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continued on the back inside cover

Cover: *Pipistrellus tenuis* recorded during the small mammalian fauna study, Manipur, India. © Uttam Saikia.

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COMMUNICATION

Effects of wind farm on land bird composition at Kachchh District, Gujarat, India

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Abstract: Bird assemblages in wind farm areas tend to change during the construction and operational phases, causing significant impacts in addition to collision mortality. Most existing studies on this issue are reported from North America and Europe, and it is largely under reported in Asian countries. We assessed patterns of bird assemblage in a wind farm and control areas in Kachchh, India, from October 2012 to May 2014, using point count method (79 sampling points with a 50 m radius). We recorded 54 species of land birds, mainly passerines. Species richness and diversity were higher in the control site, and the abundance of most passerine species was lower in the wind farm area, although the abundance of larks and wheatears was higher in the wind farm areas. Species composition was significantly different in both the sites. This difference is attributed to the presence of wind turbines and a difference in land use pattern.

Keywords: Bird sensitivity, collision mortality. displacement, habitat loss, renewable energy.

Tamil: காற்றாலைகள் அமைக்கும் போதும் அதற்கு பிறகும், அப்பகுதியில் உள்ள பறவைகளின் எண்ணிக்கையும் இன அமைப்பும் மாறுகிறது . இதுகுறித்தான ஆய்வுகள் பெரும்பாலாக வட அமெரிக்கா மற்றும் ஐரோப்பிய நாடுகளிலே நடத்தப்பட்டுள்ளன, ஆசிய பகுதிகளில் இதுகுறித்த ஆய்வுகள் மிகக் குறைவாகும் . அக்டோபர் 2012 முதல் ஏப்ரல் 2014 வரை, புள்ளி எண்ணிக்கை முறையைப் பயன்படுத்தி (50 மீ ஆரம் கொண்ட 79 மாதிரிப் புள்ளிகள்) இந்தியாவின் கட்ச் மாவட்டத்தில் உள்ள ஒரு காற்றாலை பகுதியில் இதுகுறித்து ஆய்வு நடத்தினோம். அதில் காற்றாலை உள்ள இடங்களிலும், அதற்கு அருகாமையில், காற்றாலை இல்லாத இடங்களிலும் உள்ள பறவை இனங்களின் தன்மையை ஆய்ந்தோம். இங்கு , 54 வகையான நிலப்பறவைகளை பதிவு செய்தோம். இவற்றில் பல பறவைகள் காற்றாலை இல்லாத பகுதிகளில் அதிகமான எண்ணிக்கையில் காணப்பட்டது. ஓரிரு வானம்பாடி மற்றும் புதர்ச்சிட்டு குருவியினங்கள் மட்டும் காற்றாலை பகுதியில் அதிக எண்ணிக்கையில் காணப்பட்டது. பொதுவாக இந்த இரு பகுதிகளின் இன அமைப்பில் குறிப்பிடத்தக்க மாற்றங்கள் உள்ளதை அறிந்தோம். இம்மாற்றதிற்கு காற்றாலைகளும் , நிலப்பரப்பில் ஏற்படுத்தப்படும் மாற்றங்களுமே காரணமாக உள்ளது.

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Author contributions: PRA conceived the idea. SRK and AMSA involved in the field data collection. All three were involved in writing the manuscript.

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INTRODUCTION

Wind energy is promoted worldwide (GWEC 2017), and the negative impacts of wind farms, especially on wildlife, have been well documented (Leddy et al. 1999; Villegas-Patraca et al. 2012). The major impacts of turbines on avifauna include: 1) Bird mortality and injury from collisions with rotating wind turbine blades, 2) Displacement of birds from the windfarm area due to the disturbance caused by the installation and operation of wind turbines, 3) Disruption of bird movements due to barrier effects (Drewitt & Langston 2006). Injuries to birds can also be caused by collisions with towers, nacelles and associated infrastructure of wind farms. (Drewitt & Langston 2006).

The displacement effect of wind farms on avifaunal assemblages have been extensively studied (Leddy et al. 1999; Pearce-higgins et al. 2009; Villegas-Patraca et al. 2012; Campedelli et al. 2014). For instance, the effects of wind turbines on grassland passerines of southwestern Minnesota, USA, were studied by Leddy et al. (1999), and it was found that grasslands located away from wind turbines have richer bird assemblages. Similarly, a study by Villegas-Patraca et al. (2012) in Mexico found high species richness of birds in surrounding croplands and secondary forests, intermediate richness values at 200 m from the turbines, and lowest species richness beneath turbines. A long-term study by Shaffer & Buhl (2016) using BACI (Before After Control Impact) design showed displacement in seven of nine species studied, while one species was unaffected, and one species exhibited attraction to the turbine site. They also found displacement and attraction were generally within 100 m. At times, the displacement extended even beyond 300 m. Garcia et al. (2015) studied breeding passerines in wind farms and reported that 12 out of 15 species decreased during the construction phase, and 10 of them showed an apparent increase in the population after the construction of the Valbormida wind farm in Italy.

