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REVIEW

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REVIEW

Hazards of wind turbines on avifauna - a preliminary appraisal within the Indian context

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Abstract: Wind farms are substantial sources of renewable energy in India; however, their spread across the country potentially present new hazards to local and migratory birds. This study explored the risk of electrocution and collision of birds with wind turbines close to eco-sensitive zones in India, including Bakkhali, a UNESCO World Heritage site. Geographic information system and remote sensing technology were used. The results indicate vulnerability of local bird species such as barn owl, Indian Scops Owl, Blue Rock Pigeon, Asian Koel, House Crow, Common Sandpiper, Common Snipe, Ruddy Shelduck, Lesser Whistling Duck, Cattle Egret, Great Egret, and Pond Herons, as well as migratory species such as Bar-headed Goose, Red-crested Pochard, and American Black Duck. Modification of wind turbine design and location were considered determinant factors to reduce risk of bird collisions.

Keywords: Biodiversity, birds, geographic information system, remote sensing, transect chart.

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Author contribution: TS collected the data and has full access to all data used in this study. HD and SS are responsible for data analyses. All authors equally contributed in manuscript writing. AK and SS provided critical inputs on results interpretation, modification, and approved it for submission.

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INTRODUCTION

Wind energy is touted as an eco-friendly and sustainable alternative to fossil fuel (Nazir et al. 2019). As fossil fuel sources are more and more limited, increase in wind energy production has been growing over the last decade (Morinha et al. 2014). The global wind energy council (GWEC) has predicted a 17-fold increase in generation of wind energy by 2030 (Lu et al. 2009). Such expansion in wind energy production poses serious threats to flying vertebrates (Peron et al. 2013; Singh et al. 2015). Birds and bats often collide with rotor blades of wind turbines (WTs) and associated structures such as meteorological towers and power lines (Barclay et al. 2007; Zimmerling et al. 2013; Korner-Nievergelt et al. 2013; Ferreira et al. 2015; Beston et al. 2016; Anoop et al. 2018). Mortality of birds and bats due to such collisions has been frequently reported from the USA, Canada (Johnson 2005; Arnett et al 2008; Loss et al. 2013, Smales et al. 2013; Erickson et al. 2014; Marques et al. 2014), Europe (Bach & Rahmel 2004; Dürr & Bach 2004; Welling et al. 2018), Australia (Hull et al. 2013), New Zealand (Powlesland 2009), India (Pande et al. 2013; Kumar et al. 2019), and many other countries. WTs were initially installed in coastal areas (Larsen & Guillemette 2007; Larsen & Guillemette 2007), then subsequently extended to inland agricultural areas (Rydell et al. 2010) and ecologically sensitive areas such as hills and mountains (Aschwanden et al. 2018).

Several factors have been identified as contributing to collision of birds and bats with WTs. These include morphology of birds, sensorial perception, phonology, behavior, habit richness or abundance, landscape, flight path, food availability, weather, turbine type, lightening, among others (Marques et al. 2014). Hull et al. (2013) identified key morphological, behavioural, and ecological features that make birds prone to collision. These include the ability of birds to detect and avoid moving turbine blades, mode of flight and foraging strategies. Pescador et al. (2019) observed that abundance of potential prey makes predator birds prone to collision with WTs. In an offshore wind park in Denmark, Larsen & Guillemette (2007) observed visibility conditions as a major factor for collision of birds with WTs. Plonczkier & Simms (2012) also pointed out visibility conditions as the major factor for collision and associated mortality of birds at offshore wind farms in England. As a result, nocturnal migrants face a high risk of collision with WTs (Aschwanden et al. 2018). De Lucas et al. (2012) indicated a link between wind conditions, topography, and flight behaviour as factors associated with mortality of griffon vultures within and between wind farms. In Hokkaido, Japan, Kitano et al. (2013) observed highest fatality of birds at the turbines on a costal cliff where the rotor zones of wind turbines overlapped the frequent flight paths of large birds. Pande et al. (2013) used collision index (CI) to measure avian seasonal collision rate due to WT and noted that maximum collision risk with raptors occurred predominantly during monsoon periods. In Germany, Lehnert et al. (2014) observed that both local and migratory bats were vulnerable to WTs, and fatalities varied with age and sex. Studying *Alauda arvensis* in northern Portugal, Morinha et al. (2014) found a sex biased mortality. Mortality of birds and bats was also found to vary with turbine hub height (Everaert et al. 2006; Rothery et al. 2009). Also, the modern wind turbine towers are much taller than in the past, putting more risks to birds and bats (Welling et al. 2018).

