Temporal changes to the abundance and community structure of migratory waterbirds in Santragachhi Lake, West Bengal, and their relationship with water hyacinth cover

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A study carried out during 1998–2009 showed that migratory waterbirds of Santragachhi wetland, in the vicinity of Kolkata, have declined by more than 55% over a 12-year period, and three important species have abandoned the wetland. These changes were associated with the reduction of the surface water area due to proliferation of water hyacinth. The waterbird abundance and community composition corresponded significantly with the water hyacinth cover of the wetland.

Keywords: Community structure, habitat deterioration, migratory waterbirds, wetland attributes.

WETLANDS are among the most productive biomes in the world[1] that also provide many important ecosystem services[2]. They also provide important habitats for a wide variety of waterbirds. For instance, almost all of the 655 Prioritized Indian Wetlands (by the Ministry of Environment and Forests, Government of India, 2005) are listed for their importance to waterbirds. However, due to increasing anthropogenic activities, they have become increasingly threatened, such that their value as a waterbird habitat is being eroded[3].

Among the primary threats to our wetlands are habitat degradation, conversion, overexploitation and pollution. These threats are particularly important in heavily populated areas, where anthropogenic demands on waterbodies are high relative to availability. During the last 50 years, several wetlands have been filled up and converted to urban townships, agricultural lands and industrial plots, whereas others have been degraded.

On the other hand, studies on waterbird communities are often concerned with the nature of these communities at the spatial scale of individual wetlands[4] and do not account for temporal variation that occurs within a given wetland. Such within-wetland temporal variations need to be studied to have an insight into the strategy of wetland conservation.

Santragachhi wetland, located in the vicinity of Kolkata within the industrial belt, provides an example of how the waterbird communities have been changing over time due to human impact on wetlands. It supports regionally and internationally significant populations of a range of waterbirds[3]. For this reason, the Ministry of Environment and Forests, Government of India included it under the National Wetland Conservation Programme in 2005. Eventually, it has been listed as an Internationally Important Wetland by Wetlands International[5].

The present author conducted a 12-year assessment of migratory waterbird abundance and diversity in Santragachhi wetland between 1998 and 2009. The principal objective of this study was to monitor waterbird populations to assess changes over time and with relation to habitat conditions.

Methods

Study site

The study was conducted at Santragachhi wetland, situated on the western bank of the river Hooghly about 5 km west of Kolkata, West Bengal, India (lat. 22°34.816′N; long. 88°16.970′E; Figure 1). It extends over an area of 24 ha, of which 18 ha constitutes a lake that provides suitable habitat for waterbirds. Baikal Teal (*Anas formosa*) and Swinhoe's Snipe (*Gallinago megala*) are among the waterbirds that have been visiting Santragachhi every winter for the past 30 years.

Being located inside a densely populated industrial area, Santragachhi has been subjected to degradation due to imprudent anthropogenic activities. A sizeable portion of the waterbody remains clogged with water hyacinth (*Eichhornia crassipes*) and other macrophytes throughout the year. The lake supports a wide variety of zooplanktons, molluscs and fishes that provide food for the waterbirds[3].

Bird census

Waterbirds were counted annually between 1998 and 2009. The counts were made between 1 and 30 January.