In India, wind energy contributes about ten percent of total power generation (MNRE 2022). India is the 4th largest producer of wind energy, with an installed capacity of 39.25 GW (as of 31 March 2021 (MNRE 2022)). Existing studies mostly pertain to Europe and USA, whereas there is limited knowledge on this aspect from India (Pande et al. 2013; Arun et al. 2014; Thaker et al. 2018; Kumar et al. 2019). This study is an attempt to understand and evaluate the impacts of wind farms on the diversity and assemblage of terrestrial birds in the Kachchh region of Gujarat.

METHODS

Study Area

The study was conducted at the Samakhiali region (23.25–23.18 °N to 70.05–70.64 °E) in Kachchh district of Gujarat (Figure 1). The study area is close to the Little Rann of Kachchh, an Important Bird and Biodiversity Area (IBA) (Rahmani et al. 2016). The region is a 'stopover' and 'wintering' site for birds using the Central Asian Flyway and African Eurasian Flyway (Balachandran et al. 2018). The high winds and flat terrain close to the sea make it a suitable location for wind power generation (NIWE 2022) and have resulted in a large number of wind turbines coming up in this area. The region is generally dry and arid, dotted with many wetlands. Barren lands with the invasive tree species *Prosopis juliflora* predominate the landscape, with a small number of rain-fed agricultural fields. Most of the rainfall is received from July to September. Our total study area covers around 200 km^2. There are 200 turbines in the turbine site area that were installed since 2003. Most of the turbines are of 1.8 MW capacity with 95 m hub height and a rotor diameter of 100 m.

Bird Surveys

The study area was divided into a turbine site (~120 km^2) and a control site (~80 km^2) where there are no turbines. Land use pattern in the turbine site was similar to that of the control site except for the presence of turbines. The most suitable area available with similar vegetation and land use pattern to that of the turbine site was selected as the control site. We used the point count method with a 50 m radius for bird surveys as the area had more open habitats (Petit et al. 1995; Ralph et al. 1995). A total of 79 sampling points were fixed: 48 points in the turbine site and 31 points in the control site. All control points were at least 1 km away from the nearest wind turbine. To avoid repetitive counts of the same birds, we maintained a minimum 500 m distance between each sampling point. Every single count was conducted for 10 min duration and counted all the land birds except raptors. All bird surveys were carried out from 0600 h to 0900 h.

We conducted our survey from October 2012 to May 2014. The sampling period was divided as summer (March–September) and winter (October–February) for analysis. In winter, many species of migratory birds visited the area. Among eight temporal replications, five visits were made in winter and three in summer. We could not do eight replications in all 79 points, but a minimum of three replications were done at each

