until locating a freely available meal. Further, the fishing harbor itself provides an excellent resting habitat for wading birds. It is not surprising, therefore, to have an increased abundance of a few species at this site.

In general, the SR, species evenness, and the H′ decreased with the increasing intensity of anthropogenic activities, while the N of birds showed *vice versa*. Although this latter result was surprising, it is mainly due to the abundance effect of the house crow, which thrives in highly urbanized areas. Armendariz et al (2011) also found a similar result where the abundance of the house crow increases with urbanization. It also corroborates the findings of Melles et al (2003) and DeLuca et al (2008), where the avian community diversity in estuarine-marsh habitats decreased significantly with the increasing local development.

The present study was carried out during the nonmigratory season of birds (June to September annually) to Sri Lanka. During the migratory season, the majority of migratory birds which arrive in Sri Lanka along the western migratory route (Dayawansa and Wijesinghe 2002) find their destination in Muthurajawela marsh (a RAMSAR site) and the associated Negombo estuary. As such, the diversity and the distribution of avian fauna among the eight study sites around the Negombo estuary would not be the same during the migratory season, given the fact that both the resident as well as the migratory species would be found together in these sites. Therefore, it would be interesting to repeat the study during the migratory season too, to see the avian diversity variation of these habitats.

Further, bird observation and data collection was done only in the morning hours from 6:00 AM to 9:00 AM during the study period, in order to maintain a temporal uniformity. However, the birds present in the evening at the same habitats might be different from those that were present in the morning. Therefore, it would also be better to conduct the study throughout the day or during selected hours in the morning and in the evening too, in order to obtain a detailed and comprehensive understanding of the avian diversity around the Negombo estuary.

In conclusion, the present study showed that there is a wide variation of the characteristics and land-use patterns among the selected habitats around the Negombo estuary. The birds responded accordingly where the avian SR, heterogeneity, and evenness were found to be significantly low in habitats that have been heavily altered for human needs. In order to accommodate the need for rapid urbanization of the area, modification of habitats has become imperative, so that that the degradation and the loss of natural habitat associated with the Negombo estuary continues if done in an unplanned manner. This may be the case for similar habitats elsewhere in the world as well. Therefore, developmental activities both nationally and internationally should be properly designed in consultation of current ecological theories, giving due consideration for the conservation aspects of fauna including the birds.

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