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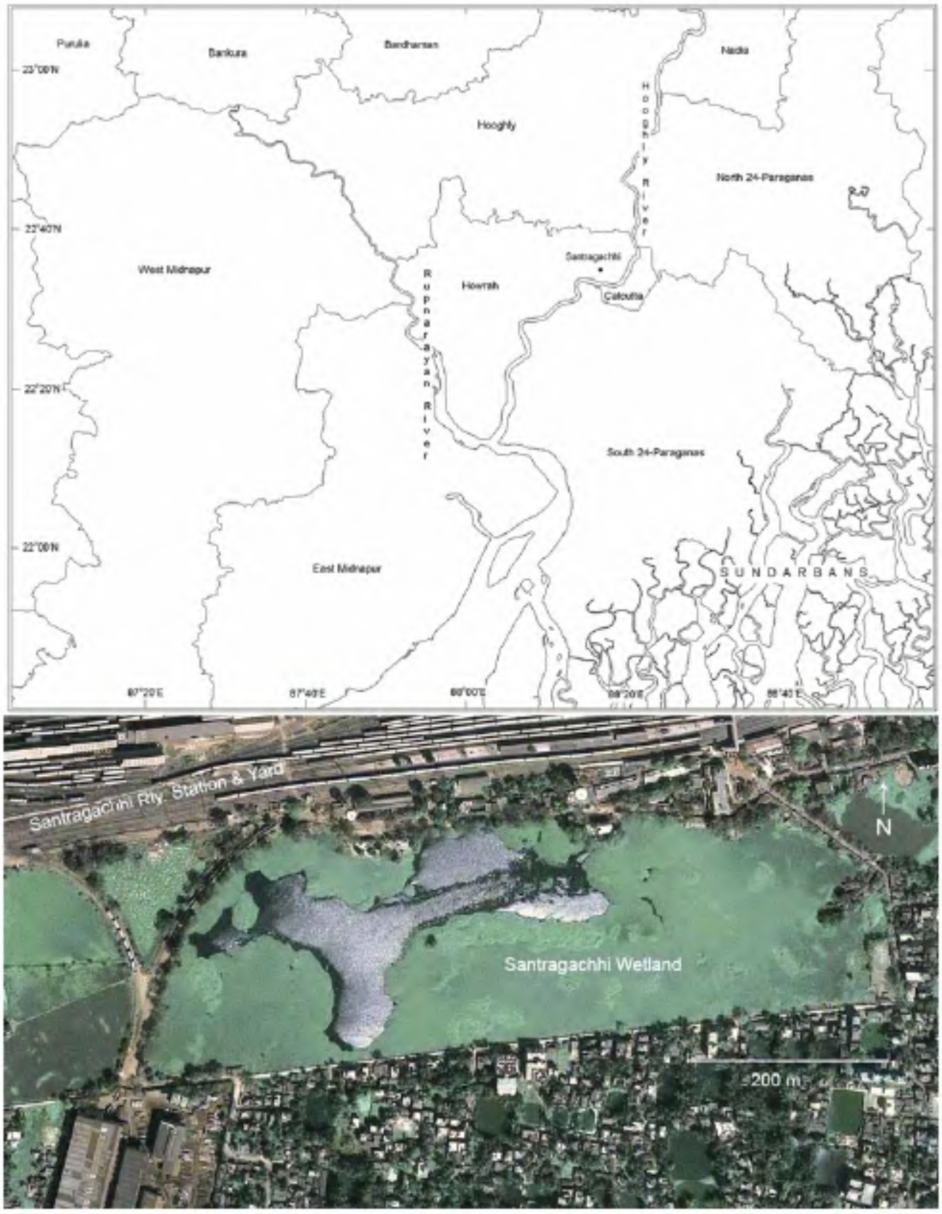

Figure 1. Portion of southeastern West Bengal showing the location of Santragachhi Lake. Aerial view of the wetland is also shown.

The census period was chosen to coincide with the large-scale Asian Waterfowl Census Programme coordinated by Wetlands International[5]. During the period three censuses were made (between 1 and 10; 11 and 20; 21 and 30 January) to get comprehensive idea about the waterbird community (12 census years and three censuses per year; $n = 3 \times 12 = 36$). Waterbird were counted on foot by 5–8 observers, each of whom was assigned to census a segment of the wetland. Thus, at each event the entire wetland was covered. During each census, counts were begun at 8:00 h IST and continued until the total waterbird count was completed.

During each census aerial digital photographs of different segments of the wetland were also taken, which were later examined on computers to count different birds. These examinations provided additional abundance data which were compared with those obtained from direct bird counts. These comparisons helped in mitigating census errors, including observer bias.