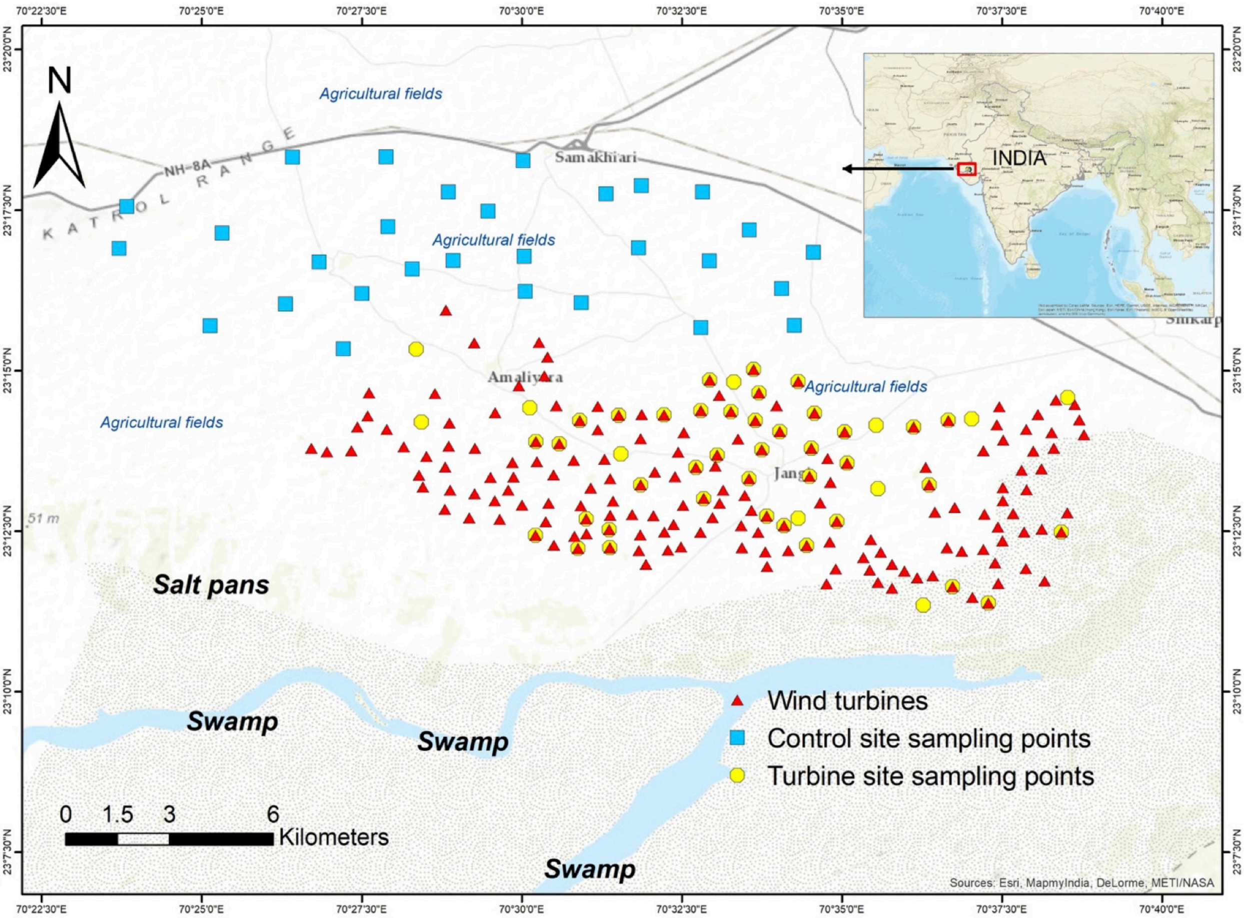

Figure 1. Location of the wind farm at Samakhiali, Gujarat, India.

point, with a total of 430 individual point counts during the study period. Identification of birds was done using standard guides (Ali & Ripley 2001; Grimmett et al. 2011), and the nomenclature of birds was followed according to del Hoyo et al. (2014).

Statistical Analysis

The bird assemblages were compared between sites and seasons using statistical measures. Relative abundance (Fr_i = number of individuals of i^{th} species / Total number of individual) of each species for all four assemblages, i.e., control and turbine sites both in summer and winter was calculated. The species with Fr_i >0.05 are considered as dominant species. This analysis was done to determine the dominant species (abundant) in each assemblage following Battisti et al. (2014). Species richness (S), Simpson diversity index, Simpson's measure of evenness, and Shannon diversity index (H') for each assemblage were also calculated. The effects of difference in sampling efforts are very minimal as the minimum samples required for representing the population have been drawn (completeness of sampling effort was tested by plotting species accumulation curves plotted using Estimate S) (Figure 2). Each assemblage's sampling points were pooled separately, and averages of each sampling point were used for estimating the diversity.

To test the spatial autocorrelation between sampling points, we performed the Mantel test with 9,999 permutations (Hammer et al. 2001). For this test we used the Euclidean similarity measure based on the geographical distance between sampling points, and Bray Curtis similarity measure based on the species composition of birds. To assess the difference in overall species composition between control and turbine sites, Non-metric Multi-Dimensional Scaling (NMDS) analysis followed by one-way PERMANOVA (NPMANOVA) test, both using Bray-Curtis similarity measure, was performed. NMDS ordinates sampling sites by their similarity in species composition. This algorithm attempts to place the data points in a two-dimensional coordinate system to preserve the ranked

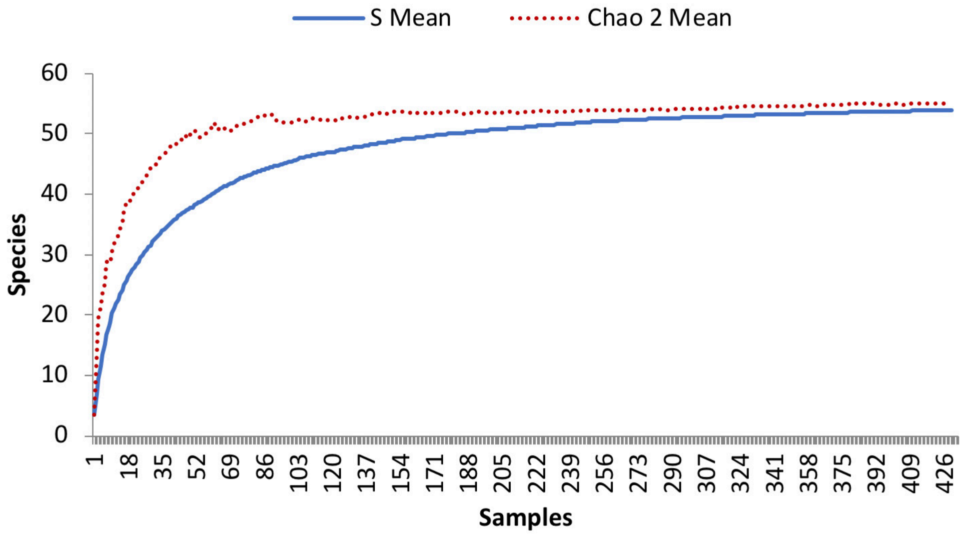

Figure 2. Speies accumulation curve shows the completeness of sampling efforts.