In recent articles, wetland birds have been reported as most susceptible to collision with WT in Turkey and Netherlands (Graff et al. 2016; Arikan & Turan 2017). Similar susceptibility of collision of wetland birds with WT near freshwater bodies have been found in Taiwan (Lin 2017). The Black Shag *Phalacrocorax carbo* and Cattle Egret *Bubulcus ibis* are the only species of water birds of New Zealand that often face fatal injury after collision with WT (Powlesland 2009). There is possibility that other species of water birds may also be affected. The IUCN Red List reveals a steady and continuing deterioration; according to the World's birds report 2018, one in eight bird species are threatened with extinction (www.birdlife.org). Therefore, it is necessary to prevent fatalities of birds from WTs**.**

Risk of collision of birds from WTs have not been explored in India aside from sporadic attempts in Gujarat (Kumar et al. 2019) and the Western Ghats (Pande et al. 2013). India is the fourth largest producer of wind energy, with an installed capacity of 32.85GW at the end of 2017. Tamil Nadu, Maharashtra, Gujarat, Rajasthan, Karnataka, and Andhra Pradesh are the leading states in the generation of wind energy in India (Chaurasiya et al. 2019). India has four biodiversity hotspots, namely: (1) the Western Ghats, (2) the eastern Himalaya, (3) the Indo-Burma region, and (4) the Sunda Islands. India is also the home to 12.6% of all avian species found in the world. Huge amount of anthropogenic activities including collision of avifauna with WT, however, have put many birds in India at a high risk of extinction (Chitale et al. 2014). This has forced the necessity to explore risk of collision of avifauna from WT in India. The main objective of this study was to investigate the collision risk of avian species, and loss of habitat due to allocation of WT in India.

METHODS

Study Area

This study considered three geographically distinct locations, namely: (i) Gujarat and its adjoining areas (68.245–75.061^{0}E and 23.770–17.093^{0}N) in the western part of India; (ii) Tamil Nadu and its adjoining areas (76.018–81.967^{0}E and 9.358–17.461^{0}N) in the southern part of India, and (iii) Bakkhali, South 24-Parganas, West Bengal (88.231–88.288^{0}E and 21.511–21.563^{0}N) located in the eastern part of India (location 3). For the first two locations we used secondary data however, we used GIS technique to identify nearby ecologically sensitive areas in these two locations and attempted to explain the collision of birds in these areas. In the third location (Bakkhali), which is situated 125km south of Kolkata in Sunderban Biosphere Reserve (Figure 1), extensive fieldwork was conducted to collect primary data on death and injuries of birds due to collision with WT of Frezerganj Wind Farm, near Bakkhali during the period February 2017 to January 2018. We interacted with local people living around WTs through printed questionnaires, and collected carcasses of 15 bird species from this location. These species included Barn Owl, Indian Scops Owl, Blue Rock Pigeon, Asian Koel, House Crow, Common Sandpiper, Common Snipe, Ruddy Shelduck, Lesser Whistling Duck, Cattle Egret, Great Egret, Indian Pond Heron, Bar-headed Goose, Red-crested Pochard, American Black Duck from this location. WTs present in Bakkhali have been presented in Figure 2.

Remote Sensing and Geographical Information System Techniques

Remote sensing (RS) and geographic information system (GIS) technology were used to identify whether actual positions of WTs caused any obstacle to bird's movement. With the help of RS and GIS technique, it is easy to prepare the map without coming into physical contact with the object under study (Effat 2014). Satellite image of the Indian subcontinent was downloaded from Google Earth Pro followed by georeferencing by GIS (TNTmips) Software. WT locations were identified and digitized on raster map (Wald and Ranchin 1995). GIS map was drawn to establish relationship between WT areas and the bird species of various ecologically sensitive areas such as national park, biosphere reserve, and biodiversity hotspot region. Seasonal wind direction was taken into consideration to assessing the bird migration direction because wind direction sometime influenced their path (Kemp et al. 2010). The map of these ecologically sensitive areas and location of WTs were downloaded and digitized on raster maps of the Indian subcontinent to generate a complete vector map

