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EFFECT OF MULTIPLE ADJOINING HABITATS ON AVIFAUNAL DIVERSITY IN AN AGRICULTURE-BASED WETLAND ADJACENT TO THE HOOGHLY RIVER, WEST BENGAL, INDIA

Manojit Sau, Mainak Chakraborty, Riya Das and Supratim Mukherjee

ABSTRACT

Sau M., Chakraborty M., Das R. and Mukherjee S. 2018. *Effect of multiple adjoining habitats on avifaunal diversity in an agriculture based-wetland adjacent to the Hooghly River, West Bengal, India*. Ring 40: 59-92.

This study was conducted on four plots having a cluster of different combinations of forest, wetland, and agricultural land, as well as a single marshland habitat near the river Hooghly. We obtained 17,817 counts for 150 species in 32 days of year-round sampling. The wetland-agricultural land associated with forest had the highest species diversity (132 species, Shannon $\bar{H}$ – 1.63), heterogeneity (Shannon J' – 0.773), and number of unique species (33 species), and the lowest dominance (Simpson Index $1/D$ – 39.35), in contrast with the marsh, which had the lowest diversity (41 species, Shannon $\bar{H}$ – 1.39), highest homogeneity (Shannon J' – 0.863), and a lack of uniqueness. The plot with secondary forest patches between an agricultural field and human settlements showed the highest species dominance (Simpsons Diversity $1/D$ – 17.465). Species rarity ranged from 68.2% to 77.6% within the area under study. There were 25 species common to all plots, which formed six distinct groups based on their abundance. Carnivores were found to be the dominant foraging guild throughout the habitats. Thirty-two per cent of the species are migratory, with the families *Scolopacidae* and *Motacillidae* predominating. The Jaccard and Sorensen indices reveal the greatest species similarity between the wetlandpisciculture plot and the marshland. These indices together with the hierarchical cluster analysis indicate the uniqueness of the plot of open forest habitat adjoining the wetland, which offers the best living conditions for migratory species. Our study concludes that when a wetland is surrounded by agriculture rather than fisheries, avifaunal diversity increases, whereas forest-associated wetland-farmland maximizes species richness with minimum dominance and hence imparts greater stability to the overall community structure.

M. Sau, M. Chakraborty, R. Das, S. Mukherjee (corresponding author), Department of Zoology, Government General Degree College Singur, Jalaghata, Singur, Hooghly, PIN-712409, West Bengal, India, address for correspondence – supratimm7@gmail.com

Keywords: bird community, habitat, diversity, wetland, foraging guild, migratory species

INTRODUCTION

Drastic changes in global land usage patterns without consideration of their impact on ecosystems is an emerging problem for conservation strategies, especially in South Asia (Tilman *et al.* 2001, Camp *et al.* 2001, Brooks *et al.* 2003, Sodhi *et al.* 2004, Koh and Gardner 2010). Continuous pristine habitats such as forests and wetlands are interrupted by agricultural lands, fisheries, and human artefacts such as urban constructions and industries (Findlay and Bourdages 2000, Verma *et al.* 2001, Koh and Wilcove 2008, Goodale *et al.* 2014, Gopi Sundar *et al.* 2015). This increasing human activity has rapidly transformed the previous large continuous habitat structure into multiple small adjoining habitat clusters forming a mosaic pattern (Bassi *et al.* 2014, Mandal and Shankar Raman 2016). Avian diversity of one native habitat is influenced by adjoining altered habitats (Raman 2006, Peh *et al.* 2006). The size and location of adjoining native forest patches have a strong influence on the community composition of urban avifauna (Gavareski 1976, Dale 2018). The quality, size and complementarities among adjoining patches are the key parameters of biodiversity (Law and Dickman 1998, Dunford and Freemark 2005, Kupfer *et al.* 2006, Smith *et al.* 2011).

The Indian subcontinent has the highest cropland cover among Asian countries, and India sustains the fastest growing, second largest global human population through its cropland production (Ramankutty *et al.* 2002). The fertile soil of the Indo-Gangetic plain contributes 22% of the rice produced by the country (Frolking *et al.* 2006). The habitat comprising the ancient river-based cultural civilization of India along the Ganges basin constitutes 26% of the country's land mass, supporting 43% of the Indian population (Indian Institute of Technology 2011). The Hooghly district on the bank of the Ganges has a high population density of 1753/km^2 (Census of West Bengal and Kolkata 2011). West Bengal has a total of 147,826 wetlands, the highest number in India (Bassi *et al.* 2014). The wetlands, including marshlands, along the banks of the Hooghly River can be classified as riverine and palustrine based on their hydrological and ecological parameters (Cowardin *et al.* 1979). Some parts of the wetlands become seasonal crop fields during the dry season, whereas during the rainy season rice is cultivated in many of the adjoining areas. The wetlands on the banks of the Ganges are immensely important from the perspective of avifaunal conservation, and according to BirdLife International, the Farraka Barrage and adjoining wetland area (IBA site code-IN-WB-02, criteria-A1, A4i, A4iii) and Naya Bandh Wetland complex (IBA site code-IN-WB-08, criteria A1) are important bird and biodiversity areas located on the Ganges in the Malda district, West Bengal (Rahamani *et al.* 2016). Wetlands are becoming degraded all over the world despite the fact that they sustain large numbers of waterfowl. As wetland areas gradually shrink, expanding agricultural fields become a complementary habitat for them (Fasola 1997, Elphick 2000, Fraser and Keddy 2005). Nearly one third of bird species exploit agricultural fields for their activity globally (Sekercioglu *et al.* 2007).

Over 1450 species of birds are found in South Asia, of which India has 1263 species belonging to 23 orders and 107 families. This is 12% of the world's avifaunal diversity (Rasmussen and Anderton 2012, Praveen *et al.* 2016). A total of 351 species of birds are reported to use agricultural lands and their associated habitats on the Indian Subcontinent (Sundar and Subramanya 2010). The occurrence of wetlands, including marshlands, and agricultural lands side-by-side is a very common regional feature of the Gangetic flood plains of West Bengal. Crop composition and farming intensity determine the species richness and abundance in the agricultural lands (Cunningham *et al*. 2013). Both wetlands and their associated marshland are presently facing deterioration, as wetlands are being used as dumping grounds and for construction of dams, and in the absence of proper management strategies these factors contribute to the alteration of the hydrological cycle and consequent reduction in the supply of water (Turner *et al*. 2000, Verma *et al*. 2001, Kumar *et al*. 2012).

The present study was conducted on five plots in the Hooghly district, West Bengal, India. Each spatially isolated individual plot was composed of a combination of different adjoining habitats: (1) a strip of forest with adjoining wetland-associated temporary agricultural fields, (2) secondary forest accompanying human settlements surrounded by cultivation fields, (3) a wetland adjoining a rice field beside a freshwater canal, and (4) a wetland cum agricultural land combined with fish farms. A single perennial marshland habitat was also included in our investigation as a reference plot to judge the alterations to the wetlands caused by human activity. The habitats were chosen so that one is located some distance away from the Hooghly River, while the rest lie closer and parallel to the river. We determined the impact of different habitat patterns, composed of various kinds and proportions of natural and seminatural habitats within the framework of a landscape, on community characteristics such as diversity, dominance, heterogeneity, foraging structure, and the occurrence of migratory species. The effects, positive or negative, of human-mediated modifications and activity on the bird community composition in the wetland-based ecosystems were measured based on the species turnover from one plot to another. The extent of plot utilization by different bird species was estimated by observing their presence or absence on the five plots during our investigation period. This observation is important for estimating the sustainability of species in the face of the changing pattern of global land usage. The current population status of individual species in each plot can be seen based on their relative abundance and the abundance-rarity index that we determined from the threshold value of average species abundance. We have also attempted to prioritize the plots or habitat patches for conservation, in order to preserve the overall integrity of the community and the ecosystem. These could be a starting base for future monitoring.

MATERIALS AND METHODS

Study sites

Five plots distinguished within a landscape of 120 square kilometres were surveyed for bird counting. The landscape was located west of the Hooghly River bank in rural West Bengal (Fig. 1). This portion of southern West Bengal, which is part of a tropical moist deciduous biotope, contains seasonal wetlands, perennial marshland, agricultural fields, man-made water bodies for fishery industries called '*bheries*', isolated forest patches, and villages. Our study follows two areas, one parallel and close to the Hooghly River and the other at a distance away from it. The area that is parallel to the river is a zone of wetland and marshland, depending upon the water depth and topographical features. Between the plots and the river there is an urbanized zone along both sides of the river course. The other area, located some distance away from the Hooghly River, follows a gradient from a wetland to a permanent cultivation field. The intensity of cultivation increases along this gradient from east to west. The population density also thins out along this gradient, creating an urban to rural polarity. The plots were chosen in such a way that an individual plot contains either a combination of more than one adjacent habitat or a single habitat.

Four plots are located in the Singur block, designated as *WFA* – wetland-forest--agricultural land; *WA1* and *WA2*, which are both wetland-agricultural land with no forest patches; and *W*, a perennial marshland. *WFA* is a mosaic plot with an isolated forest patch (1.04 km^2) and a large adjacent temporary wetland (1.18 km^2), which becomes an agricultural field in the dry season of winter and summer. The agricultural usage follows a gradient from forest to wetland depending upon the seasonal water stagnancy of the land (Fig. 2 Upper panel). Areas immediately adjacent to the forest have crop fields on which two crops are grown over the year, one of which is rice. The lands adjacent to this but away from the forest are rice fields cultivated once a year.