differences. PERMANOVA (Non-Parametric MANOVA, also known as NPMANOVA) is a non-parametric test of significant differences between two or more groups based on distance measures (Anderson et al. 2013). PERMANOVA calculates an F value in analogy with ANOVA. The significance is computed by permutation of group membership, with 9,999 replicates. To test the species most affected by wind turbines, the difference in mean abundance between control and turbine site for species with >20 sightings (including both sites) were tested using independent t-test. In order to overcome the differences in sampling efforts, the mean abundance of each sampling point was calculated and used to analyze the difference in abundance. Data for summer and winter were tested separately. Analyses such as PERMANOVA, Mantel test, and Diversity indices calculation were performed using 'Past 3.10' (Hammer et al. 2001). NMDS was performed using 'CANOCO-5' (ter Braak & Šmilauer 2012).

The Generalized Linear Models (GLM) was used to infer which factors among habitat variables influences bird species richness and diversity. Two GLMs were run, one with point-wise species richness (cumulative species richness at each sampling point) as the response variable and another with point-wise diversity index (Shannon diversity index). The explanatory variable included turbine variables such as the density of turbines (hereafter referred as 'turbine density') and distance to the nearest wind turbine from sampling points. The turbine density (number of turbines within one km radius) for each sampling point was calculated using QGIS 2.10.1. Among the variables, 'turbine density' and 'distance to the nearest turbine' strongly correlated with each other; hence only turbine density was included in the analysis. Habitat variables include normalised differential vegetation index (NDVI), distance (in km) from each sampling point to the nearest freshwater body (ponds, lakes, and check dams), human habitation, road (tarred), and salt marsh (salt pans).

NDVI for each sampling point corresponding to the months in which bird samplings were done was extracted from Google Earth Engine, a repository for geospatial data (this NDVI is calculated using Landsat-7 Satellite Imagery with 30 m resolution). NDVI is measured every 32 days. For this analysis, only values for the month in which the bird survey was conducted were extracted and the mean of this was included in the analysis (Mean of 8 temporal replications). NDVI is considered as the measure of plant productivity and a major determinant of bird species richness (Ding et al. 2006; Qian et al. 2009).

Precipitation for all the sampling points was collected from Worldclim global climatic data repository (http://www.worldclim.org/bioclim) (Fick & Hijmans 2017*).* Precipitation data is an average of 50 years from 1950 to 2000. The spatial resolution of this data is 30 seconds (~1 sq km). Though it may not be accurate and predicted based on the available historical data, this data set is readily available and widely used by biologists. This data is used to see whether precipitation plays any role in changing bird assemblage between sampling points.

Other variables such as distance (in km) from each sampling point to the nearest freshwater body (Ponds, Lakes, and Check dams), human habitation, road (tarred), and salt marsh (salt pans) were measured using Google Earth 2013 imagery & QGIS 2.10.1.

RESULTS

We recorded 54 species of birds belonging to 25 families, among which Muscicapidae had a maximum number of species (8 species, 34%), followed by Cisticolidae (6 species, 24%) (Table 1). Forty species were residents to the area, 12 were winter migrants, and two were passage migrants. All 54 species were categorized as Least Concern by IUCN (2018), however, 51 species were categorized as Schedule IV as per the Indian Wildlife Protection Act 1972. We recorded 53 species in the control site and 46 in the turbine site (Table 1). Species such as Greater Coucal, Dusky Crag Martin, Chestnut-shouldered Petronia, Brahminy Starling, Sykes Warbler, Black Redstart, and Blue throat were recorded only in the control site, however, the frequency of their sightings was very low (<4). The Great Grey Shrike was recorded only in the turbine site during the survey period (with 11 sightings).

In summer, species such as Rock Dove, Grey-breasted Prinia, House Sparrow, Red-vented Bulbul, and Rosy Starling were dominant (Fr_i >0.05) in control site and Ashy-crowned Sparrow Lark, Eurasian Collared Dove, and Rosy Starling were dominant in turbine site. In winter, House Sparrow, Rosy Starling, and Common Babbler were dominant in the control site and Ashy-crowned Sparrow Lark, House Sparrow and Rosy Starling were dominant in the turbine site (Table 1).