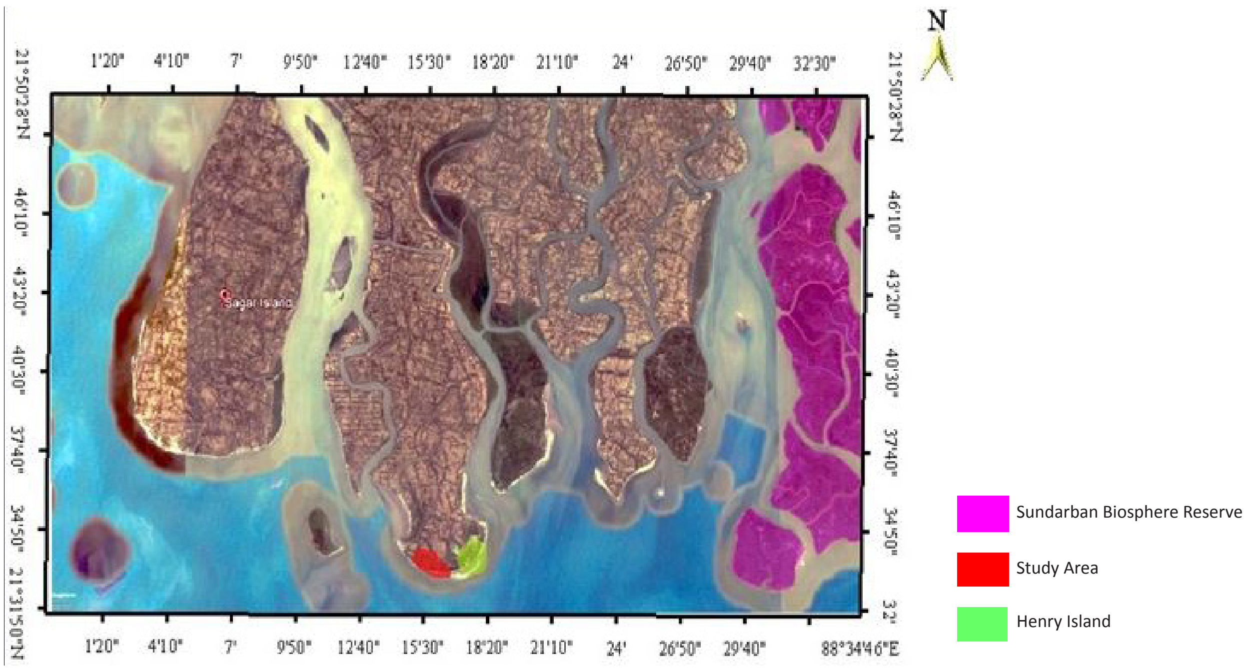

Figure 1. Geographic information system for field study area at Frezerganj Wind Farm, Bakkhali (South 24-Parganas; West Bengal; 87.916–94.051^{0}E and 21.552–25.533^{0}N)

Figure 2. Exact location of wind farms in the study area at Location-3 near Bakhkali (www.google.com/earth/)

of intersection between bird habitat area and location of WTs. B-spline curve (Origin Lab), the natural way to represent a continuous curve from a set of discrete points, was used to represent collision data collected from the Bakkhali (Eilers & Marx 1996; Cao & Wang 2008).

Transect Chart

Transect charts were used to assess collision of bird with WT (Xie et al. 2015; Roeleke et al. 2016; Sivakumar & Ghosh 2017; Tucker et al. 2018). A transect represents a line following a route along which observations are considered. Transect chart is a geographic tool which demonstrates the changes and interdependency of human characteristics on physical object from one place to another (Jcngsma et al. 1989). In this study, we used the line transect method to illustrate a particular gradient or linear pattern along which birds' location and WTs are intersected based on the latitude and longitude of that location. This tool can potentially illustrate collision risk of birds with WTs location (Saha et al. 2019). At first, a GIS map was made for three study areas by incorporating WTs location in that area (TNTmips). Then, latitude, longitude, and altitude were measured of those areas. Altitude was identified from Google Earth Pro. Then horizontal transect lines were drawn between those latitudes and longitudes. From the GIS map location of WTs, national park, biosphere reserve, biodiversity hotspot, and habitat of 15 bird species were transferred to the edge of the screen from one end of transect line to the other. The x-axis represented horizontal distance covered by transects. In this way, we tried to demonstrate whether biosphere reserve, biodiversity hotspots or any national parks are in the area of influence of installed WTs.

RESULTS

Figure 3 represents GIS and RS mapping of seasonal wind movement, WTs locations and key biodiversity areas. It demonstrates that WTs are installed near national parks, biosphere reserves & biodiversity hotspots, and thus can potentially interrupt the natural movement of birds. This figure also identifies the direction of monsoon winds in summer and winter, which fall along the path of movements of some local and migratory birds. Distributions of 15 bird species found in location-3 have been presented in Figure 4. Figures 5a–c present data of collision of birds with WT generated from location 3. These figures reflect seasonal variation in collision. The dead and wounded birds included Barn Owl, Indian Scops Owl, Rock Pigeon, Asian Koel, House Crow, Common Sandpiper, Common Snipe, Great Egret, Ruddy Shelduck, Lesser Whistling Duck, Cattle Egret, Indian Pond Heron, and migratory bird species such as Bar-headed Goose, Red-crested Pochard, and American Black Duck (Table 1). The transect charts were used to visualize the location of WTs along a transect line to inspect whether their loci intersected birds' movement