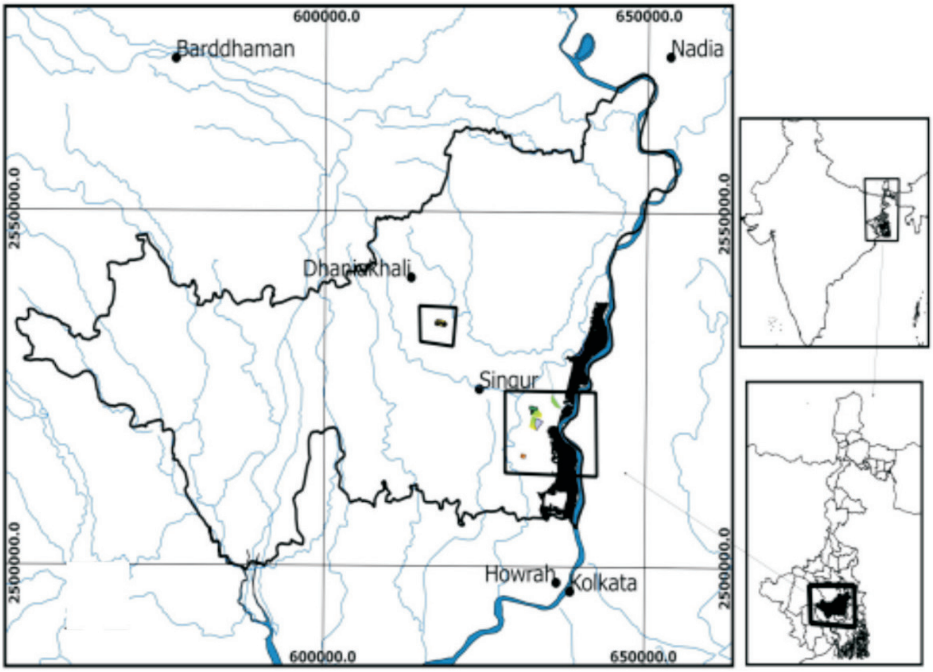

Fig. 1. General location of the study area: Hooghly district in West Bengal, India (right panels). Boxes within the Hooghly district boundary (left panel) indicate the study areas; the smaller one indicating FA and the larger one including the other four (see text for abbreviation details). Water channels are shown traversing the district (blue lines).

The lands adjoining the forest patch are the site of high agricultural usage, diminishing gradually along the forest-wetland gradient and ultimately leading to marshlands with no agricultural activity. The mixed forest patch of *WFA* is dominated by mango (*Mangifera*) and bamboo (*Bambusa*), mixed at the periphery with banana (*Musa*). *WA1* includes two blocks (Fig. 2 Upper panel). The first has an area of 1.39 km^2, with many man-made water bodies used for commercial fish farming by private owners under government subsidy, and the other is an adjacent agricultural wetland block of 1.39 km^2, with the same agriculture-wetland gradient. In the latter block, however, harvest is only once a year. Some of the land is used exclusively for onion, and other parts for jute or paddy. The land away from the cultivation field is typical wet grassland with *Vetiveria zizanioides* at the periphery. *WA2* is essentially a wetland, located nearest to the Hooghly River of all the plots, with a rice field block (1.24 km^2) which is cultivated once a year. A perennial water canal is located adjacent to the field block connected to the Hooghly River nearby. The part of the canal we investigated has an area of about 0.22 km^2. The canal adjoining the lowland area has a wetland character, dominated by grasses such as *Schoenoplectus corymbosus*, *S articulates* and *Juncellus inundates*. *WA1* and *WA2* are wetland-based agricultural lands and were distinguished because the agricultural wetland block of *WA1*, associated with human-managed water bodies, is used in commercial carp production, whereas the natural perennial canal associated with rice fields in *WA2* is not manipulated by human activity. However, plot *WA2* is only about 100-200 metres from the urbanized areas along the river (Fig. 1 and 2 Upper panel). Plot *W* (0.38 km^2) is part of natural marshland located at the southern periphery of the Singur block (Fig. 1 and 2 Upper Panel), typically with tall reed beds and grasses, and maintains a critical water level to sustain its marshland character. The predominant vegetation includes floating vegetation, *Eichhornia* and *Neptunia*, rooted floating vegetation, *Nymphoides hydrophylla* and *Nymphaea pubescens*, and rooted standing vegetation, *Ipomoea fistulosa*, *Saccharum*, *narenga*, *Phragmites karka*, *Typha angustifolia*, *Aeschynomene*, *Sagittaria* spp., *Schoenoplectus articulatus*, *Polygonum*, *Coix lacryma*, and *Sesbania bispinosa*. All four plots beside the Hooghly River, i.e. *WFA*, *WA1*, *WA2* and *W*, are sample areas of a once existing continuous wetland running parallel to the Hooghly River and bear traces of human activity; they have been transformed partly into a permanent rice field, temporary crop fields, and a man-made fish farming zone. Only *W* is a permanent marshland located at the extreme end of this wetland axis. The *FA* plot consists of fragmented forest patches associated with agricultural fields undergoing intense cultivation three times a year. This plot encloses an area of 1.61 km^2 located in the village of Porabazar, Dhaniakhali block. It is the farthest of the plots from the Hooghly River and contains sparsely distributed secondary forest patches with human habitation, ponds, roads and ditches (Fig. 1 and 2 Upper panel).

Counting methodology

The line transect and point transect methods were used for bird counting, based on the method's suitability for a given habitat (Shankar Raman 2003, Chatterjee 2013). Both transect methods follow predefined routes with predetermined sample survey areas (Gregory *et al.* 2004). For uniform habitats such as wetlands and agricultural fields with an open field of view, we used the line transect method. The line transect method consisted in continuous counting along the axis of the observer's linear pathway of movement with a more or less constant walking speed on either side of the line. The point transect method was used for forest patches, because in forested areas the field of view is restricted by dense vegetation. In this method, the observer has to travel along a transect and stop at regular intervals of 50 metres, allow the birds to settle for two minutes, and record their numbers for 20 minutes (Gregory *et al.* 2004). The predefined route for the point transect was chosen in such a way that microhabitats such as bamboo groves, mango forest patches and other vegetation-based forest patches had equal chances of coming within the purview of sample counting. All the birds seen or heard were counted. Observations were conducted in each plot for three hours after sunrise per day with good visibility conditions. Bird counting was carried out on separate days for each of the plots.

A year-round study was conducted from February 2017 to April 2018 (Table 1). Study seasons were broadly divided into two phases – summer and winter – and suitable times were chosen for each plot to encompass maximum species variety occurring due to winter, summer and passage migration.

Table 1
Data collection days (sampling) over the months 2017-2018. Numbers correspond to the number of field days in each month. Shaded months are indicative of summer, including the monsoon season.

Plots	**Time distribution of sampling over the seasons**													**Total**
	Year	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	
WA1	2017								1	1	1	1		5
	2018	1												
W	2017								1				1	3
	2018		1											
FA	2017							1	1	1	1	1	1	6
WA2	2017											1	1	4
	2018	1			1									
WFA	2017		1	1				1	1	1	1	1	3	14
	2018	1	1	1	1									

Materials

Olympus 8×40 binoculars (DPS I field 8.2, Porro prism type, 182 × 139 × 58 mm, Olympus Corporation, India) were used for bird watching and counting. Photos of birds were taken with the Panasonic Lumix FZ28 and FZ 150 and the Nikon B700 (compact cameras) and the Nikon D750 Body (dSLR) with a Nikkor 300 f/2.8 prime lens and Nikon 2x teleconverter (only used when species identification was in doubt).

Species account

Birds were identified by taking photographs and subsequent confirmation using field guide books by Grimmett (Grimmett *et al*. 2011), and Kazmierczak (Kazmierczak 2000). The sequence of birds in the appendix is largely based on Dickinson (2003), and order names are adopted from Ali and Ripley (Ali and Ripley 1980, Grimmett *et al*. 2011). Common names, taxonomic notations from family to species, species distribution and migration pattern are based on Rasmussen (Rasmussen and Anderton 2012). Some changes in distribution were made as per Grimmett, as on a few occasions it matched the local migration pattern in the study areas. Foraging groups are broadly classified into phytophagous-carnivorous, granivorous, frugivorous, carnivorous, insectivorous and omnivorous based on field observations and on Ali and Ripley (Ali and Ripley 1980, Chatterjee *et al*. 2013).

Data analysis

BioDiversity Pro software (McAleece 1997, Biodiversity Professional, Scottish Association for Marine Science and the Natural History Museum, London, UK) was used to analyse biodiversity indices and the rank abundance curve. Estimation of whether a species was rare or abundant within a plot was based on a base value set as the average number of individuals per species divided by the total number of individuals seen during sampling in a given plot [Average count per species = Total number of individuals found or Total count/Total number of species, Base value = average count per species/Total count]. Put simply, it is the average expected abundance of individual species among all those occurring in a given plot (Aditya *et al*. 2010). The observed relative abundance value of each species was compared with this average abundance value to designate a species as 'rare' or 'abundant'. The similarity between two communities in terms of species composition was estimated by the Jaccard and Sorensen coefficients: *Jaccard coefficient* $= M/(M+N)$ and *Sorensen coefficient* $= 2M/(M+N)$. The number of species common to two communities is designated as M, whereas the total number of unique species present in both communities is designated N. Classical cluster analysis was used to verify the similarity measurement between plots. The distance of similarities between habitats is expressed by a dendrogram based on the Euclidean similarity index. Relative abundance values of the generalist species in the five plots are used for principal component analysis in PAST v. 3.0, and the percentage of variance for component 1 (*WFA*) is plotted against component 2 (*WA1*). Component analyses between other plots yielded similar results (data not shown). The scattered plot analysis was based on the variance-covariance matrix between the groups. The projection map, drawing, and area measurement of the plots were done in QGIS software v. 2.18 using a Google satellite map.

RESULTS

Species diversity and abundance

We identified 150 species belonging to 16 orders and 55 families in the plots studied over the year. *WA1*, *W*, *FA*, *WA2*, and *WFA* were observed to have 61, 41, 76, 85 and 132 species, respectively (*Appendix*).