There was no significant spatial autocorrelation of species composition between the sampling points (Mantle test: R = 0.028; p = 0.204). Simpson Diversity and Evenness index values were lower in turbine site than in the control site in all two seasons (Table 2).

The first two axis of NMDS plot for summer explained 73.27 % of variation and showed distinction between the control and the turbine sampling points. Similarly, the NMDS plot for winter explained 71.3 % of variation, and it followed a similar pattern as that of summer (Figure 3). Overall (two seasons combined), species composition in both the sites were significantly different (PERMANOVA: F = 6.531; p = 0.001) and this pattern existed across the seasons (summer: F = 6.721; p = 0.001 and winter: F = 5.883; p = 0.001). In summer, 11 species had more than 20 sightings, and its abundance tested for significant differences between control and turbine sites. Among these, Asian Koel, Common Babbler, Eurasian Collared-dove, Grey-breasted Prinia, House Crow, House Sparrow, Indian Robin, Laughing Dove, Purple Sunbird, and Red-vented Bulbul had significantly lower abundance in the turbine site (Table 3). In winter, 15 species of birds were recorded with more than 20 sightings wherein, Black Drongo, Eurasian Collared-dove, Grey-breasted Prinia, House Crow, House Sparrow, Indian Robin, Laughing Dove, Purple Sunbird, and Red-rumped Swallow had lower abundance in the turbine site. However, birds like Rufous-tailed Lark and Variable Wheatear had a higher abundance in the turbine site (Table 3).

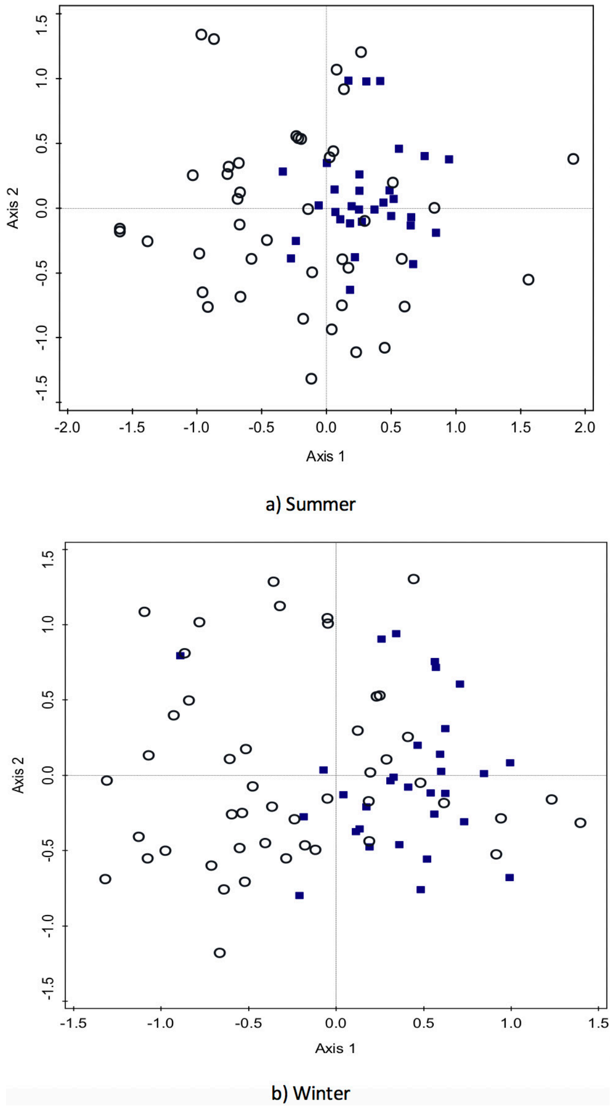

Figure 3a and b. Non-metric MDS plots show overlapping of control and turbine sampling points (Circles: Turbine site sampling points; Squares: Control sampling points). The plot is created using Bray Curtis dissimilarity distance with 499 permutations.

The GLM model with plot wise species richness as response variable was significant (F = 15.39, p = 0.001). The species richness was positively influenced by NDVI

Table 1. List of bird species recorded and their relative abundance at the control and turbine sites in summer and winter.