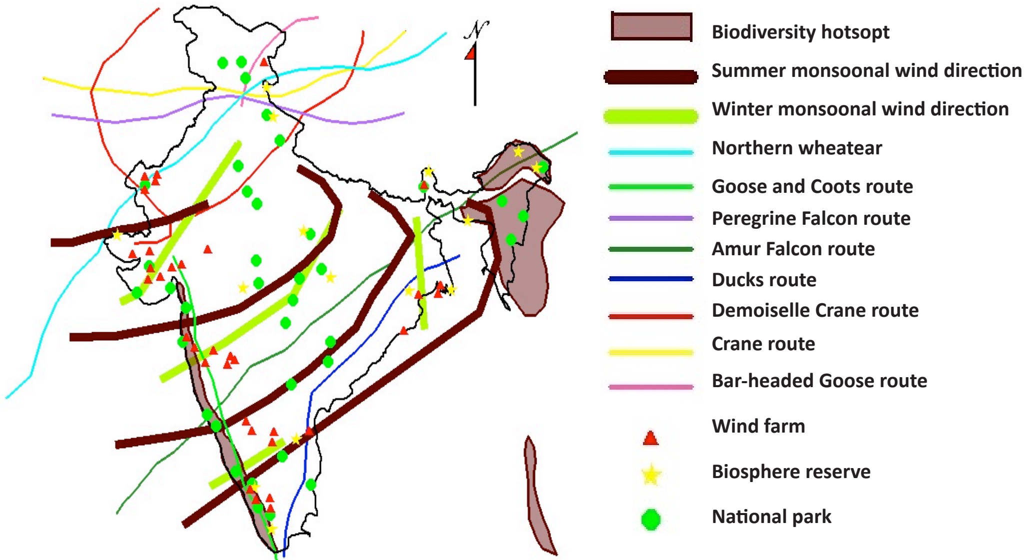

Figure 3. Remote sensing and geographical information system mapping showing the location of biodiversity hotspots, national parks, biosphere reserves, seasonal wind directions, wind farms, and migration rout of some bird species in India (www.microimages.com/products/tntmips. html).

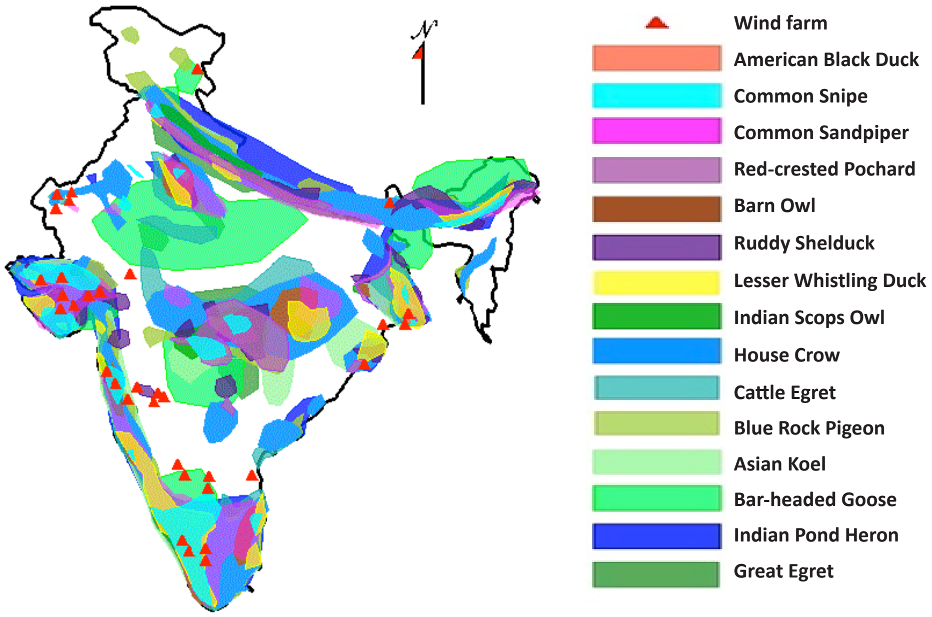

Figure 4. Remote sensing and geographical information system mapping showing the distribution mapping of fifteen bird species considered in this study (https://ebird.org/).

directly in Gujarat (Figure 6a), Tamil Nadu (Figure 6b), and Bakkhali (Figure 6c).

DISCUSSION

The IUCN Red List status of the birds sampled from location-3 (Bakkhali) is listed in Table 1. All these birds belong to IUCN category 'Least Concern'. Bakkhali is also home to Spoon-billed Sandpiper, a 'Critically Endangered' species. Further observations are required to assess if this bird species is vulnerable to WTs installed