The Shannon diversity indices ($\bar{H}$, *Hmax* and Shannon *J'*) showed that plot *WFA* had the highest $\bar{H}$ (1.638) and *Hmax* (2.121) (Table 2). $\bar{H}$ is the measure of the sum of the relative abundance of all species found, while *Hmax* is the highest species number found during the observational period. Shannon *J'* is the ratio of $\bar{H}$ to *Hmax*, a measure of species evenness [*e*]. The marshland (*W*) avian community was the most homogeneous (Shannon *J'* 0.863). Species heterogeneity expressed by the *J'* value was higher in *WFA* (0.773) and *WA2* (0.776) than in the other plots, due to the greater number of unique habitat species found in these two plots. The Simpson indices measure dominance, with higher values corresponding to greater dominance and lower values to greater diversity (Odum and Barrett 2005). Dominance was highest in *FA* (*D* – 0.057), followed by *W* (0.047). In comparison to the other plots, *WFA* had a markedly lower value (0.025), signifying the lowest dominance.

Table 2
Shannon and Simpson's diversity indices for the five study areas.
WA1 – wetland-agricultural land with man-made fisheries, *W* – perennial wetland, *FA* – forest patch with agricultural field, *WA2* – wetland-agricultural land with natural river canal, *WFA* – wetland-forest strip-agricultural land

Index	**WA1**	**W**	**FA**	**WA2**	**WFA**
Shannon H' Log Base 10	1.446	1.391	1.440	1.497	1.638
Shannon H_{max} Log Base 10	1.778	1.613	1.881	1.929	2.121
Shannon J'	0.813	0.863	0.766	0.776	0.773
Index	**WA1**	**W**	**FA**	**WA2**	**WFA**
Simpson's Diversity (D)	0.042	0.047	0.057	0.040	0.025
Simpson's Diversity (1/D)	23.647	21.135	17.465	24.853	39.35

The species count, when plotted in descending order for all the species (Fig. 3), was highest in *WFA*, followed by *WA2*. Plot *W* had the lowest species count. The area under the curve was greater for *WFA* and *WA2*, as they had the highest *Hmax*. However, as this does not show the proportional contribution of each species to the community, we plotted a species abundance curve (Fig. 4). It shows two aspects of species diversity; the steepness of the curve is negatively correlated with the species diversity of a community and positively correlated with the dominance (Odum and Barrett 2005). *WFA* had the flattest curve of the five, so it was obviously the most diverse and had the lowest species dominance. *FA*, the agricultural field associated with fragmented secondary forest surrounding human habitation, showed the highest dominance and the lowest diversity. As dominance and diversity are inversely proportional, the three remaining plots, *W*, *WA1* and *WA2*, showed intermediate diversity and dominance.

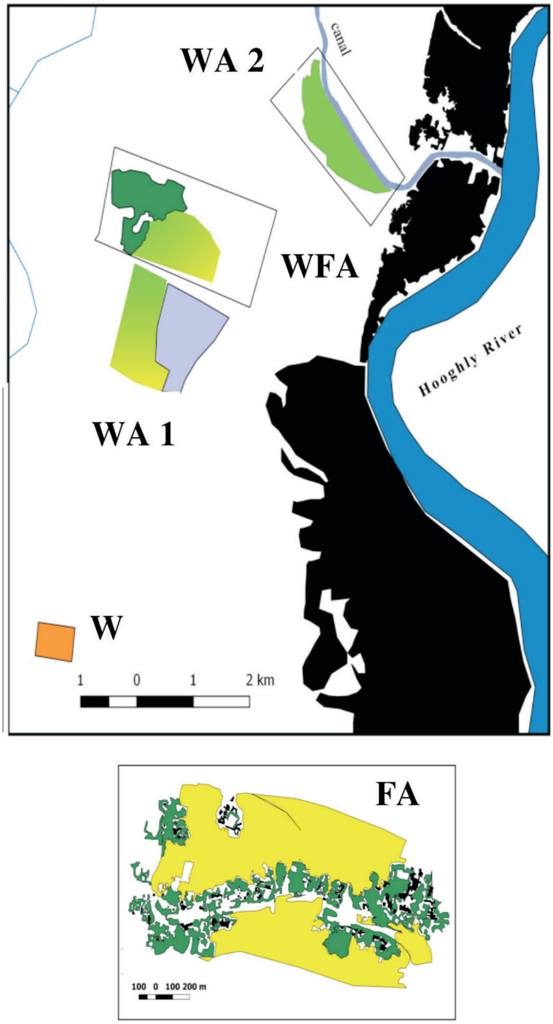

Fig. 2. Upper panel: four plots lie west of and parallel to the Hooghly River (blue). *WFA* and *WA2* (see text for abbreviation details) are shown in boxes. *WFA* contains two blocks, a continuous mixed forest patch (deep green) and an adjoining wetland-associated agricultural field. A gradient of green to yellow indicates the polarity of the usage of the wetland – from the agricultural field in green to the wetland in yellow. The wetland block of *WA1* is shown using the same gradient, with the adjoining pisciculture block in sky blue. *WA2* has a green block correlating with stable usage of this wetland-associated landmass as rice fields with a perennial river canal (sky blue). *W* (orange) is a single perennial marshland habitat. Black areas along the west of the Hooghly River bank indicate high population density. Lower panel: plot *FA* with agricultural land (yellow) and associated secondary forest patches (deep green) and human habitation (black). Unshaded regions within the shaded landscape are ponds or roads.

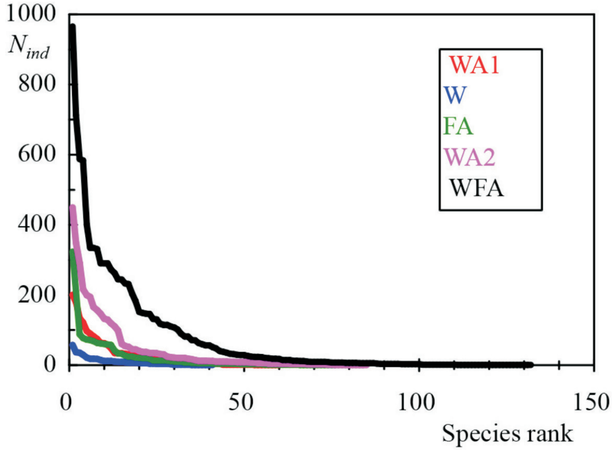

Fig. 3. Total numbers of individuals of observed species (N_{ind}) ranked in descending order for the five plots (see text for abbreviation details)

Based on the average count per species, we determined a critical value of average species abundance per count for the plots (*Appendix*). These critical values were 0.0166, 0.0243, 0.0131, 0.0117 and 0.0075 for *WA1*, *W*, *FA*, *WA2* and *WFA*, respectively. Species showing relative abundance equal to or greater than this value are '*abundant*' and those with lower values are '*rare*'. This makes it easy to differentiate rare and abundant species for each plot. Based on the data, *WFA* had 34 abundant species and 98 rare species (74.2%). The *WA1* and *WA2* habitats had 43 (70.5%) and 66 (77.6%) rare species, respectively. The marshland (*W*) habitat had 28 (68.2%) rare species, while 58 (76.3%) species were rare in the human-associated rural forest patch and agricultural lands. Hence rarity varies from 68.2% to 77.6% for all habitat types or mosaic habitats under observation; on average 7 of 10 bird species found in the habitat/combination of habitats were rare.

Species turnover and habitat associations

We found 25 species (16.67%) in all five of the plots, confirming that they are highly flexible in habitat utilization and most common in wetland and agricultural lands. On the other hand, 48 species (32%) were found in only one plot or in any particular habitat. Although there is no hard and fast rule that they cannot be found in other plots or habitats, the chances of their occurrence in any habitat are lower. At the same time they are rarer than the others, with a very low chance of encounter. Among the 48 species found in a single habitat association, 33 of the species (68.75%) are found in the *WFA* plot association, 11 in *WA2* (22.91%) and 4 (8.34%) in *FA* (Fig. 5). Strikingly, neither the perennial marshland nor *WF1* had any unique species. Diversity of habitats seems to be important for the sustenance of rare species (Anderson 2001).

Species that were found in all the plots did not exploit the habitats equally; a species could be abundant in one habitat but rare in another (Fig. 6). Among the 25 generalist species found, only House Crow (*Corvus splendens*) and Asian Pied Starling

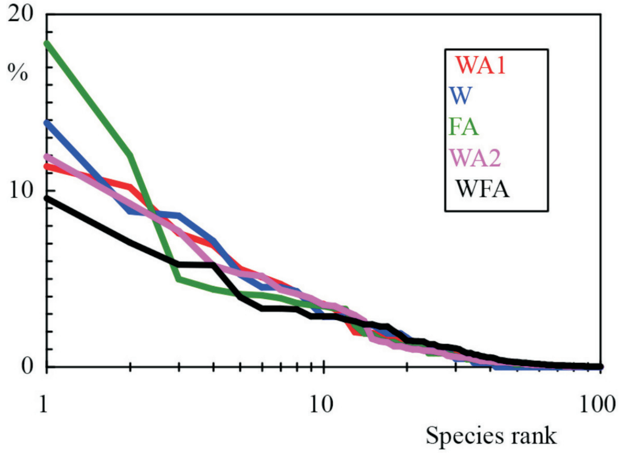

Fig. 4. Dominance diversity curves plotted as percentages of relative abundance (%) of each species ranked in descending order. Species rank is shown in log scale to distinguish the initial segments occupied by dominating species.