Community analysis

Community analyses were performed on the abundance data of all waterbird species recorded during the study period. For the ordination of waterbird communities, a non-metric multidimensional scaling (NMS) analysis was performed on the fourth-root-transformed census data for all waterbirds grouped by year, using Bray–Curtis dissimilarities. The ordination presented here shows the relative distance between the waterbird communities in multivariate space: waterbird communities that are more similar in species composition appear closer together on the ordination plot than communities that are dissimilar[6,7]. Grouping by year allowed the determination of temporal variation in community structure of the wetland.

A multi-response permutation procedure (MRPP) was performed on the data using the Bray–Curtis dissimilarities as the distance measure and years as the grouping variable. MRPP is a nonparametric procedure widely used in the analysis of ecological data, which often do not meet the required assumptions of parametric statistical methods[7]. The resultant *T*-statistic describes the separation between the groups (years in this case), whereas the *A*-statistic describes within-group (i.e. within three censuses in each study year) homogeneity compared to random expectation. This test was used in the present study to determine whether the waterbird communities differed statistically among the wetlands.

Indicator species analysis

In order to identify the species that were important in structuring the waterbird community, Indicator Species Analysis (ISA)[8] was performed for those species for which more than a total of 100 individuals were recorded over the 12 census years, with samples grouped by year. ISA identifies species associated with groups (i.e. years) by calculating an indicator value (ranging between 0 and 100), which reflects both frequency and abundance of species in defined groups. High indicator values reflect both high abundance and prevalence within a group. Significance of indicator values was assessed using Monte Carlo simulations with 4999 permutations; *P* values represent the probability of a similar observation relative to randomized data.

Habitat relationships

The condition of waterbird habitat, with respect to chocking and building of new land masses inside the wetland and the area clogged with aquatic vegetation (especially water hyacinth, *Eichhornia crassipes*) was assessed during all the census years. The per cent cover of water hyacinth was estimated mainly from aerial photographs and global positioning system data. The area of the wetland covered by water hyacinth and land mass was estimated on Map Maker Pro Package.

The relationship between water hyacinth cover and the waterbird community was examined by comparing waterbird assemblages in areas with and without water hyacinth. Aerial photographs were also taken, which helped in making the initial layout of the wetland. The relationship between waterbird abundance (number of birds) and water hyacinth cover (in ha) was tested using both Kendall Tau and Pearson *r* correlation tests ($\alpha = 0.05$). Other factors posing threats to the wetland and its denizens were also recorded as and when possible.

The relationship between water hyacinth cover and waterbird community composition was analysed on the data for common waterbird species (more than a total of 100 birds recorded during the study period) using Canonical Correspondence Analysis (CCA). CCA tests whether community composition is more strongly influenced by this habitat parameter than by chance. It plots species composition and habitat parameter in a multivariate space and searches for patterns in community structure explained by environmental variables (water hyacinth cover in this case)[9,10].

Software packages used

All the multivariate analyses were performed using PC-ORD for Windows, Version 5.3 (ref. 11), and standard procedures outlined in McCune and Grace[7]; and MVSP, Version 3.13 (www.kovcomp.cm). For the tests of significance PAST, Version 1.95 was used[12]. Map of the study sites, including the area measurements was generated on Map Maker, Version 3.5 (www.mapmaker.com).

Results

Waterbird diversity and abundance

A total of 195,866 migratory waterbirds belonging to 15 species were recorded during the study. All these species declined between 1998 and 2009 (Table 1). The species showing dramatic decline included Spot-billed Duck (*Anas poecilorhyncha*), Mallard (*Anas platyrhynchos*) and Baikal Teal. The last representatives of the first two species (three pairs and one pair respectively) were recorded in 2002, whereas Baikal Teal was last recorded in 2003.