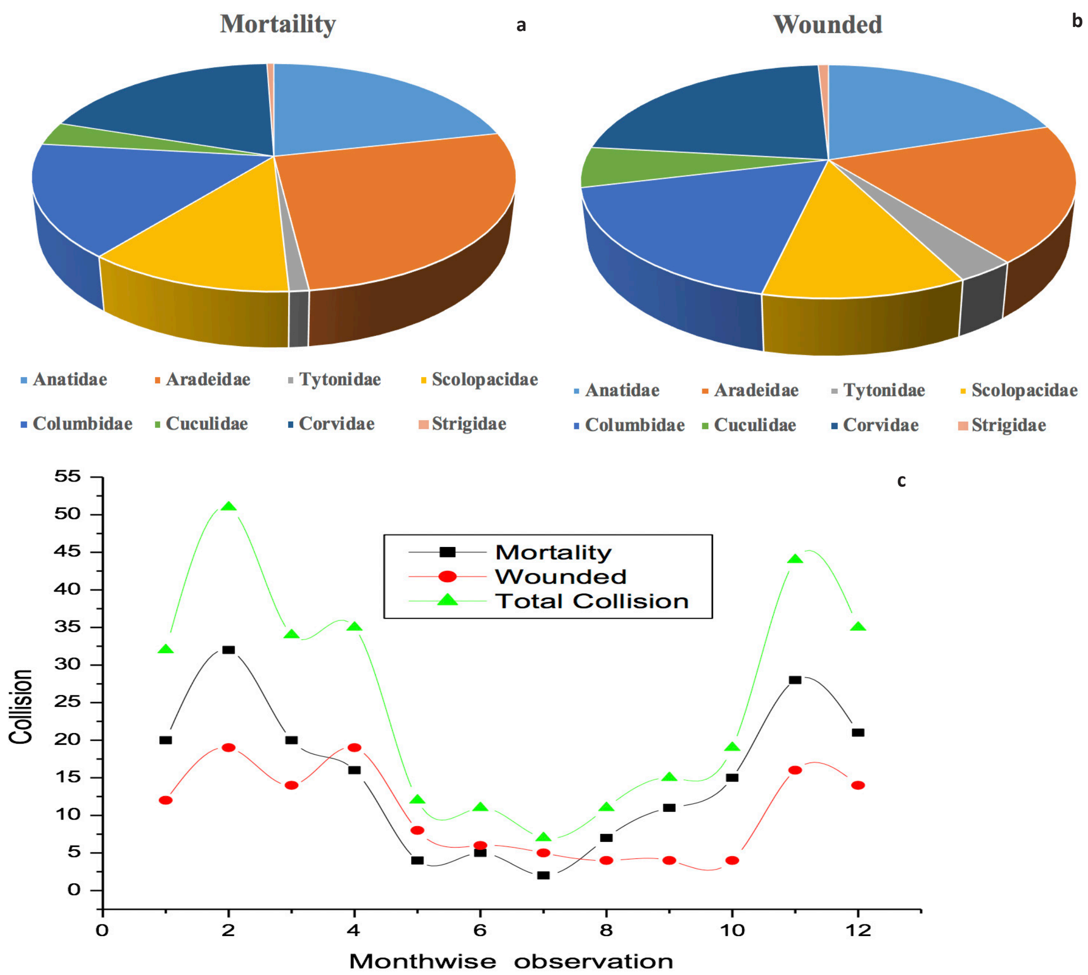

Figure 5. Records of collision of birds near Bakkhali (South 24-Parganas; West Bengal): a—family wise wounded | b—family wise mortality | c—monthwise observation between February 2017 and January 2018.

in this area.

The casualty of birds found in location-3 may be attributed to seasonal variation in concentration of migratory birds as well as seasonal variation in food habits of local birds. The probability of collision of birds with WT, however, cannot be concluded from the raster map alone. This study reveals maximum mortality of Cattle Egret, Indian Pond Heron, and Great Egret (Ardeidae) in location-3 followed by Common Sandpiper, Common Snipe (Scolopacidae), Bar-headed Goose, Red-crested Pochard, Lesser Whistling Duck, American Black Duck, Ruddy Shelduck (Anatidae), Rock Pigeon (Columbidae), and House Crow (Corvidae). Barn Owl, Asian Koel, and Indian Scops Owl were the least affected species of birds. Maximum number of species killed or wounded by WT belonged to the family Anatidae with five species, followed by the family Ardeidae with three species, Scolopacidae with two species, and Tytonodae, Columbidae, Cuculidae, Strigidae & Corvidae with one species each (Table 1, Figure 5a,b).

The birds belonging to the families Ardeidae and Anatidae are mostly water birds (such as Indian Pond Heron) and are abundant in this location. Wetlands of southern part of West Bengal are the preferred habitats for many birds, including the Bar-headed Goose and Red-crested Pochard that migrate annually from trans Himalayan region during December–January (Majumder et al. 2007). There are sporadic evidences from Turkey and Netherlands also that wetland birds are susceptible to collision with WTs (Krigsveld et al. 2009; Arikan et al. 2017), probably because of affinity of the migratory birds to wetlands. Habitat association (Thaxter et al. 2017) and abundance appeared to be key factors behind collision of the birds of the family Ardeidae and Anatidae in Bakkhali.

Kumar et al. (2019) observed several bird species around Kutch District (part of Location-1, Gujarat) between October 2011 and July 2014, and found