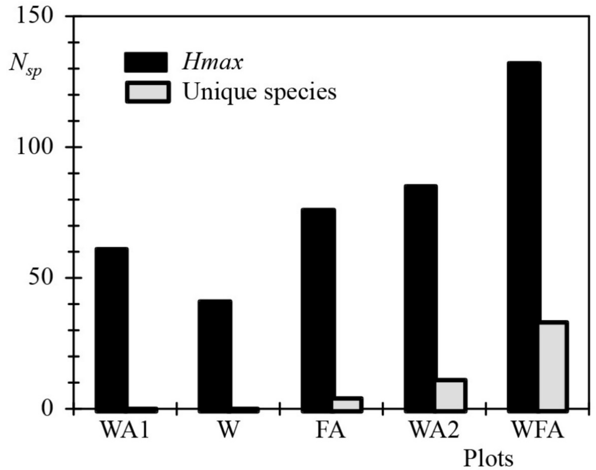

Fig. 5. Number of unique species against the number of total species found compared for each area

(*Gracupica contra*) were relatively abundant in all sites studied (Fig. 6). Six species, Asian Openbill (*Anastomus oscitans*), Indian Pond-heron (*Ardeola grayii*), Eastern Cattle Egret (*Bubulcus coromandus*), Spotted Dove (*Spilopelia chinensis*), Black Drongo (*Edolius macrocercus*), and Common Myna (*Acridotheres tristis*), showed population abundance in four of the five plots. Rock Pigeon (*Columba livia*), Red-vented Bulbul (*Pycnonotus cafer*), Plain Prinia (*Prinia inornata*), and White Wagtail (*Motacilla alba*) were abundant in three of the sites, while Wood Sandpiper (*Tringa glareola*), Eurasian Collared-dove (*Streptopelia decaocto*), and Citrine Wagtail (*Motacilla citreola citreola*) were abundant in only two habitats. Little Cormorant (*Microcarbo niger*), White-throated Kingfisher (*Halcyon smyrnensis*), Bengal Bushlark (*Mirafra assamica*), Common Tailorbird (*Orthotomus sutorius*), and Western Yellow Wagtail (*Motacilla flava*) were abundant in only one of the plots. Five species, i.e. Black Kite (*Milvus migrans migrans/govinda*), White-breasted Waterhen (*Amaurornis phoenicurus*), Greater Coucal (*Centropus sinensis*), Common Kingfisher (*Alcedo atthis*), and Brown Shrike (*Lanius cristatus cristatus*), were found to be relatively rare in all plots. Although these five species were rarely found in the plots, they did contribute to species diversity as generalists. Six classes were thus found for the 25 generalist species. Species abundant in all five, four, three, two, one and none of the plots are designated as class 5, 4, 3, 2, 1, and 0, respectively. The six classes of generalist species groups form six spatially distinct clusters (Fig. 7). Species belonging to class 5 (Fig. 7) are located on the right side of the graph. This group comprises House Crow (*Corvus splendens*) and Asian Pied Starling (*Gracupica contra*). The relative distance between the points of these two species shows that they are the most abundant species, and their numbers fluctuate from one plot to another much more than other member species of the communities. The association of the species for the rest of the classes increases in principal component analysis from right to left. The relative abundance of the species constituting class 0 is relatively stable. Thus classes 0, 1, and 2 are the most stable population group among the six classes in terms of consistency in relative abundance. The sum of the relative abundance for the 25 species in the plots reveals the highest percentage contribution in *W* (76%), followed by *WA1* (71.20%) (Table 3). This is obvious, because these two communities are the least diverse. *WFA* (55.4%) and *WA2* (47.4%) thus contribute least to abundance. The paired independent *t*-test shows (at a 5% significance level) no significant differences in the sample mean, but the standard deviation is high for *WA1*, *FA* and *W*. Hence fluctuation in relative abundance within the abundance class is higher in these three plots.

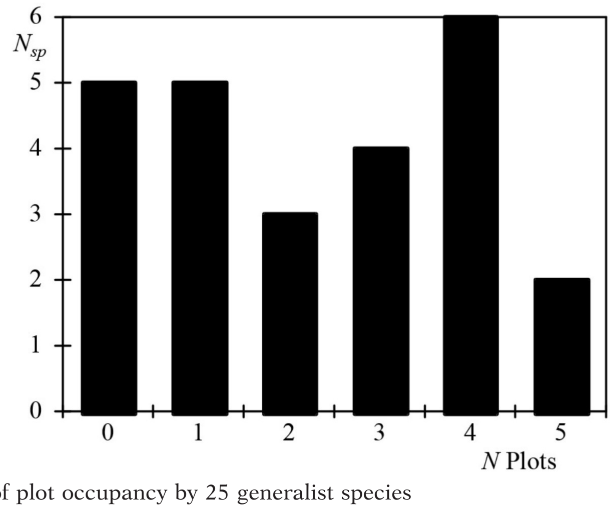

Fig. 6. Extent of plot occupancy by 25 generalist species

Table 3
Relative percentage contribution of 25 species common to the plots studied to community composition

Habitats	Total (%)	mean	Standard deviation
WA1	71.2	2.80	3.2
W	76.0	3.03	3.3
FA	56.7	2.27	3.7
WA2	47.4	1.89	1.8
WFA	55.4	2.20	1.9

Migratory species assemblage

We found 48 species exploiting the habitats around the study areas, mainly raptors, waders, shrikes, swallows, warblers, chats, flycatchers and wagtails. The families were Anatidae (1), Threskiornithidae (2), Ardeidae (1), Falconidae (2), Accipitridae (2), Charadriidae (2), Scolopacidae (6), Glareolidae (1), Cuculidae (2), Upupidae (1), Meropidae (1), Picidae (1), Campephagidae (1), Laniidae (3), Dicruridae (1), Oriolidae (2), Hirundinidae (3), Acrocephalidae (3), Phylloscopidae (2), Sturnidae (1), Muscicapidae (6) and Motacillidae (4). *WFA* has the highest number of migrants (37), while *WA1* and *WA2* plots are utilized by 14 and 24 migrant species, respectively (Fig. 8). *FA* and the single habitat *W* can provide refuge for 12 and 9 migratory species, respectively. *WA1* and *WA2* are very similar plots, differing only in the presence of a managed fishery in WA1 and a natural river canal in *WA2*, but there is a huge difference in the number of migratory species. The reason may be that human-controlled habitats become more homogeneous than natural habitats and hence offer less diversity of food and shelter, leading to low species diversity. We found 23 migratory species that were restricted to a single plot. Among these, 14 species are associated strictly with *WFA*, seven were found in *WA2*, and two exploited *FA*.

Habitat similarity assessment

Four of the plots, *WA2*, *WFA*, *WA1* and *W*, are parts of a wetland beside the bank of the Hooghly River. The first three are modified by human activities such as agriculture and fisheries. *W*, the perennial marshland, is more or less undisturbed, and can be used as a yardstick to assess the community alteration in other wetland-associated habitats. *FA* is an example of an avian community structure surrounding intensive agricultural activity and human habitation in a rural context. To determine the changes in habitat features, we assess the similarity of the avian community composition between plots. Bird assemblage studies are used as an ecological indicator to measure ecosystem alteration (Bradford *et al.* 1998, Canterbury *et al.* 2000). The perennial marshland (*W*) and wetland associated with fisheries (*WA1*) were the habitat clusters with the most similar species composition. The Jaccard and Sorensen similarity coefficients for these two study areas were 0.159 and 0.274, respectively (Table 4). In contrast, the perennial wetlands (*W*) and agricultural fields with a small forest patch in

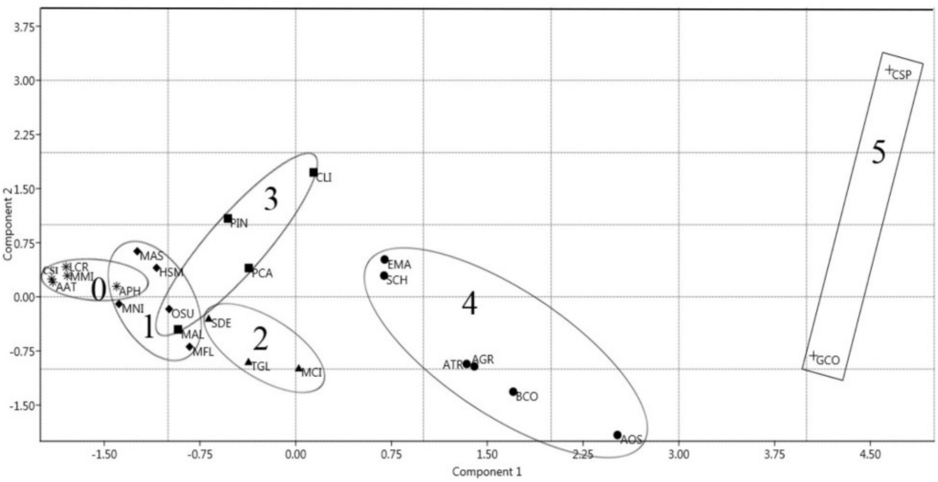

Fig. 7. Principal component analysis of the relative abundance of generalist species found at all the sites. Generalist species are grouped into six classes (using contours of a rectangle and ellipses) based on their abundance in plots. The numerical values correspond to the number of plots where the species concerned are abundant. '0' indicates that the species are rare at all the sites. Three letter abbreviations with the first generic letter and first two specific letters are used. AOS – *Anastomus oscitans*, AGR – *Ardeola grayii*, BCO – *Bubulcus coromandus*, MNI – *Microcarbo niger*, MMI – *Milvus migrans*, APH – *Amaurornis phoenicurus*, TGL – *Tringa glareola*, CLI – *Columba livia*, SDE – *Streptopelia decaocto*, SCH – *Spilopelia chinensis*, CSI – *Centropus sinensis*, HSM – *Halcyon smyrnensis*, AAT – *Alcedo atthis*, LCR – *Lanius cristatus*, EMA – *Edolius macrocercus*, CSP – *Corvus splendens*, MAS – *Mirafra assamica*, PCA – *Pycnonotus cafer*, PIN – *Prinia inornata*, OSU – *Orthtomus sutorius*, ATR – *Acridotheres tristis*, GCO – *Gracupica contra*, MFL – *Motacilla flava*, MCI – *Motacilla citreola*, MAL – *Motacilla alba*.

a human-dominated area (*FA*) had Jaccard and Sorensen similarity coefficients of 0.114 and 0.205, respectively, and were the least similar in terms of species composition. Hierarchical cluster analysis based on community assemblage revealed the uniqueness of *WFA* in comparison with the other habitat clusters (Fig. 9). The dendrogram put the *WFA* uniquely aside, whereas W and *WA1* form a monotypic plot closely associated with *FA*. *WA 2*, on the other hand, is a plot with a transitional relationship between *WFA* and the other plots, i.e. *FA*, *W* and *WA1*. The strip of forest associated with the wetland thus formed a uniquely diversified regime among the habitat clusters investigated.