An overall decline by 55% between 1998 and 2009 was significant ($t = 40.48$; $df = 15$; $P < 0.001$). However, the decline between 2003 and 2009 was much more drastic than that between 1998 and 2003. In fact, during the period between 1998 and 2003, Fulvous Whistling Duck (*Dendrocygna bicolor*), Comb Duck (*Sarkidiornis melanotos*), Common Teal (*Anas crecca*) and Tufted Duck (*Aythya fuligula*) showed an increase by 5%, 33%, 10% and 11% respectively, although the period was marked by the disappearance of Spot-billed Duck and Mallard. Nonetheless, the census data for that period represented a significant overall decline of 5% ($t = 18.15$; $df = 15$; $P < 0.001$). In contrast, decline during the period between 2003 and 2009 ranged from 16% (Gadwall, *Anas strepera*) to 60% (Cotton Pygmy Goose, *Nettapus coromandelianus*). The data represented a significant overall decline of 52% ($t = 31.06$; $df = 13$; $P < 0.001$; Table 1).

Table 1. Changes in the abundance of migratory waterbirds in Santragachhi wetland during 1998–2009. Mean (± SE) abundance for each species is given for 1998, 2003 and 2009. Per cent change represents the per cent increase (positive) or decrease (negative) in abundance relative to the abundance in 1998 (for changes during 1998–2003 and 1998–2009) and in 2003 (for changes during 2003–2009)

Species	Species code	Number (mean ± SE) 1998	2003	2009	Per cent change 1998–2003	2003–2009	1998–2009
Lesser Whistling Duck (*Dendrocygna javanica*)	DENJA	6467 ± 12.8	6142 ± 0.9	2841 ± 0.7	–5.0	–53.8	–56.1
Fulvous Whistling Duck (*Dendrocygna bicolor*)	DENBI	20 ± 0.3	21 ± 0.6	10 ± 0.3	5.0	–52.4	–50.0
Comb Duck (*Sarkidiornis melanotos*)	SARME	3 ± 0.4	4 ± 0.0	2 ± 0.0	33.3	–50.0	–33.3
Northern Pintail (*Anas acuta*)	ANAAC	94 ± 1.2	88 ± 1.2	60 ± 0.0	–6.4	–31.8	–36.2
Common Teal (*Anas crecca*)	ANACR	19 ± 0.7	21 ± 0.9	14 ± 0.9	10.5	–33.3	–26.3
Baikal Teal (*Anas formosa*)	ANAFO	5 ± 0.4	2 ± 0.0	0	–60.0	–100	–100
Spot-billed Duck (*Anas poecilorhyncha*)	ANAPO	9 ± 2.3	0	0	–100	–	–100
Mallard (*Anas platyrhynchos*)	ANAPL	8 ± 0.0	0	0	–100	–	–100
Gadwall (*Anas strepera*)	ANAST	162 ± 3.1	151 ± 0.7	126 ± 0.6	–6.8	–16.6	–22.2
Garganey (*Anas querquedula*)	ANAQU	32 ± 0.0	31 ± 0.7	18 ± 0.3	–3.1	–41.9	–43.8
Northern Shoveler (*Anas clypeata*)	ANACL	33 ± 0.6	28 ± 1.2	13 ± 1.0	–15.2	–53.8	–60.6
Cotton Pygmy Goose (*Nettapus coromandelianus*)	NETCO	33 ± 0.6	28 ± 1.2	13 ± 0.7	–15.2	–53.8	–60.6
Ferruginous Pochard (*Aythya nyroca*)	AYTNY	9 ± 0.3	9 ± 0.7	4 ± 0.3	0	–55.6	–55.6
Tufted Duck (*Aythya fuligula*)	AYTFU	9 ± 0.7	10 ± 0.3	4 ± 0.0	11.1	–60.0	–55.6
Common Coot (*Fulica atra*)	FULAT	5 ± 0.3	5 ± 0.3	3 ± 0.3	0	–40.0	–40.0
	Overall	6909	6538	3108	–5.36	–52.48	–55.02