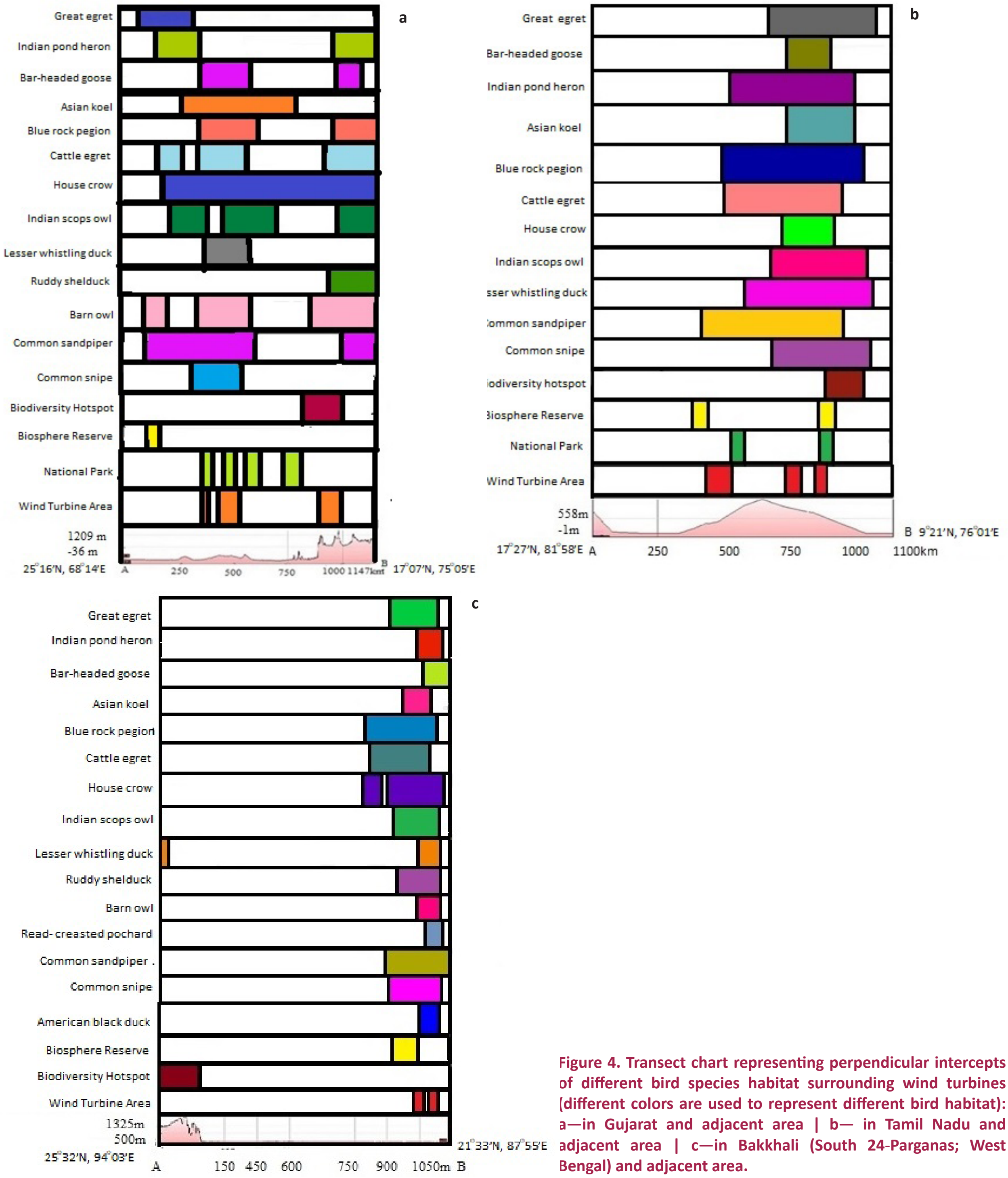

Figure 4. Transect chart representing perpendicular intercepts of different bird species habitat surrounding wind turbines (different colors are used to represent different bird habitat): a—in Gujarat and adjacent area | b— in Tamil Nadu and adjacent area | c—in Bakkhali (South 24-Parganas; West Bengal) and adjacent area.

carcasses of 47 birds belonging to 11 species. Since a few national parks are situated in this area (Figure 3), many more species are at risk from the WTs. Pande et al. (2013) observed 89 species of birds, from July 2008 to June 2010 in Bhambarwadi Wind Farm Plateau in northern Western Ghats, out of which 27 birds were under risk by rotor blades. During this period, the authors found 12 dead birds belonging to seven different species, *viz.*, Black Kite *Milvus migrans*, Bonelli's Eagle *Aquila fasciata*, Changeable Hawk Eagle *Nisaetus cirrhatus*, Red-rumped Swallow *Cecropis daurica*, Dusky Crag-martin *Ptyonoprogne concolor*, Slaty-legged Crake *Rallin aeurizonoides,* and Common Crow. These birds, however, are not depicted in Figures 6a–6c, which

Table 1. IUCN status of the bird species collision found in location -3 (www.iucnredlist.org)

Family	Name	Scientific name	IUCN status
Anatidae	Bar-headed Goose	*Anser indicus*	Least Concern
	Red-crested Pochard	*Netta rufina*	Least Concern
	Lesser Whistling Duck	*Dendrocygna javanica*	Least Concern
	American Black Duck	*Anas rubripes*	Least Concern
	Ruddy Shelduck	*Tadoma ferruginea*	Least Concern
Ardeidae	Cattle Egret	*Bubulcus ibis*	Least Concern
	Indian Pond Heron	*Ardeola grayii*	Least Concern
	Great Egret	*Ardae alba*	Least Concern
Tytonidae	Barn Owl	*Tyto alba*	Least Concern
Strigidae	Indian Scops Owl	*Otus bakkamoena*	Least Concern
Scolopacidae	Common Sandpiper	*Actitis hypoleucos*	Least Concern
	Common Snipe	*Gallinago gallinago*	Least Concern
Columbidae	Rock Pigeon	*Columba livia*	Least Concern
Cuculidae	Asian Koel	*Eudynamys scolopaceus*	Least Concern
Corvidae	House Crow	*Corvus splendens*	Least Concern

consider only 15 birds whose carcasses are recorded from location-3. Western Ghats is a biodiversity hotspot region and is home to many birds, which are vulnerable to collision with WTs installed in this region. Another 'Critically Endangered' species of bird, the Great Indian Bustard (Dasgupta 2017) is found mostly in Rajasthan, a state with high wind energy installations.