Table 4
Jaccard's (J) and Sorensen's (S) similarity indices between plots

	WA1		**FA**		**W**		**WA2**	
	J	S	J	S	J	S	J	S
WFA	0.142	0.248	0.124	0.250	0.116	0.208	0.142	0.248
WA1	–	–	0.122	0.218	0.159	0.274	0.149	0.260
FA	–	–	–	–	0.114	0.205	0.150	0.260
W	–	–	–	–	–	–	0.145	0.253

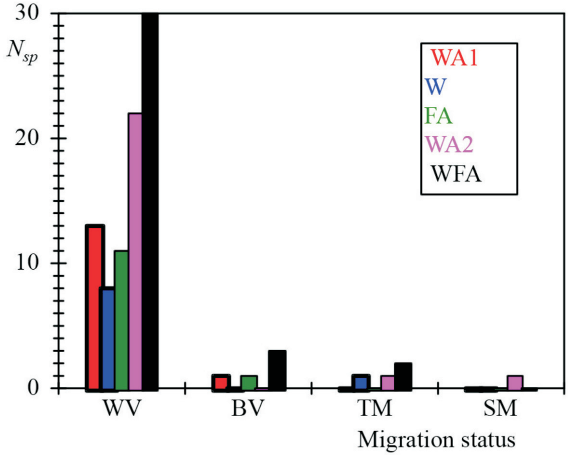

Fig. 8. Occurrence of migratory species in plots. Migratory species are classified as per Rasmussen and Anderton (2012). WV – Winter visitor, TM – Two-season migrant, BV – Breeding visitor, SM – Spring migrant; see text for plot abbreviation details.

Study of foraging guilds

Among the 150 species observed, one in three species was found to be carnivorous (33.3 %), 28% were omnivorous, and 23.3% were insectivorous (Table 5). Purely vegetarian species – granivores and frugivores – constituted only 9.3% of the total species. The phytophagous-carnivorous (*Ph-Cr*) species found here (6%) mainly exploited water bodies or areas adjoining them. In *WFA*, carnivorous and omnivorous species were equally common (31.1%). Carnivores were dominant in both the *W* (36.5%) and *WA2* (37.6%) habitats. Omnivores, with 34.4% and 34.2%, were dominant over carnivores in *WA1* and *FA*, with 31.1% and 30.2%, respectively. Insectivorous species were found in the lowest proportion (15.7%) in *FA* and the highest in *WFA* (24.2%). Frugivorous species were entirely absent in *W*. Among migratory species, 20 carnivorous, 20 insectivorous, seven omnivorous and one phytophagous-carnivorous species were found to be distributed throughout the habitats. The majority of the migratory species exploiting open cultivated fields and wetland-associated habitats were raptors, ibises, waders, shrikes, swallows, warblers, chats and wagtails. Among the 25 generalist species, there were nine carnivores, eight omnivores, four insectivores, three granivores and one phytophagous carnivore. When we compared the numbers of generalist species among all the species found within one foraging guild, three of the eight species of granivores were found to be generalist (37.5%), and they were proportionately dominant over carnivores (18%), omnivores (19%), and insectivores (11.4%). Frugivores were the most sensitive guild, as they were rare in the communities. Five winter migrants were found at all five sites, of which three were wagtails.

Table 5
Foraging guilds across five plots. The percentage of each foraging guild is given in parentheses for each plot.

Guild	Total	WA1 (61)	W (41)	FA (76)	WA2 (85)	WFA (132)
Phytophagous-Carnivorous, (Ph-Cr)	9	2 (3.3)	2 (4.9)	5 (6.6)	6 (7.1)	7 (5.3)
Granivorous (Gr)	8	4 (6.5)	5 (12.2)	5 (6.6)	5 (5.9)	6 (4.5)
Frugivorous (Fg)	6	2 (3.3)	0	5 (6.6)	6 (7.1)	5 (3.8)
Carnivorous (Cr)	50	19 (31.1)	15 (36.6)	23 (30.2)	32 (37.6)	41 (31.1)
Insectivorous (In)	35	13 (21.3)	9 (21.9)	12 (15.8)	17 (20)	32 (24.2)
Omnivorous (Om)	42	21 (34.4)	10 (24.4)	26 (34.2)	19 (22.3)	41 (31.06)
Total	150	61	41	76	85	132

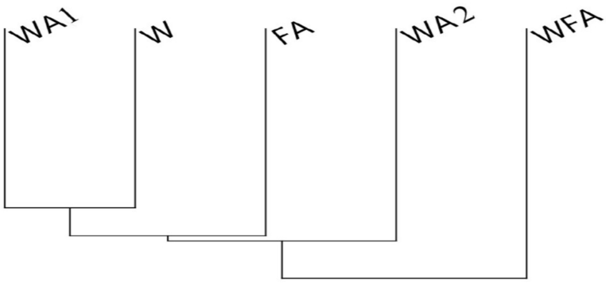

Fig. 9. Hierarchical cluster analysis of similarity in species composition among the five studied plots (see text for plot abbreviation details)

DISCUSSION

The concept of habitat patchiness has two aspects. On the one hand, it results in increasing spatial heterogeneity and thus contributes to community stability (Den Boer 1968, Levins and Culver 1971), but on the other hand, patchiness resulting in the fragmentation of a large pristine habitat generally has a negative effect on the former existing community (Villard and Metzger 2014, Hanski 2015). Forest patches, agricultural lands, wetlands (temporary or permanent), and man-made or modified ecosystems all have a mosaic pattern within the landscape. The question of whether the association of certain habitats provides additional benefits to the adjoining communities has not been well studied in tropical Asia, especially in the case of wetland-based habitats (Dudgeon 2003). India is facing a population explosion, and as a consequence the conversion of forests and wetlands for housing, industries and cultivation has become common, conflicting with the sustainability of pristine habitats. The avian community structure of marshland changes after a threshold limit alteration for the habitat (DeLuca *et al.* 2004). The conversion of pristine habitats into rice fields and adjacent secondary habitats results in increased abundance of 64 bird species at the expense of 45 bird species that existed in the former undisturbed habitat (Sundar and Subramanya 2010).

West Bengal, which is the fourth most populated state in India and ninth in the world, faced population growth of 13.8% with a density of 1,028 km^2 during the years 2001-2011 (Census of West Bengal and Kolkata 2011). The continuous wetland along the sides of the River Ganges was disrupted by human settlement, growing industries, developing fishery industries, and cultivated lands. The area of wetland was reduced by 52% in Haryana, India between 1970 and 2000 (Sundar *et al.* 2015). Our study has shown that wetland or marshland alone is less diverse, but if there are agricultural lands in the vicinity, the mosaic pattern thus created increases the diversity of bird species. While agricultural expansion certainly affects the community composition of a former habitat that previously consisted mainly of forests (Newbold *et al.* 2015), it does support rich faunal diversity and can play a critical role in future conservation management (Wright *et al.* 2012, Sutcliffe *et al.* 2015). The combination of diffuse secondary forests with agricultural fields (FA) when present beside human settlements seems to increase the dominance of some bird species, most of which have the capability to exploit all sorts of habitats, thereby reducing diversity. Intensification of rice cultivation in a natural woodland habitat increases many common species of birds (Parasharya *et al.* 2006) while at the same time threatening numerous endemic species (Gaston 1984, Rahamani and Soni 1997). *FA*, the site most distant from the Hooghly River and an intensely cultivated field, can be categorized as a multi-crop cultivation field. Agricultural intensity and crop composition determine the biodiversity of agricultural fields (Fahrig 2013, Cunningham *et al.* 2013). Lands with intensive crop production are less diverse (Tryjanowski *et al.* 2011, Durán *et al.* 2014). An agricultural land configuration, for example, increases the patchiness of the landscape and is thus more suitable for species that can exploit two or more adjacent habitats (Perfecto *et al.* 2008, Fahrig *et al.* 2011). On the other hand, if agricultural lands become larger, resulting in smaller patches of natural habitats, the diversity of specialist species that used to live in the natural habitat may decline (Devictor *et al.* 2008). Our data reveal that the habitat features and the nature of human exploitation of a temporary wetland can determine avifaunal diversity. If we compare *WA1* and *WA2*, plot *WA1* contains private pisciculture fields where the water level can be artificially controlled, independently of the seasonal hydrological cycle, and nutrients are provided artificially as well. Such human-made altered habitats show low species diversity compared to *WA2*. *WA2* is essentially a wetland with a natural irrigation canal connected to the Hooghly River, and contains wetland-based agricultural fields where only paddy is cultivated once a year. With this low level of human-mediated disturbances and crop composition, it shows fairly high diversity of birds (Colwell and Dodd 1995). Rice is established as a crop to increase diversity in Asia (Maeda 2001, Sundar and Subramanya 2010). The hierarchical cluster analysis showed marshland (*W*) and wetland-associated fisheries (*WA1*) to be very similar in the bird assemblages, both showing higher dominance and evenness than the other plots with different regimes. *WA2* is the next most similar plot type, but with less dominance. Hence marshland alone is not very diverse in terms of avifauna. The addition of water bodies changes the scenario somewhat without changing other aspects, such as dominance and overall species composition. A wetland containing an irrigational canal and rice fields unquestionably changes community composition in a positive direction.

Sundar and Kittur (2013) have observed 99 bird species in a wetland-associated agricultural landscape in North India, which is thought to be the most diverse of any wetland-associated habitat patch in South Asia. Private fish farms receiving government subsidies have become a growing business in India, which is believed to decrease bird abundance and diversity (Chand Gupta and Kaushik 2012). Detailed long term study is required to determine the impact of these artificial water bodies located in unprotected wetlands (Chester and Robson 2013).