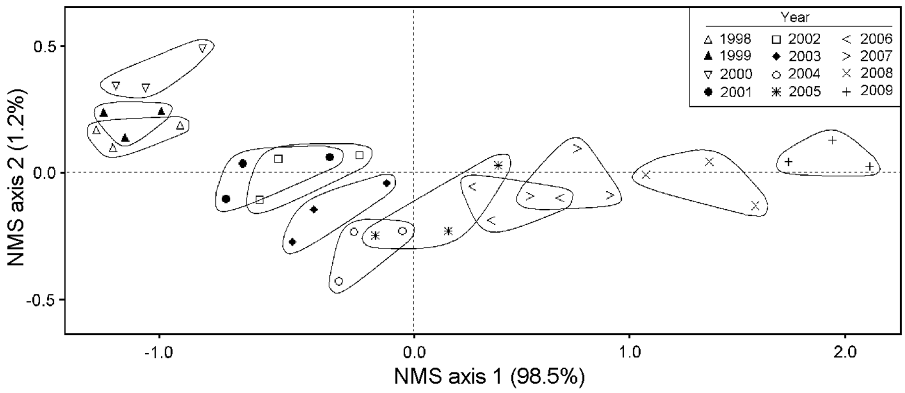

Figure 2. Non-metric multidimensional scaling (NMS) ordination plot of Bray–Curtis dissimilarities for all migratory waterbird species recorded in Santragachhi wetland during 1998–2009 ($n = 3 \times 12 = 36$ wetland years). Percentages shown on the axes represent the amount of variance explained by that axis. Stress for this two-dimensional solution = 2.62.

Community analyses

Non-metric multidimensional scaling ordination of the waterbird species abundance data for the period 2003–2010 yielded a two-dimensional solution with a low stress value of 2.62 (Figure 2). The two NMS axes explained most of the variance (axis 1 = 98.5%; axis 2 = 1.2%).

A strong temporal gradient existed in the waterbird community structure of Santragachhi wetland. The NMS analysis suggested a notable variation in the community structure between the census years. Seven distinct clusters were observed in the ordination plot. The first cluster was formed by the waterbird communities for the census years 1998 and 1999. The waterbird communities for 2000 made up the second cluster. The communities for 2001 and 2002 constituted the third cluster, with a stronger overlap in community composition between them than that between 1998 and 1999. The waterbird communities for 2003 (the year marked by the disappearance of spot-billed Duck and Mallard) constituted a distinct fourth cluster. A fifth distinct, large cluster was comprised of the communities for 2004 (the year marked by disappearance of Baikal Teal), 2005, 2006 and 2007. The waterbird communities for the census years 2008 and 2009 formed appreciably distinct sixth and seventh clusters respectively.

The MRPP test confirmed that waterbird community structure differed significantly between these years ($T = -9.081$, $A = 0.835$, $P < 0.0001$). The large negative value of T-statistic confirmed that the waterbird community structure differed substantially between these study years, whereas a large A-statistic clearly reflected the distinct

Table 2. Significant indicator species that were important in structuring migratory waterbird communities of Santragachhi wetland during 1998–2009. The indicator values reflect both abundance and prevalence of species within a group (census year in this case). The *P* value is the proportion of random trials in which the indicator value was equal to or greater than the observed value. The census year in the table indicates the period in which the species acted as significant indicators

Species	Indicator value	*P*	Census year/s
Lesser Whistling Duck	10.627	< 0.0001	1998
Fulvous Whistling Duck	9.813	< 0.0001	1999, 2001, 2003, 2004
Northern Pintail	9.631	0.0005	1998
Common Teal	9.633	0.0001	2003, 2004
Gadwall	9.588	< 0.0001	2000
Garganey	9.649	< 0.0001	1999, 2000
Northern Shoveler	10.855	< 0.0001	1998, 1999
Cotton Pygmy Goose	10.820	< 0.0001	1998, 1999
Tufted Duck	10.784	< 0.0001	1999, 2000

qualities of species composition in each study year and high within-year homogeneity.