In India, more than 95% of the wind power capacity is installed in the two southern states, Tamil Nadu & Karnataka and three western states, Gujarat, Rajasthan & Maharashtra (Chaurasiya et al. 2019). Since many wildlife protected areas are situated in these states, there is possibility of overlap of home range of the local and migratory birds and the WT installations.

4.1 Mitigation Measures

Bose et al. (2018) used ecological niche factor analysis (ENFA) to identify overlaps collision niche between species of birds, which are susceptible to injuries from WTs. Wind energy is a dominant renewable energy source in India, and there is possibility of expansion of the WT installation capacities in many other states including within ecologically sensitive areas. Therefore, it is necessary to develop environmentally sustainable planning at wind turbine installations to prevent collision of birds with WTs. Since birds that migrate during the day have a lower risk of colliding with WTs (Nichols et al. 2018), restriction of WTs during daytime may be an effective measure to reduce collision probabilities. Temporary shutdown during high risk period has also been recommended by a few authors (Marques et al. 2014; May 2015). Visual approaches to alert birds by painting wind turbine blades with conspicuous and contrast colors or using ultraviolet reflective paint on rotor blades for UV-sensitive species and using pulsating lights or other wavelengths may also reduce fatalities (Arnet & May 2016). Although use of bio-acoustic sound and electromagnetic signals have been found effective for some species of birds and bats (Marques et al. 2014; May et al. 2015), effectiveness of radar as a potential measure to deter birds and bats is questionable (Arnett et al. 2008).

CONCLUSIONS

We examined distribution of bird species across India and possibility of their collision with WTs. From digitization on raster maps, this study demonstrates that wind farms in India are located along the ecologically sensitive zones like national parks, biosphere reserves, biodiversity hotspots, and coastal areas. Transect charts ensure the possibility of collision of birds with WTs in these areas. Bakkhali is located in Sundarban Biosphere Reserve, an ecologically sensitive zone and a UNESCO World Heritage site. This study reveals that 12 local and three migratory species of birds in Bakkhali are vulnerable to collision with wind turbines. There is utmost urgency to modify design of wind turbines to save these birds from collision. Further studies are required to assess accurate causes of bird fatalities near wind farms in India, detailed assessment of the most affected local and migratory species of birds, their dependency with other species, and implementation of additional & complementary measures to protect birds from wind turbines. As a future extension, one needs to conduct risk analysis through robust statistical analysis.