The average abundance value determines species rarity and abundance itself. This explains that wetland birds have higher average abundance than rest of the four plots. *WA1* is second after *W* with respect to average abundance. The Shannon *J'* index also established that *W* (*J'* – 0.863) and *WA1* (J' – 0.813) were the most homogenous in community composition. Numbers of rare species, however, did not vary greatly among plots, with the wetland and *WA1* showing fewer rare species than the others. On average, approximately 73% of species were found to be rare in all plots studied. These included Black-headed Ibis (*Threskiornis melanocephalus*), a near-threatened species, and Indian Spotted Eagle (*Aquila hastata*), a vulnerable species, in *FA* and *WFA*, respectively. There are still over 13,000 species of birds on Earth, but unfortunately one of eight bird species has become globally threatened. Alarmingly, we have lost 161 species of birds in the last 500 years (HBW and BirdLife International 2017, BirdLife International 2018). India has 96 threatened species and 55 endemic species (IUCN 2017). Checklist preparation and avian taxonomy have become increasingly important, as many global case study reports show that many bird species and their unique habitats have been completely wiped out only because they were mistakenly treated as conspecific to a closely related extant cousin (BirdLife International 2018). An estimated 10% of bird diversity has been ignored due to taxonomic error. The IUCN Red List Index (RLI) reveals a steep decline in the bird population in the years 1988-2016, while the Wild Bird Index has shown a massive decline in the population of farmland birds in Europe since 1980 (Donald *et al*. 2006).

In one of the five plots we found 48 species considered unique for that habitat, although there are many species known to be much more widespread than our observations might suggest (authors' personal observations). These include Cotton Teal (*Nettapus coromandelianus*), Black-headed Ibis (*Threskiornis melanocephalus*), Cinnamon Bittern (*Ixobrychus cinnamomeus*), Grey Heron (*Ardea cinerea*), most raptors, Common Hoopoe (*Upupa epops epops*), Blue-tailed Bee-eater (*Merops philippinus*), Red-rumped Swallow (*Cecropis daurica*), Oriental Skylark (*Alauda gulgula*), and Pale-billed Flowerpecker (*Dicaeum erythrorhynchos*). This problem arose due to time-bound sampling and the counting method we used. During our survey we found Glossy Ibis as an abundant species in some of the locations, but this finding could be highly biased. Glossy ibises are winter visitors and their roosting and feeding locations are random (Rasmussen and Anderton 2012). Most activity is in large flocks, so during counting the flock was considered as a whole. Very few flocks enter the Gangetic plains and are nomadic to the region studied (Ali and Ripley 1980). During the first week of April we encountered a large number of western yellow wagtails (*Motacilla flava*) and citrine wagtails (*Motacilla citreola citreola*) in *WFA*. This is due to their flocking behaviour, which occurs for a few days before their return migration. Many species are encountered in low frequency due to their elusive habits, but they may not be as rare as they seem. The five study plots were of different size; in particular, plot *W* was smaller than the others. As *W* was a perennial marshland, most of its area was inaccessible. Although we measured indices based on relative abundance, as the species number and frequencies were highly biased, the calculated indices were also affected to some extent. Penetration and visibility through reed grasses are two common problems encountered in marshland studies, and this may have contributed to the lack of rare species in our data. A long-term assessment for marshland is thus required to establish the uniqueness of its species composition. The study was conducted during the day, so obviously nocturnal birds such as bitterns, night herons, owls and nightjars were encountered less frequently. Many species may be rare or even absent in the data simply because they were not encountered in the areas around the transect line or point during the period of observation.

During our sampling study we identified five winter migrants among the 25 generalist species showing the lowest fidelity to any particular habitat. White Wagtail (*Motacilla alba*), Citrine Wagtail (*Motacilla c. citreola*) and Western Yellow Wagtail (*Motacilla flava*) were abundant in three, two, and one plot, respectively.Wood Sandpiper (*Tringa glareola*) is abundant in WFA and WA 2 and Brown Shrike (*Lanius cristatus cristatus*) is relatively rare among the habitats. WFA also plays a major role in holding the migratory species (77.08 %) followed by WA 2 (50%). The 14 migratory species that specifically exploited *WFA* included Indian Cuckoo (*Cuculus micropterus*), Black-headed Cuckooshrike (*Lalage melanoptera*), Ashy Drongo (*Edolius leucophaeus*), Black-naped Oriole (*Oriolus chinensis diffusus*), Greenish Warbler (*Phylloscopus trochiloides viridanus*), Green-crowned Warbler (*Seicercus burkii*), Verditer Flycatcher (*Eumyias thalassinus*), and Blue-throated Flycatcher (*Cyornis rubeculoides*), which are exclusive forest species only found in woodland forests (authors' personal observation) in India. The presence of habitat-sensitive, migratory forest species in an urban area depends upon the native forest space (Dale 2018). Eurasian Wigeon (*Mareca penelope*), Little Ringed Plover (*Charadrius dubius curonicus*), Common Greenshank (*Tringa nebularia*), Green Sandpiper (*Tringa ochropus*), and Little Stint (*Ereunetes minutus*) are among the seven exclusive migrant species found in *WA2*, and these normally prefer to exploit river-associated wetland habitats in the Indo-Gangetic Plain (authors' personal observation). Thus *WFA* and *WA2*, due to the inclusion of forest and riverine systems in their respective plots, became important for sustaining exclusive migratory species. The foraging guild composition over the area shows the dominance of carnivores and omnivores. Dominance of carnivores is a by-product of agricultural intensification on the Indian Subcontinent (Sundar and Subramanya 2010). The proportion of insectivores in *WFA* was greater (24.2%) than in the other plots, as many of the insectivores were found exclusively in the continuous forest patch inclu- ded in this plot. These are the Indian Cuckoo (*Cuculus micropterus*), Plaintive Cuckoo (*Cacomantis merulinus*), Large-tailed Nightjar (*Caprimulgus macrurus*), Blue-tailed Bee-eater (*Merops philippinus*), White-throated Fantail (*Rhipidura albicollis*), Black-naped Blue Monarch (*Hypothymis azurea*), Greenish Warbler (*Phylloscopus trochiloides viridanus*), Green-crowned Warbler (*Seicercus burkii*), Verditer Flycatcher (*Eumyias thalassinus*), and Blue-throated Flycatcher (*Cyornis ru-*

beculoides). Dominance of insectivores has also been seen in studies conducted in Sub-Himalayan broadleaf forests (Chatterjee *et al.* 2013).

Four of the plots, *WA1*, *FA*, *WA2* and *WFA*, have multiple adjoining blocks of different habitats. These plots unquestionably have distinct margins or ecotones, the transition between two dissimilar ecosystems. The impact of the ecotone is fairly prominent in bird community studies (Odum 1958, Sisk and Margules 1993). We have two clear boundaries between forest and wetland (*WFA* plot) and between secondary forest and agricultural land (*FA* plot). The margin between the wetland and agricultural block of both *WA1* and *WA2* has a narrow treeline or grass line demarcating the two blocks. Among the 150 species identified, we examine the ecotone effect by considering 74 species with at least a 40% encounter rate in any of the four plots (Baker *et al.* 2002). Among these, 18 species are found in the forested block of plot *WFA*, the secondary patchy forest within the human habitation block (plot *FA*), and the treeline between the wetland and agricultural field of plots *WA1* and *WA2*. These are Yellow-footed Green Pigeon (*Treron p. phoenicopterus*), Lineated Barbet (*Megalaima lineata*), Blue-throated Barbet (*Megalaima asiatica*), Black-rumped Goldenback (*Dinopium benghalense*), Golden Oriole (*Oriolus kundoo*), Black-hooded Oriole (*Oriolus xanthornus*), Rufous Treepie (*Dendrocitta vagabunda*), Cinereous Tit (*Parus cinereus*), Jungle Babbler (*Turdoides striata*), Oriental Magpie Robin (*Copsychus saularis*), Asian Koel (*Eudynamys scolopaceus*), Rose-ringed Parakeet (*Psittacula krameri*), Spotted Owlet (*Athene brama*), Blyth's Reed Warbler (*Acrocephalus dumetorum*), Red-throated Flycatcher (*Ficedula albicilla*), Purple-rumped Sunbird (*Leptocoma zeylonica*), Purple Sunbird (*Cinnyris asiaticus*), and Bronzed Drongo (*Chaptia aenea*). Plots *WA1* and *WA2* undoubtedly gained some additional species due to the ecotonal vegetation. Four species, Little Cormorant (*Microcarbo niger*), Indian Shag (*Phalacrocorax fuscicollis*), Stork-billed Kingfisher (*Pelargopsis capensis*), and Common Kingfisher (*Alcedo atthis*), are found in the wetland blocks of plot *WA* and/or around the waterbodies and canals in the human-dominated patchy forest of plot *FA*. A single species, Pheasant-tailed Jacana (*Hydrophasianus chirurgus*), in the wetland block of *WA2* and seven species in the wetland block of *WA1*, i.e. Little Grebe (*Tachybaptus ruficollis*), Grey Heron (*Ardea cinerea*), Common Greenshank (*Tringa nebularia*), Green Sandpiper (*Tringa ochropus*), Lesser Pied Kingfisher (*Ceryle rudis*), Indian Reed Warbler (*Acrocephalus stentoreus brunnescens*), and Siberian Rubythroat (*Calliope calliope*), are wetland species. Twenty-six species were found to exploit both the wetland and agricultural block of *WFA*, *WA* and/or *FA*. Seventeen species were found to be ecotone-neutral species, as they were found in all types of blocks studied. House sparrow (*Passer domesticus*) was found in the agricultural block of *FA* and not in any other block, although this type of habitat is very common near human settlements. No species was found that was observed by other authors to be ecotone-specific (Sisk and Margules 1993, Baker *et al.* 2002).