	Family name	Common name	Scientific name	Relative abundance in summer		Relative abundance in winter	
				Control (n = 35)	Turbine (n = 25)	Control (n = 47)	Turbine (n = 43)
1	Alaudidae	Ashy-crowned Sparrow-Lark	*Eremopterix grisea*	0.029	**0.080**	0.047	**0.153**
2	Alaudidae	Crested Lark	*Galerida cristata*	-	0.008	0.002	0.008
3	Alaudidae	Rufous-tailed Lark	*Ammomanes phoenicura*	0.005	0.014	0.014	0.046
4	Alcedinidae	White-breasted Kingfisher	*Halcyon smyrnensis*	0.016	-	0.019	0.007
5	Columbidae	Rock Dove	*Columba livia*	**0.114**	0.002	0.045	0.019
6	Columbidae	Eurasian Collared-dove	*Streptopelia decaocto*	0.040	**0.057**	0.045	0.033
7	Columbidae	Laughing Dove	*Spilopelia senegalensis*	0.043	0.040	0.035	0.020
8	Columbidae	Red Turtle Dove	*Streptopelia tranquebarica*	0.005	0.028	0.005	0.009
9	Coraciidae	European Roller**	*Coracias garrulus*	0.000	0.000	0.004	0.005
10	Coraciidae	Indian Roller	*Coracias benghalensis*	0.001	0.000	0.002	0.001
11	Corvidae	House Crow	*Corvus splendens*	0.044	0.024	0.028	0.014
12	Cuculidae	Asian Koel	*Eudynamys scolopaceus*	0.033	0.004	0.010	0.003
13	Cuculidae	Greater Coucal	*Centropus sinensis*	0.003	0.000	0.000	0.000
14	Cisticolidae	Ashy Prinia	*Prinia socialis*	0.000	0.000	0.002	0.003
15	Cisticolidae	Common Tailorbird	*Orthotomus sutorius*	0.005	0.000	0.003	0.002
16	Cisticolidae	Grey-breasted Prinia	*Prinia hodgsonii*	**0.053**	0.025	0.040	0.013
17	Cisticolidae	Jungle Prinia	*Prinia sylvatica*	0.002	0.000	0.014	0.004
18	Cisticolidae	Plain Prinia	*Prinia inornata*	0.000	0.000	0.002	0.001
19	Cisticolidae	Rufous-fronted Prinia	*Prinia buchanani*	0.003	0.000	0.001	0.000
20	Dicruridae	Black Drongo	*Dicrurus macrocercus*	0.000	0.001	0.005	0.009
21	Estrildidae	Indian Silverbill	*Euodice malabarica*	0.004	0.038	0.010	0.000
22	Hirundinidae	Barn Swallow*	*Hirundo rustica*	0.004	0.000	0.017	0.005
23	Hirundinidae	Dusky Crag-martin	*Ptyonoprogne concolor*	0.003	0.000	0.000	0.000
24	Hirundinidae	Red-rumped Swallow	*Cecropis daurica*	0.019	0.003	0.017	0.008
25	Hirundinidae	Wire-tailed Swallow	*Hirundo smithii*	0.000	0.001	0.003	0.000
26	Laniidae	Bay-backed Shrike	*Lanius vittatus*	0.000	0.000	0.007	0.003
27	Laniidae	Long-tailed Shrike	*Lanius schach*	0.000	0.000	0.003	0.005
28	Laniidae	Isabelline Shrike*	*Lanius isabellinus*	0.000	0.000	0.011	0.004
29	Laniidae	Great Grey Shrike	*Lanius meridionalis*	0.000	0.000	0.000	0.007
30	Meropidae	Asian Green Bee-eater	*Merops orientalis*	0.021	0.014	0.024	0.036
31	Motacillidae	Paddyfield Pipit	*Anthus rufulus*	0.003	0.000	0.008	0.004
32	Nectariniidae	Purple Sunbird	*Cinnyris asiaticus*	0.039	0.028	0.030	0.011
33	Passeridae	House Sparrow	*Passer domesticus*	**0.066**	0.010	**0.189**	**0.098**
34	Passeridae	Chestnut-shouldered Petronia	*Petronia xanthocollis*	0.001	0.000	0.000	0.000
35	Phasianidae	Grey Francolin	*Francolinus pondicerianus*	0.008	0.033	0.000	0.011
36	Phasianidae	Indian Peafowl	*Pavo cristatus*	0.021	0.003	0.000	0.000
37	Ploceidae	Baya Weaver	*Ploceus philippinus*	0.013	0.008	0.004	0.000
38	Psittacidae	Rose-ringed Parakeet	*Psittacula krameri*	0.017	0.000	0.002	0.002
39	Pycnonotidae	Red-vented Bulbul	*Pycnonotus cafer*	**0.071**	0.049	0.039	0.036
40	Sturnidae	Brahminy Starling	*Sturnia pagadarum*	0.004	0.000	0.002	0.000
41	Sturnidae	Rosy Starling*	*Pastor roseus*	**0.190**	**0.410**	**0.145**	**0.249**
42	Sylviidae	Hume's Whitethroat**	*Sylvia althaea*	0.002	0.000	0.000	0.001