Indicator species analysis

The results of ISA, presented in Table 2, revealed that five species acted as significant indicators for the waterbird community in 1999, indicating its species-rich nature. Among them, Garganey (*Anas querquedula*) and Northern Shoveler (*Anas clypeata*) were winter visitors from the northern areas of Eurasia, while Tufted Duck travels from Europe and western Asia[13]. The other two species, Fulvous Whistling Duck and Cotton Pygmy Goose were local migrants. All of them are typically associated with freshwater and estuarine wetland systems of South Bengal[14]. Four species acted as significant indicators of the waterbird communities for 1998, also revealing its species-rich nature. This was followed by the communities for 2000 (three significant indicators), 2003 and 2004 (two significant indicators each) and 2001 (one significant indicator). Waterbird communities for the other census years did not include any significant indicators, revealing their species-poor nature. Thus, the results clearly indicate that the waterbird communities of Santragachhi have delivered with the passage of time.

Habitat relationships

Relationship between water hyacinth cover and waterbird abundance: Tables 3 and 4 indicate that the Santragachhi wetland has been fast deteriorating. During the period from 1998 to 2003 the surface water area was reduced from 17.50 to 12.22 ha, indicating a 32.19% reduction. The reduction in the water surface area was more convincing between 2003 and 2009, yielding a value of 68.58%; only 8.38 ha area remained available for the waterbirds. The percentage of surface water area loss due to these factors (Table 3) shows that they played a significant role in the reduction of surface water area of the Santragachhi wetland. A significant positive correlation existed between the surface water area and the abundance of migratory waterbirds, especially the dabbling ducks (Table 4).

Relationship between water hyacinth cover and waterbird community composition: The results of CCA are shown in Figure 3, in which axis 1 represents water hyacinth cover. Large values of interset correlation (0.651) and canonical coefficient (i.e. 1.00) of axis 1 in this analysis suggested a strong relationship between the water hyacinth cover and waterbird community composition. The census year 2009 had the highest water hyacinth cover (9.64 ha), but the lowest waterbird species diversity (Table 1). The CCA scores for axis 1 during that year (i.e. 4.62, 5.48 and 7.01 for three censuses) were the highest, suggesting a stronger correspondence between water hyacinth cover and waterbird community composition than that observed during other census years (Figure 3 *a*).

Notable trends from the CCA species ordination plot (Figure 3 *b*) indicated weak correlation of Lesser Whistling Duck (*Dendrocygna javanica*) and Common Coot (*Fulica atra*) (since their locations were close to the zero-score line of axis 1) and strong relationship of the other species with water hyacinth cover. Seven of the 12 common waterbirds showed positive correspondence with water hyacinth cover. They included all the dabbling ducks, except Northern Shoveler. Common Teal corresponded more closely than the other migratory waterbird species of the Santragachhi wetland, because it had the highest CCA axis 1 score (2.137). Diving ducks like Ferruginous Pochard (*Aythya nyroca*) and Cotton Pygmy Goose showed negative correspondence with water hyacinth cover (Figure 3 *b*).

Other threats

Human encroachment to the waterbody was another serious threat to the waterbirds. Almost 0.5 ha of the wetland

Table 3. Percentage of original surface water area (i.e. 17.5 ha in 1998) filled up by new land masses and covered by water hyacinth in 2003 and 2009

	2003		2009			
Cause of surface water area loss	Mean	SD	Mean	SD	*t* value	Difference
Land masses	4.78	0.14	9.02	0.15	–26.23	$P = 0.001$
Heavy clogging by water hyacinth	13.96	1.08	23.48	1.59	–32.33	$P < 0.001$
Fast-proliferating water hyacinth	8.11	0.36	15.40	1.03	–18.85	$P = 0.001$

Table 4. Relationship between surface water area (ha) and abundance (i.e. total number) of migratory waterbirds in Santragachhi wetland during 1998, 2003 and 2009 ($n = 9$)

	Year			Correlation with surface water area			
Variable	1998	2003	2009	Kendall τ	P	Pearson r	P
Open surface water area (ha)	17.50 ± 0.57	12.62 ± 0.61	8.38 ± 0.57				
Mean (± SD) no. of waterbirds	6908 ± 39.51	6538 ± 11.06	3108 ± 7.94	0.722	0.007	0.95	< 0.001
Mean (± SD) no. of dabbling ducks	362 ± 14.15	319 ± 2.00	230 ± 4.36	0.778	< 0.001	0.88	0.006
Mean (± SD) no. of other waterbirds	6546 ± 25.79	6219 ± 6.03	2878 ± 3.61	0.778	< 0.001	0.88	0.007