It can be concluded from our data that the combination of temporary wetlands with light cultivation activity and an adjacent forest strip (*WFA*) away from human settlement provides the greatest diversity and the lowest abundance. Conservation of healthy forest patches is an important requirement to maintain high species diversity and migratory species assemblages. Low-intensity farming and distance from human settlement may result in such relatively rich diversity (Sutcliffe *et al*. 2015). The Sarus Crane, a globally threatened species, prefers wetlands for breeding in the vicinity of cultivation fields, especially rice, and avoids human-mediated disturbances (KS Gopi 2009). The intensified farming and increasing human settlement in *FA* increases species dominance but also decreases the proportion of insectivores, which cannot be sustained in severely fragmented vegetation patches. Fish farms within the wetland did not alter community composition as much as we expected in our comparison of *WA1* and *W*, but a detailed long-term assessment of marshland is required to observe the effect of this habitat alteration. Species diversity increases with increasing habitat complexity, and two or more adjoining habitats obviously provide broader niches for species, including some specialists, to thrive (Remsen and Parker 1983, Jullien and Thiollay 1996, Laska 1997). Our study gives a rough description of habitat heterogeneity in the area. Avifaunal diversity increases with habitat heterogeneity, which is evident from the comparison of species dominance and evenness in the five sites.

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APPENDIX

Species account. The percentage of relative abundance is given for each species in respective plots and based on the average species abundance value; abundant species are marked in bold; migratory species are designated with their mode of migration in the migration status column: WV – Winter visitor, TM – Two- season migrant, BV – Breeding visitor, SM – Spring migrant; others are resident and not designated. Birds are divided into six foraging guilds: Ph-Cr, Cr, Om, Gr, In and Fg, as described in the text.

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Order: Anseriformes							
Anatidae							
Lesser Whistling-duck (*Dendrocygna javanica*)		×	×	1.13	**9.27**	0.26	Ph-Cr
Cotton Teal (*Nettapus coromandelianus*)		×	×	×	0.13	×	Ph-Cr
Eurasian Wigeon (*Mareca penelope*)	WV	×	×	×	0.1	×	Ph-Cr
Order: Podicipitiformes							
Podicipedidae							
Little Grebe (*Tachybaptus ruficollis*)		×	×	×	0.29	×	Cr
Order: Ciconiiformes							
Ciconiidae							
Asian Openbill *(Anastomus oscitans)*		**10.2**	**2.84**	1.24	**3.18**	**7.06**	Cr
Threskiornithidae							
Black-headed Ibis (*Threskiornis melanocephalus*)	WV	×	×	0.22	×	×	Cr.
Glossy Ibis (*Plegadis falcinellus*)	WV	×	×	1.19	×	**1.09**	Cr
Ardeidae							
Yellow Bittern (*Ixobrychus sinensis*)		×	×	×	0.03	0.01	Cr
Cinnamon Bittern (*Ixobrychus cinnamomeus*)					0.03		Cr
Black Bittern (*Dupetor flavicollis*)		0.11	0.47	×	×	0.04	Cr
Black-crowned Night Heron (*Nycticorax nycticorax*)		×	×	0.06	0.03	0.06	Cr
Indian Pond-heron (*Ardeola grayii*)		**6.91**	1.9	**3.62**	**3.89**	**3.31**	Cr

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Grey Heron (*Ardea cinerea*)		×	×	×	×	**1.3**	Cr
Purple Heron (*Ardea purpurea*)	WV	×	0.23	0.06	0.21	0.01	Cr
Eastern Cattle Egret (*Bubulcus coromandus*)		**5.55**	1.9	**3.45**	**3.52**	**5.82**	In
Great Egret (*Egretta alba*)		0.11	×	×	1	0.22	Cr
Intermediate Egret (*Egretta intermedia*)		**3.62**	×	×	0.9	0.71	Cr
Little Egret (*Egretta garzetta*)		**3.28**	×	0.17	1.01	**0.89**	Cr
Order: Pelecaniformes							
Phalacrocoracidae							
Little Cormorant (*Microcarbo niger*)		0.9	0.23	0.62	0.6	**1.16**	Cr
Indian Shag (*Phalacrocorax fuscicollis*)		0.9	×	0.79	0.15	**1.44**	Cr
Order: Falconiformes							
Falconidae							
Common Kestrel (*Falco tinnunculus*)	WV	0.05	×	×	×	0.02	Cr
Peregrine Falcon (*Falco peregrinus calidus*)	WV	×	×	×	×	0.01	Cr
Accipitridae							
Black-winged Kite (*Elanus caeruleus*)		×	0.47	×	×	0.02	Cr
Black Kite (*Milvus migrans migrans/govinda*)		0.11	0.95	0.17	0.13	0.35	Om
Oriental Honey Buzzard (*Pernis ptilorhynchus*)		×	×	×	×	0.06	Cr
Crested Serpent-eagle (*Spilornis cheela*)		×	×	×	×	0.01	Cr
Western Marsh Harrier (*Circus aeruginosus*)	WV	×	×	×	×	0.02	Cr
Shikra (*Accipiter badius*)		×	×	0.11	×	0.14	Cr
Indian Spotted Eagle (*Aquila hastata*)		×	×	×	×	0.01	Cr
Booted Eagle (*Hieraaetus pennatus*)	WV	×	×	×	0.08	×	Cr
Changeable Hawk Eagle (*Nisaetus limnaeetus*)		×	×	0.05	×	0.01	Cr
Order: Gruiformes							
Turnicidae							
Barred Buttonquail (*Turnix suscitator*)		×	×	0.05	×	×	Gr

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Rallidae							
White-breasted Waterhen (*Amaurornis phoenicurus*)		1.87	0.95	0.45	0.34	0.47	Ph-Cr
Watercock (*Gallicrex cinerea*)		×	×	0.56	×	0.19	Ph-Cr
Eurasian Coot (*Fulica atra*)		×	×	×	×	0.01	Ph-Cr
Order: Charadriiformes							
Jacanidae							
Pheasant-tailed Jacana (*Hydrophasianus chirurgus*)		0.73	×	0.05	×	0.01	Ph-Cr
Bronze-winged Jacana (*Metopidius indicus*)		×	2.62	0.4	0.55	0.63	Ph-Cr
Charadriidae							
Grey-headed Lapwing (*Vanellus cinereus*)	WV	**4.25**	×	×	**1.19**	**2.41**	Cr
Red-Wattled Lapwing (*Vanellus indicus*)		**2.77**	×	**1.92**	**1.4**	**2.88**	Cr
Little Ringed Plover (*Charadrius dubius curonicus*)	WV	×	×	×	0.02	×	Cr
Rostratulidae							
Greater Painted Snipe (*Rostratula benghalensis*)		×	×	×	0.08	0.01	Ph-Cr
Scolopacidae							
Common Snipe (*Gallinago gallinago*)	WV	0.34	×	×	0.5	0.06	Cr
Common Greenshank (*Tringa nebularia*)	WV	×	×	×	0.16	×	Cr
Green Sandpiper (*Tringa ochropus*)	WV	×	×	×	0.3446	×	Cr
Wood Sandpiper (*Tringa glareola*)	WV	1.64	1.19	0.11	**4.4**	**1.01**	Cr
Common Sandpiper (*Actitis hypoleucos*)	WV	×	×	0.28	0.92	0.08	Cr
Little Stint (*Ereunetes minutus*)	WV				0.05		Cr
Glareolidae							
Oriental Pratincole (*Glareola maldivarum*)	SM	×	×	×	0.31	×	In
Order: Columbiformes							
Columbidae							
Rock Pigeon (*Columba livia*)		0.85	**8.6**	**3.9**	0.66	**1.81**	Gr

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Eurasian Collared-dove (*Streptopelia decaocto*)		0.73	1.91	0.73	**2.94**	**1.07**	Gr
Red Collared Dove (*Streptopelia tranquebarica*)		×	×	×	×	0.01	Gr
Spotted Dove (*Spilopelia chinensis*)		**3.57**	**4.53**	4.13	**2.62**	**2.29**	Gr
Yellow-footed Green Pigeon (*Treron p. phoenicopterus*)		×	×	**2.38**	0.39	**0.81**	Fg
Order: Psittaciformes							
Psittacidae							
Rose-ringed Parakeet (*Psittacula krameri*)		×	×	0.28	0.58	0.12	Fg
Plum-headed Parakeet (*Psittacula cyanocephala*)		×	×	×	0.1	×	Fg
Order: Cuculiformes							
Cuculidae							
Jacobin Cuckoo (*Clamator jacobinus*)	B	0.11	×	0.11	×	0.02	In
Common Hawk-cuckoo (*Hierococcyx varius*)		×	×	0.11	×	0.01	Om
Indian Cuckoo (*Cuculus micropterus*)	B	×	×	×	×	0.01	In
Plaintive Cuckoo (*Cacomantis merulinus*)		×	×	×	×	0.03	In
Asian Koel (*Eudynamys scolopaceus*)		0.11	×	0.79	0.02	0.11	Om
Greater Coucal (*Centropus sinensis*)		0.05	0.23	0.4	0.02	0.23	Cr
Order: Strigiformes							
Tytonidae							
Barn Owl (*Tyto alba*)		×	×	×	×	0.01	Cr
Strigidae							
Indian Scops Owl (Otus bakkamoena)		×	×	×	×	0.01	Cr
Spotted Owlet (*Athene brama*)		×	×	0.11	0.08	0.02	Cr
Brown Hawk Owl (*Ninox scutulata*)		×	×	×	×	0.02	Cr
Order: Caprimulgiformes							
Caprimulgidae							
Large-tailed Nightjar (*Caprimulgus macrurus*)		×	×	×	×	0.02	In