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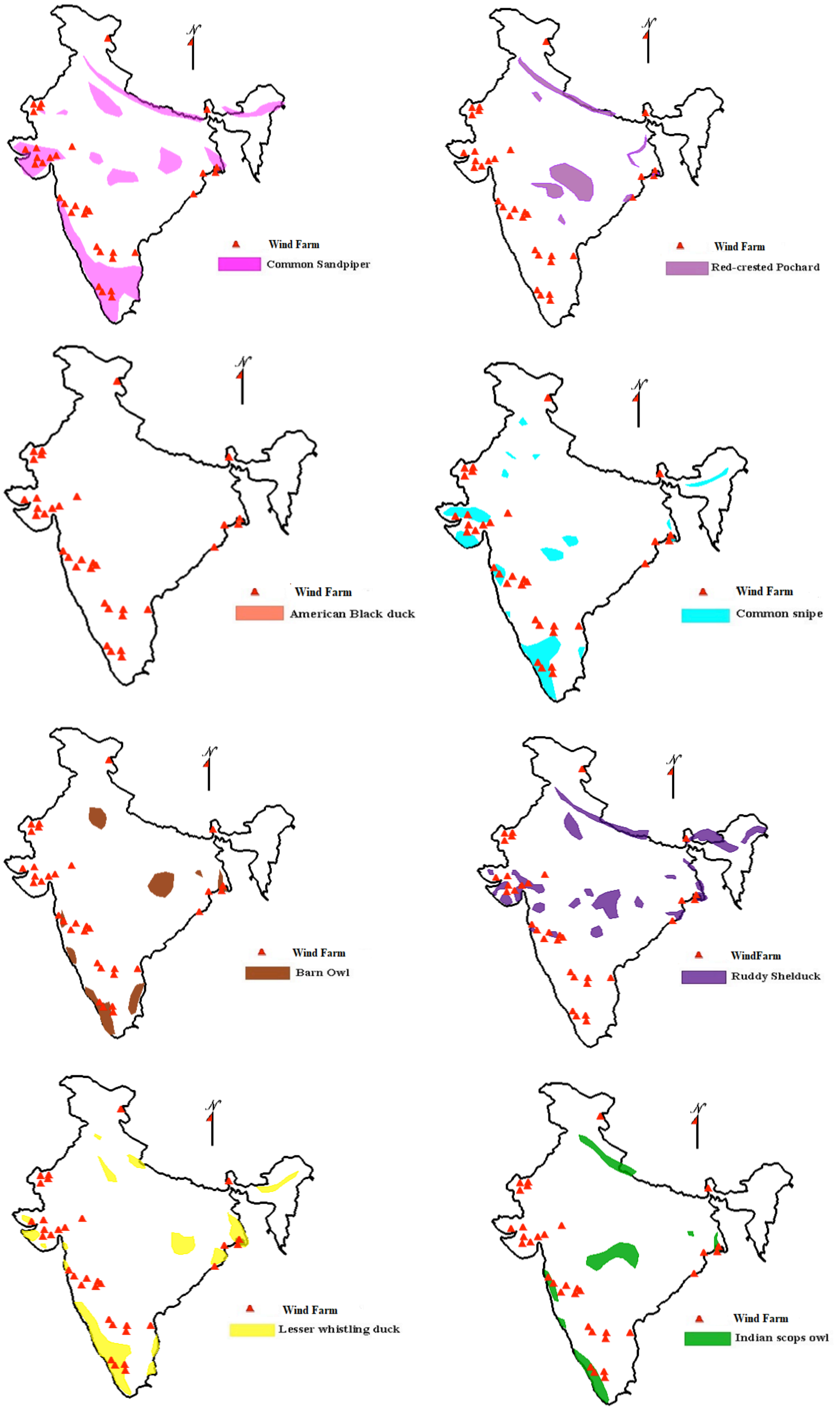
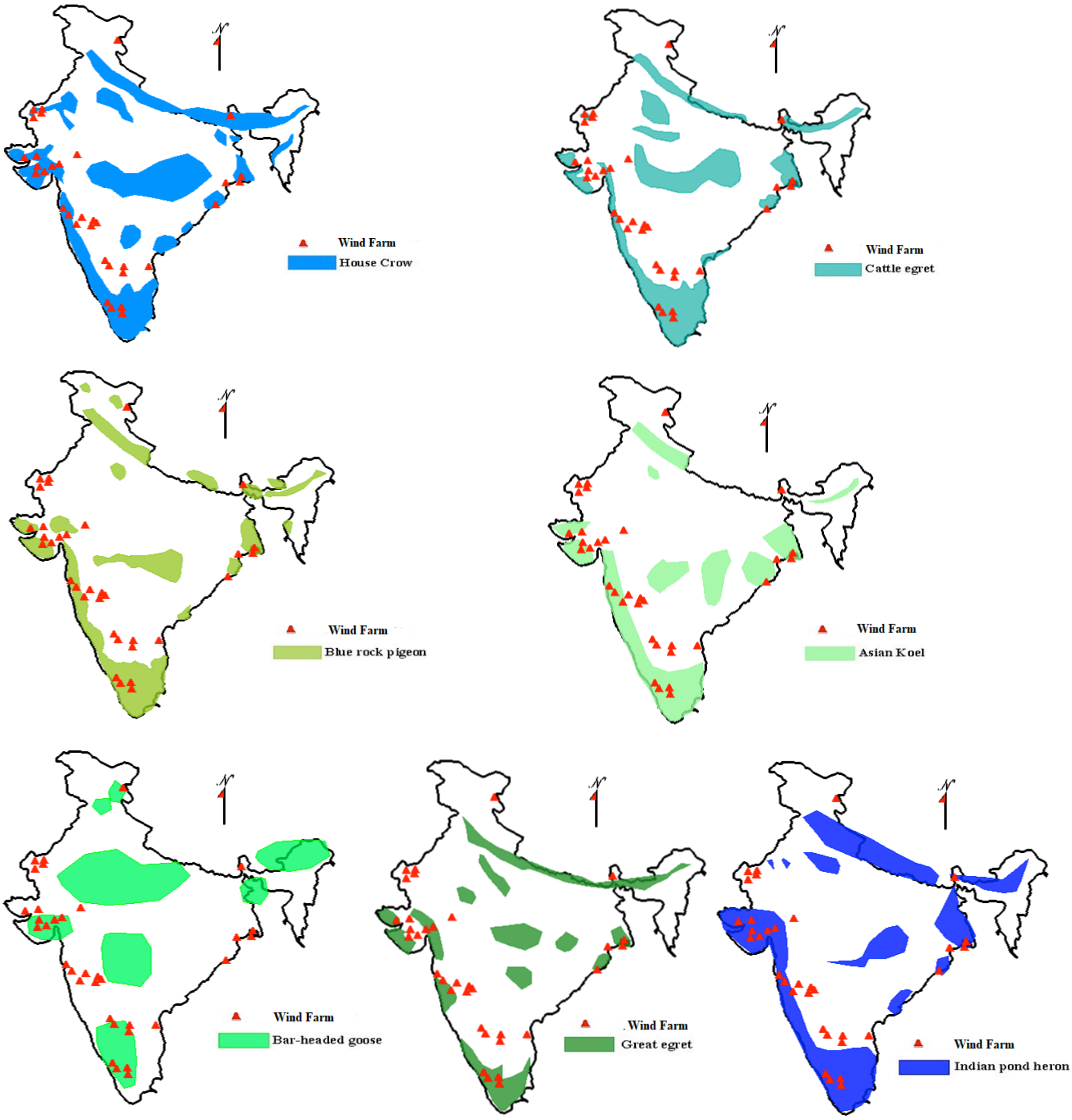


Appendix 1. Home ranges for fifteen birds considered in this study (continued on next page...)



Appendix 1. Home ranges for fifteen birds considered in this study (.... continued from previous page)

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