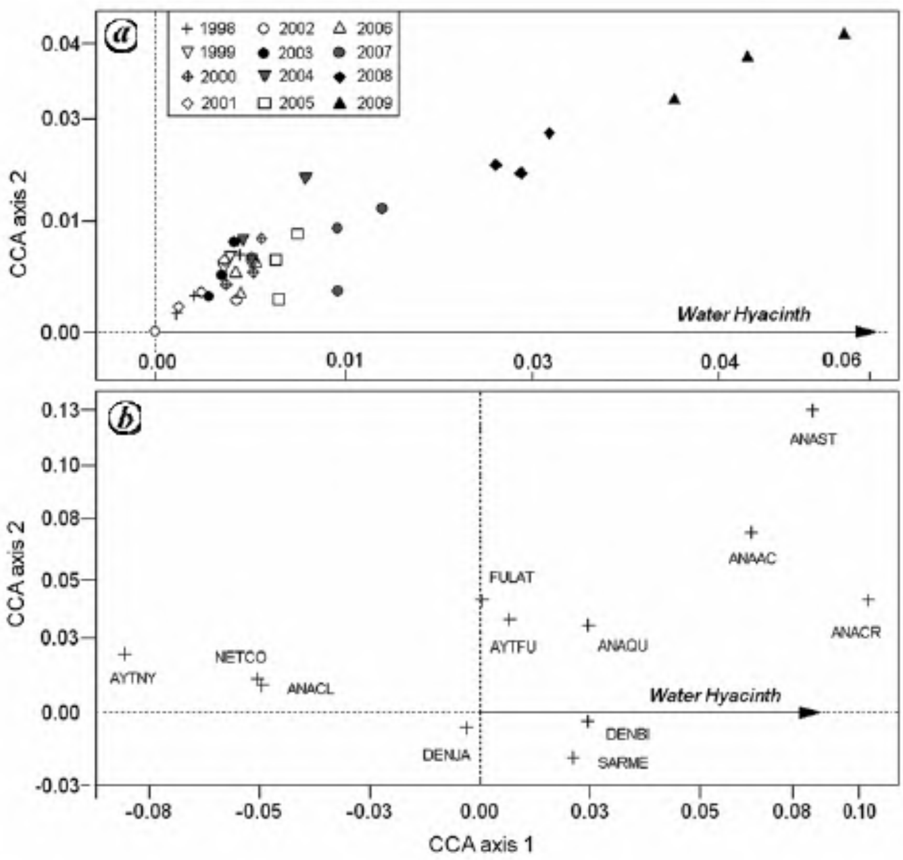

Figure 3. Community (***a***) and species (***b***) plots based on canonical correspondence analysis of the abundance data for 12 common migratory waterbird species (>100 birds recorded during the study period) and water hyacinth cover. Species codes are similar to those used in Table 1.

area was lost during the period from 1998 to 2009 by filling up of its fringes with trash material, solid waste, garbage and plastic (Figure 4). In fact, the waterbody has been continuously exploited for several purposes by the people inhabiting around it.

Pollution to the waterbody also poses harm to the waterbirds. Several outlets carrying effluents from different sectors, including the industrial sector, as well as domestic sewage were seen continuously polluting the water mass. A high concentration of chromium (ranging between 128 and 137 mg/kg) in the bottom soil of the wetland reflected this fact.

Discussion

Freshwater ecosystems are among the most significantly human-altered systems in the world[15] and Santragachhi wetland well exemplifies this. The present study shows that the migratory waterbirds have declined substantially (55%) during 1998–2009. The numbers of waterbirds recorded in 2009 was lowest (mean number 3108) since these censuses began. Moreover, three important species (Spot-billed Duck, Baikal Teal and Mallard) have already disappeared from the Santragachhi wetland during this period, whereas Ferruginous Pochard, Tufted Duck and Common Coot are almost on the verge of disappearance.