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Order: Apodiformes							
Apodidae							
Asian Palm Swift (*Cypsiurus balasiensis*)		**1.75**	**×**	**4.08**	**1.45**	**2.7**	In
Order: Coraciiformes							
Upupidae							
Common Hoopoe (*Upupa epops epops*)	WV	×	×	×	×	0.04	In
Coraciidae							
Indian Roller (*Coracias benghalensis benghalensis*)		0.05	×	×	0.1	0.07	Cr
Alecdinidae							
Stork-billed Kingfisher (*Pelargopsis capensis*)		×	0.47	0.28	0.16	0.04	Cr
White-throated Kingfisher (*Halcyon smyrnensis*)		1.36	2.38	1.07	0.3	**1.14**	Cr
Common Kingfisher (*Alcedo atthis*)		0.11	0.23	0.28	0.26	0.07	Cr
Lesser Pied Kingfisher (*Ceryle rudis*)		×	0.23	×	0.13	0.01	Cr
Meropidae							
Little Green Bee-eater (*Merops orientalis*)		0.28	×	**1.41**	0.55	**1.47**	In
Blue-tailed Bee- eater (*Merops philippinus*)	B	×	×	×	×	0.08	In
Order: Piciformes							
Megalaimidae							
Lineated Barbet (*Megalaima lineata*)		0.11	×	0.17	0.08	0.38	Fg
Blue-throated Barbet (*Megalaima asiatica*)		0.05	×	0.8	0.23	0.14	Fg
Coppersmith Barbet (*Xantholaema haemacephala*)		×	×	0.56	0.1	0.03	Fg
Picidae							
Eurasian Wryneck (*Jynx torquilla*)	WV	×	0.23	×	0.02	0.01	In
Rufous Woodpecker (*Micropternus brachyurus*)		×	×	0.17	×	×	Om
Fulvous-breasted Pied Woodpecker (*Dendrocopos macei*)		×	×	×	×	0.01	Om
Streak-throated Woodpecker (*Picus xanthopygaeus*)		×	×	×	0.02	0.01	Om

Family	Migration Status	Plot					Foraging Guild
		WA1	**W**	**FA**	**WA2**	**WFA**	
Black-rumped Goldenback (*Dinopium benghalense*)		0.11	×	0.28	0.02	0.2	Om
Greater Flameback (*Chrysocolaptes guttacristatus*)		×	×	×	×	0.03	Om
Order: Passeriformes							
Artamidae							
Ashy Woodswallow (*Artamus fuscus*)		×	×	0.05	×	0.11	In
Campephagidae							
Black-headed Cuckooshrike (*Lalage melanoptera*)	TM	×	×	×	×	0.01	Om
Aegithinidae							
Common Iora (*Aegithina tiphia*)		×	×	0.17	×	0.04	In
Laniidae							
Brown Shrike (*Lanius cristatus cristatus*)	WV	0.05	1.43	0.11	0.1	0.17	Cr
'Black headed' Long-tailed Shrike (*Lanius schach tricolor*)	WV	×	0.95	×	0.08	0.24	Cr
Grey-backed Shrike (*Lanius tephronotus*)	WV	×	×	0.05	×	0.02	Cr
Dicruridae							
Black Drongo (*Edolius macrocercus*)		**5.1**	**5.25**	**3.5**	0.92	**2.88**	Om
Ashy Drongo (*Edolius leucophaeus*)	WV	×	×	×	×	0.05	Om
Bronzed Drongo (*Chaptia aenea*)		0.05	×	0.45	×	0.12	Om
Oriolidae							
Indian Golden Oriole (*Oriolus kundoo*)	WV	0.06	×	0.06	×	0.07	Om
Black-naped Oriole (*Oriolus chinensis diffusus*)	WV	×	×	×	×	0.06	Om
Black-hooded Oriole (*Oriolus xanthornus*)		0.22	×	0.8	0.23	0.7	Om
Rhipiduridae							
White-throated Fantail (*Rhipidura albicollis*)		×	×	×	×	0.03	In
Monarchidae							
Asian Paradise Flycatcher (*Terpsiphone paradisi*)		×	×	0.34	0.02	0.04	In
Black-naped Blue Monarch (*Hypothymis azurea*)		×	×	×	×	0.08	In

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Corvidae							
Rufous Treepie (*Dendrocitta vagabunda*)		0.9	×	**1.58**	0.21	**1.5**	Om
Indian Jungle Crow (*Corvus [macrorhynchos] culminatus*)		×	×	0.22	×	0.11	Om
House Crow (*Corvus splendens*)		**7.59**	**13.84**	**18.35**	3.44	**3.97**	Om
Paridae							
Cinereous Tit (*Parus cinereus*)		0.45	×	0.11	×	0.51	Om
Hirundinidae							
Streak-throated Swallow (*Petrochelidon fluvicola*)	WV	×	×	×	0.08	0.01	In
Barn Swallow (*Hirundo rustica*)	WV	**1.92**		**12.01**	**11.93**	**9.56**	In
Red-rumped Swallow (*Cecropis daurica*)	WV	×	×	×	×	0.0396	In
Alaudidae							
Bengal Bushlark (*Mirafra assamica*)		1.36	**3.58**	0.11	0.29	0.4	Om
Oriental Skylark (*Alauda gulgula*)		×	×	×	×	0.09	Om
Pycnonotidae							
Red-whiskered Bulbul (*Pycnonotus jocosus*)		×	×	×	0.23	0.29	Om
Red-vented Bulbul (*Pycnonotus cafer*)		0.96	**2.86**	**3.28**	1.08	**2.3**	Om
Cisticolidae							
Yellow-bellied Prinia (*Prinia flaviventris*)		0.11	1.67	×	×	0.18	In
Plain Prinia (*Prinia inornata*)		**1.98**	**7.16**	0.11	0.31	**1.14**	In
Zitting Cisticola (*Cisticola juncidis*)		0.56	**4.29**	×	0.26	0.14	In
Common Tailorbird (*Orthotomus sutorius*)		1.02	0.71	1.13	0.82	**2.02**	In
Acrocephalidae							
Indian Reed Warbler (*Acrocephalus stentoreus brunnescens*)	WV	0.05	×	×	0.23	0.06	In
Paddyfield Warbler (*Acrocephalus agricola*)	TM	×	0.23	×	0.05	×	In
Blyth's Reed Warbler (*Acrocephalus dumetorum*)	WV	×	×	×	0.55	0.01	In

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Phylloscopidae							
Greenish Warbler (*Phylloscopus trochiloides viridanus*)	WV	×	×	×	×	0.01	In
Green-crowned Warbler (*Seicercus burkii*)	WV	×	×	×	×	0.01	In
Timaliidae							
Jungle Babbler (*Turdoides striata*)		**1.53**	**×**	**3.34**	**1.19**	**2.6**	Om
Zosteropidae							
Oriental White-eye (*Zosterops palpebrosus*)		×	×	×	×	0.01	Om
Sturnidae							
Jungle Myna (*Acridotheres fuscus*)		×	×	0.17	×	0.02	Om
Common Myna (*Acridotheres tristis*)		**4.7**	1.43	**4.98**	**5.17**	**2.88**	Om
Asian Pied Starling (*Gracupica contra*)		**11.4**	**8.83**	**4.41**	**5.75**	**5.78**	Om
Grey-headed Starling (*Sturnia malabarica*)		0.56	×	0.34	0.3	0.6	Om
Rosy Starling (*Pastor roseus*)	WV	×	×	×	×	0.01	Om
Turdidae							
Orange-headed Thrush (*Geokichla citrina*)		×	×	0.05	×	0.01	Om
Muscicapidae							
Bluethroat (*Luscinia svecica svecica*)	WV	0.56	0.95	×	×	0.01	In
Siberian Rubythroat (*Calliope calliope*)	WV	×	×	×	0.13	×	In
Oriental Magpie-robin (*Copsychus saularis*)		×	×	0.68	×	0.28	Om
Siberian Stonechat (*Saxicola maurus maurus/indicus*)	WV	0.45	4.53	×	×	0.08	In
Red-throated Flycatcher (*Ficedula albicilla*)	WV	×	×	0.06	0.13	0.56	In
Verditer Flycatcher (*Eumyias thalassinus*)	WV	×	×	×	×	0.02	In
Blue-throated Flycatcher (*Cyornis rubeculoides*)	TM	×	×	×	×	0.02	In
Dicaeidae							
Pale-billed Flowerpecker (*Dicaeum erythrorhynchos*)		×	×	×	×	0.07	Om

Family	Migration Status	Plot					Foraging Guild
		WA1	W	FA	WA2	WFA	
Nectariniidae							
Purple-rumped Sunbird (*Leptocoma zeylonica*)		0.22	×	**1.41**	×	0.56	Om
Purple Sunbird (*Cinnyris asiaticus*)		0.34	×	0.34	×	**0.81**	Om
Passeridae							
House Sparrow (*Passer domesticus*)		×	×	**1.87**	×	0.31	Om
Ploceidae							
Black-breasted Weaver (*Ploceus benghalensis*)		×	×	×	**5.3**	**2.42**	Om
Indian Baya Weaver (*Ploceus philippinus philippinus*)		×	×	×	**7.71**	0.28	Om
Fringillidae							
Indian Silverbill (*Euodice malabarica*)		0.56	**2.86**	×	×	0.32	Om
Red Avadavat (*Amandava amandava*)		×	1.2	×	×	0.03	Gr
Scaly-breasted Munia (*Lonchura punctulata*)		0.34	×	0.28	0.34	**1.3**	Gr
Tricoloured Munia (*Lonchura malaca*)		×	0.47	×	0.13	×	Gr
Motacillidae							
Western Yellow Wagtail (*Motacilla flava*)	WV	1.13	0.11	0.11	0.84	**3.31**	In
Citrine Wagtail (*Motacilla citreola citreola*)	WV	0.05	2.38	0.05	**4.16**	**3.27**	Cr
Grey Wagtail (*Motacilla cinerea*)	WV	×	×	0.17	×	×	Cr
White Wagtail (*Motacilla alba*)	WV	**1.92**	0.47	0.34	**1.61**	**1.45**	Om
Paddyfield Pipit (*Anthus rufulus*)		1.07	2.14	×	0.45	0.18	Om
Olive-backed Pipit (*Anthus hodgsoni hodgsoni*)		×	×	×	×	0.23	Om