	Family name	Common name	Scientific name	Relative abundance in summer		Relative abundance in winter	
				Control (n = 35)	Turbine (n = 25)	Control (n = 47)	Turbine (n = 43)
43	Sylviidae	Lesser White-throat*	*Sylvia curruca*	0.000	0.000	0.006	0.001
44	Acrocephalidae	Sykes's Warbler*	*Iduna rama*	0.000	0.000	0.003	0.000
45	Leiothrichidae	Common Babbler	*Turdoides caudatus*	**0.074**	0.071	**0.088**	0.114
46	Muscicapidae	Black Redstart*	*Phoenicurus ochruros*	0.000	0.000	0.001	0.000
47	Muscicapidae	Bluethroat*	*Luscinia svecica*	0.000	0.000	0.005	0.000
48	Muscicapidae	Common Stonechat *	*Saxicola torquatus*	0.000	0.000	0.003	0.002
49	Muscicapidae	Desert Wheatear*	*Oenanthe deserti*	0.000	0.000	0.002	0.003
50	Muscicapidae	Indian Robin	*Saxicoloides fulicatus*	0.041	0.046	0.035	0.024
51	Muscicapidae	Isabelline Wheatear*	*Oenanthe isabellina*	0.000	0.000	0.008	0.005
52	Muscicapidae	Pied Bush Chat*	*Saxicola caprata*	0.005	0.000	0.009	0.002
53	Muscicapidae	Variable Wheatear*	*Oenanthe picata*	0.000	0.001	0.004	0.020
54	Upupidae	Eurasian Hoopoe	*Upupa epops*	0.000	0.000	0.005	0.002

*—winter visitor | **—Passage migrant. The bold letter indicates the dominant species (with relative abundance >0.05).

Table 2. Diversity indices of bird assemblages of control and turbine sites in winter and summer. Sampling effort, i.e., number of independent point counts surveyed for each season, is given in parenthesis. Annual samplings were distributed as two visits in 2012 (winter: 2 visits), four in 2013 (summer: 2; winter: 2) and two in 2014 (summer: 1; winter: 1).

Diversity indices	Summer (155)		Winter (275)		Overall (430)	
	Control (84)	Turbine (71)	Control (111)	Turbine (164)	Control (195)	Turbine (235)
Species richness	35	25	47	42	53	46
Simpson diversity index	0.920	0.805	0.919	0.883	0.921	0.896
Simpson's evenness	0.359	0.205	0.263	0.204	0.241	0.210
Shannon diversity index	2.892	2.299	3.02	2.687	3.077	2.819

(t = 3.74, p = 0.001) and negatively influenced by turbine density (t = -2.65, p = 0.01) (Table 4). The model with Shannon diversity index as response variable was also significant (F = 3.33, p = 0.008). Shannon diversity was positively influenced by NDVI (t = 2.25, p = 0.028).

DISCUSSION

The study area supports typical land birds of a semi-arid region of India. We detected evidence for the effects of wind turbines on bird assemblage at Kachchh, Gujarat. The overall species richness and diversity were higher at the control site than the turbine site in both seasons. The majority of the species showed lower abundance in the wind farm area; however, a few species had higher abundance in the wind farm. A similar pattern of low species richness in wind farm in comparison to adjacent areas was also reported by Villegas-Patraca et al. (2012) in Mexico; they found increasing species richness as one moves away from the base of the wind turbine.

Species richness as an indicator of habitat quality can be misleading, since degraded habitats can be occupied by generalist species, thereby increasing the overall species richness (Magurran 2016). Hence, it is recommended to consider species composition to reflect habitat quality and habitat degradation (Magurran 2016). In the present study species composition of birds was different in turbine and control areas. Generalist species like Common Babbler, Rosy Starling, and House Sparrow were present abundantly in both sites. However, certain species of larks and wheatear, including Variable Wheatear, Ashy-crowned Sparrow-Lark, Crested Lark, and Rufous-tailed Lark were found to be more abundant in turbine area. Generally, the abundance of most species except the above-mentioned larks was low in the turbine area.

Species which prefer trees and shrubs, such as Asian

Table 3. Difference in the abundance of species with more than 20 sightings between control and turbine site in summer and winter. Compared using independent t test; (n = 79 sampling points).