Although much of the work to date has focused on the effects of water hyacinth on lower trophic communities (e.g. invertebrates and fishes), little attention has been paid to the effects on waterbirds[16]. The lack of information pertaining to waterbirds prevents a full understanding of the effects of water hyacinth, making it difficult to adopt appropriate management strategies. Water hyacinth could affect waterbird communities in many ways. Waterbird distribution is greatly dependent on habitat structure and prey availability[17,18]. Therefore, if an exotic plant tends to make the habitat unsuitable for a particular species or the community as a whole, we may expect an inverse relationship between water hyacinth cover and waterbird diversity. However, aquatic vegetation, especially water hyacinth, provides a suitable habitat for invertebrate and fish production[17,19–21], which suggests a potential positive relationship between water hyacinth cover and waterbirds. However, water hyacinth is known to decrease phytoplankton productivity leading to decrease in dissolved oxygen, which can have negative consequences for fish and other waterbird prey under these mats[22,23]. Moreover, water hyacinth has the ability to remove nutrients from the water[24–26]. Thus, whether water hyacinth cover is beneficial or harmful to the waterbirds, remains unresolved. This study is an attempt to improve our understanding of the effect of water hyacinth on waterbirds.

Figure 4. Two portions of the Santragachhi wetland showing (***a***) filling up of the waterbody and water hyacinth cover, and (***b***) garbage dumps which are posing serious threats to the wetland along with its denizens.

The results of CCA suggest a close relationship between water hyacinth cover and waterbird community composition. This relationship was strongest during 2009, the year marked by the highest water hyacinth cover. Weak correspondences were found in the census years from 1998 to 2002. Notable correspondences were observed after 2003. Because water hyacinth cover in 2003 was 20.8%, the results may suggest that a water hyacinth cover of less than 20% may not be sufficient enough to deter or attract waterbird species. Although the species that were least affected or negatively affected were consistent with my expectations, I expected positive correspondences for all the dabbling ducks because they require open surface water for feeding and will not be able to manoeuvre with a dense water hyacinth cover. Baikal Teal, Spot-billed Duck and Mallard may well be excluded from this list, as their abundances were too low and inconsistent to exhibit any notable correspondence. The case of Northern Shoveler was most disappointing. This dabbler visited Santragachhi in greater abundances and showed 44% decline during the time-span. These facts indicate that although water hyacinth is considered to be a leading threat to global aquatic biodiversity[27], there are other factors that alone and in concert with the spread of water hyacinth contribute to the loss of aquatic species[28].

All the waterbird species in the Santragachhi wetland have declined in the period between 1998 and 2009. Multivariate analysis also revealed that the community as a whole has changed and become poorer in this time-span. Limiting this comparison to only one habitat attributes (water hyacinth cover) subsequently limits the conclusions that can be drawn regarding the causes of changes in waterbird community composition. Several factors may be involved and the relative importance of these may vary over time. However, analysis of the relationships between water hyacinth cover and waterbird community indicated that the decline in numbers and variations in the community composition observed during census year

2003 onwards was almost entirely due to loss of surface water area, resulting mainly from water hyacinth cover. These invasive weeds pose a serious threat to the waterbirds because they cover the water surface of wetlands reducing their feeding areas[29].

Thus, the processes governing fluctuations in waterbird abundance and community composition are not well understood at present. This lack of knowledge will certainly limit the options for implementing management strategies aiming at optimizing biodiversity, and should be addressed in future studies of wetland communities. The present study suggests that the waterbird diversity of the Santragachhi wetland as a whole is on a decline. This is reflected in changes to the waterbird community, with the abundance of all the species for which the Santragachhi wetland is important having declined over the past 12 years. For some of these species (e.g. Baikal Teal and Swinhoe's Snipe), Santragachhi has been one of the most important sites in South Bengal, and a local decline in habitat suitability (as has already occurred) may thus have serious implications for these species regionally and internationally.

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