Common name	Scientific name	Summer		Winter	
		t- value	p-value	t- value	p-value
Asian Koel	*Eudynamys scolopaceus*	4.530	**0.000**	-	-
Ashy-crowned Sparrow-Lark	*Eremopterix grisea*	-0.355	0.724	-1.944	0.056
Black Drongo	*Dicrurus macrocercus*	-	-	2.343	**0.022**
Common Babbler	*Turdoides caudate*	3.577	**0.001**	0.661	0.511
Eurasian Collared-dove	*Streptopelia decaocto*	2.064	**0.042**	2.867	**0.005**
Asian Green Bee-eater	*Merops orientalis*			0.017	0.987
Grey-breasted Prinia	*Prinia hodgsonii*	5.804	**0.000**	4.991	**0.000**
House Crow	*Corvus splendens*	3.972	**0.000**	3.639	**0.000**
House Sparrow	*Passer domesticus*	4.651	**0.000**	2.573	**0.012**
Indian Robin	*Saxicoloides fulicatus*	3.212	**0.002**	3.307	**0.001**
Laughing Dove	*Spilopelia senegalensis*	3.634	**0.001**	3.482	**0.001**
Purple Sunbird	*Cinnyris asiaticus*	4.707	**0.000**	4.737	**0.000**
Red-rumped Swallow	*Cecropis daurica*	-	-	2.047	**0.044**
Red-vented Bulbul	*Pycnonotus cafer*	2.970	**0.004**	1.862	0.066
Rufous-tailed Lark	*Ammomanes phoenicura*	-	-	-2.056	**0.043**
Variable Wheatear*	*Oenanthe picata*	-	-	**-3.049**	**0.003**

*—winter visitors. Bold letters indicate species with a significant difference.

Table 4. GLM Models explaining the influence of turbine and habitat variables on bird assemblage. (Model 1 = Species Richness as response variable; Model 2 = Shannon diversity as response variable). Bold letters indicate P value <0.05.

Variables	Model 1: Species Richness				Model 2: Shannon Diversity			
	AIC = 481.2, F = 15.399, p = 0.001				AIC = 156.93, F = 3.33, p = 0.008			
	beta	SE	t value	p -value	beta	SE	t value	p value
Intercept	7.848	2.141	3.670	0.000	11.010	4.765	2.310	**0.024**
Turbine Density (in 1 km^2 radius)	-0.060	0.022	-2.650	**0.010**	-0.036	0.043	-0.850	0.400
Distance to Human Habitation (km)	-0.025	0.041	-0.610	0.541	0.061	0.084	0.730	0.470
Distance to Ponds/Lakes (km)	-0.099	0.062	-1.610	0.112	-0.186	0.130	-1.430	0.157
Distance to Road (km)	-0.019	0.035	-0.550	0.585	-0.039	0.080	-0.490	0.629
NDVI	3.220	0.861	3.740	**0.000**	4.393	1.955	2.250	**0.028**
Distance to Salt Pans (km)	0.020	0.017	1.180	0.244	0.019	0.036	0.540	0.592
Precipitation	-0.014	0.005	-2.650	**0.010**	-0.023	0.011	-2.010	**0.048**

Koel, Grey-breasted Prinia, Indian Robin, Red-vented Bulbul, and Purple Sunbird were found in low numbers in the turbine site. This was evident from the individual 't' test conducted for differences in the abundance of individual species . Most species tested had a lower abundance in the wind farm area. Similar avoidance of wind turbine by a majority of birds was also reported from Mexico by Villegas-Patraca et al. (2012).

GLM analysis revealed that the diversity of birds was influenced by turbine presence along with NDVI. From the above pattern, the regular clearing of vegetation which alters the habitat in the turbine site may be one of the reasons for lower abundance of shrub preferring birds in the turbine area, along with the disturbance caused by the turbine's presence. This may be the reason for the high abundance of birds preferring open habitats like Larks and Wheatears in turbine site. The increased number of Larks and Wheatears in turbine sites might be due to the alteration of the landscape during the development of wind farms. The supply roads, trenches, and cleared open areas below the turbine which had not existed before, maybe the causatives for this change (Hötker 2006). The negative influence of precipitation on bird richness as per GLM might be a random result as the study area is small the effect of variation in rainfall on bird community may not be strong.

Our study confirms that there is an effect of wind turbines and its related habitat alteration on the birds of the Kachchh region is evident. A combined effect of presence of turbine, alteration of habitats by clearing vegetation and disturbances has contributed to this low abundance of bird species. Although attempts were made to correct the bias due to difference in the sampling size, to certain extant habitat, there is a possibility that this bias might have some influence on the results.

India has varied geographical and climatic conditions, and results from the semi-arid landscape at Gujarat may not apply to other habitats. The wind farms located in Western Ghats and East-coast may have different impacts on birds based on varied bird composition of those areas. In order to reduce the carbon footprint, the Indian government provides huge subsidies for establishing renewable energy production; especially for wind energy (MNRE 2022) and with a very few studies on the impact of wind farms on birds in India, it is difficult to measure the magnitude of its impacts on bird populations and their habitats. The findings of this study can be taken as an indicative result that some species tend to avoid turbine areas; further, a more comprehensive study is required to confirm our results by looking into the various other relevant variables such as predator-prey interaction, vegetation diversity and nesting success of birds in wind farms must be studied to gain a better understanding of the dynamics of bird assemblages in the wind farms.

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