COMMUNICATION

Journal of Threatened Taxa | www.threatenedtaxa.org | January 2013 | 5(1): 3504–3515

CRITICAL ECOSYSTEM PARTNERSHIP FUND

Western Ghats Special Series

ISSN
Online 0974-7907
Print 0974-7893

OPEN ACCESS

Avian collision threat assessment at 'Bhambarwadi Wind Farm Plateau' in northern Western Ghats, India

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Abstract: To address the shortage of power in India, wind energy is increasingly harnessed as an alternate and renewable energy source. There is a rapid increase in the number of wind farms at suitable sites all over the country. Some of the key sites with optimal wind velocities are the plateaus on the Western Ghats - a global hotspot of biological diversity. The rocky plateaus on the Western Ghats are terrestrial habitat islands facing extreme micro-environmental conditions; however, scanty information is available on the ecology of these plateaus. We undertook a two-year study to assess the impact of wind farms on birds. We also documented the avian diversity at Bhambarwadi Plateau, northern Western Ghats, India. To the best of our knowledge this is the first such study in India. We recorded 89 avian species on the plateau, 27 of which flew in the risk area swept by the rotor blades, and hence are potentially at risk of collision. The collision index (the number of bird collisions with wind turbines over a period of one year assuming that the birds do not take any avoidance measure) for these species were estimated. We also identified species at risk from collision with transformers and wind-masts, and at risk from electrocution. Reduction in avian activity in the study area was evident with progress of wind farm erection. Despite the small footprint of an individual wind turbine, the associated infrastructure development causes wider habitat modification and destruction resulting in a displacement effect. Therefore, wind farm erections in strategic locations such as biodiversity hotspots should be subject to prior site based strategic environmental assessments (SEA) as well as environmental impact assessment (EIA) studies.

Keywords: Bird collision index, bird collision probability, electrocution, plateaus, raptors, risk species, Western Ghats, wind farm.

Marathi Abstract: भारतातील विजेची टंचाई दूर करण्यासाठी एक प्रभावी अ-पारंपारिक ऊर्जा स्रोत म्हणून दिवसेंदिवस पवन ऊर्जेचा प्रसार झपाट्याने होत आहे. त्या अनुषंगाने वाऱ्याच्या उपलब्धतेनुसार संपूर्ण देशात नवनवीन ठिकाणी पवन-चक्क्या उभारल्या जात आहेत. या पैकी काही महत्वाची ठिकाणे म्हणजे पश्चिम-घाटातील कातळ-पठारे होत, जी वैश्विक जैवविविधता संपन्न प्रदेशात समाविष्ट होतात. पश्चिम-घाटातील ही कातळ-पठारे म्हणजे टोकाच्या सूक्ष्म पर्यावरणीय स्थितीला तोंड देत असलेल्या भूस्थित अधिवासांची बेटे आहेत. परंतू आजमितीस त्यांच्या विषयी फारच थोडी माहिती उपलब्ध आहे. अशा कातळ-पठारांवरील पवन-चक्क्यांचा पक्ष्यांवर होणारा परिणाम तपासण्यासाठी आम्ही दोन वर्षांचा एक अभ्यास प्रकल्प हाती घेतला होता. त्याच बरोबर उत्तर पश्चिम-घाटातील भाम्बरवाडी पठारावरील पक्षी-वैविध्य देखील आम्ही नोंदविले. आमच्या माहिती नुसार भारतातील अशा प्रकारचा हा पहिला-वहिला प्रकल्प व अभ्यास आहे. त्यात आम्हाला ८९ प्रजातींचे पक्षी आढळले. त्यातील २७ प्रजातींचे पक्षी पवन-चक्क्यांच्या पंख्यांच्या जवळील धोक्याच्या भागातून उडताना आढळले. त्या मुळे या २७ प्रजातींच्या पक्ष्यांना पवन-चक्क्यांपासून धोका उद्‌भवू शकतो. या २७ प्रजातींसाठी आम्ही एक कोलिजन इंडेक्स (पक्षी पवन-चक्कीला धडकण्याची शक्यता) संगणित केला आहे. हे करताना असे गृहित धरले आहे की उडताना समोर पवन-चक्क्या आल्यास पक्षी धडक टाळण्याचा प्रयत्न करत नाहीत (प्रत्यक्षात मात्र ९० टक्क्यांपेक्षा जास्त वेळा पक्षी अशी धडक टाळतात). कोलिजन इंडेक्स बरोबरच ट्रान्सफॉर्मर, विंड-मास्ट तसेच वीज-वाहक तारा यांना धडकून मरण्याचा धोका असलेल्या प्रजाती देखील आम्ही अभ्यासल्या. या अभ्यासादरम्यान आम्हाला पवन-चक्क्या उभारणीतील कामाच्या प्रगतीबरोबर पक्ष्यांचा वावर कमी कमी होत गेलेला आढळला. याला डिसप्लेसमेंट इफेक्ट असे संबोधले जाते. जरी एक पवन-चक्की तुलनेने छोट्या जागेवर उभी रहात असली तरी ती उभारण्यासाठी करण्यात येणारी अवजड यंत्र सामुग्रीची वाहतुक, त्या साठी लागणारे लांब रुंद रस्ते इत्यादींमुळे त्या परीसंस्थेचे मोठे नुकसान होते असे आम्हास आढळले. म्हणून विशेष करून पश्चिमघाटा सारख्या वैश्विक जैवविविधता संपन्न प्रदेशात पवन-चक्क्या उभारण्यापूर्वी स्थानिक पर्यावरणीय निकषांनुसार सैद्धांतिक पातळीवरील परिसंस्थांचा अभ्यास (एस. इ. ए.) तसेच पर्यावरण परिणाम अभ्यास (इ. आय. ए.) केला जाणे अपरिहार्य करावे असे आम्हास वाटते.

DOI: http://dx.doi.org/10.11609/JoTT.o3096.210 | **ZooBank:** urn:lsid:zoobank.org:pub:4A0537C3-C80F-4F0B-95D8-EEB73968C2BA

Editor: Reuven Yosef, International Birding & Research Centre, Eilat, Israel. **Date of publication:** 26 January 2013 (online & print)

Manuscript details: Ms # o3096 | Received 12 February 2012 | Final received 20 October 2012 | Finally accepted 08 December 2012

Citation: Pande, S., A. Padhye, P. Deshpande, A. Ponkshe, P. Pandit, A. Pawashe, S. Pednekar, R. Pandit & P. Deshpande (2013). Avian collision threat assessment at 'Bhambarwadi Wind Farm Plateau' in northern Western Ghats, India. *Journal of Threatened Taxa* 5(1): 3504–3515; doi:10.11609/JoTT.o3096.210

Funding: Enercon India Ltd.

Competing Interest: None.

Ela Foundation

Acknowledgement: The project was partially funded by Enercon India Ltd. The clearance and permissions for the study were given by the Maharashtra State Forest Department. We are thankful to Mr. M.K. Rao, CCF (Wildlife), Kolhapur for facilitating the study. We are thankful to Neelesh Dahanukar, IISER Pune, for his valuable suggestions and help during the Manuscript Praparation. We are thankful to Neelesh Dahanukar, IISER Pune, for his valuable suggestions and help during the Manuscript Praparati; Madhura Niphadkar-Bandekar, who prepared the map of the study site and Dr. Anil Mahabal, who allowed access to avian specimen in Z.S.I. Pune. We also thank Mr. Rupsinh Nimbalkar, Mr. S. Banubakode and Mr. S.S. Notey, for their valuable assistance.

The publication of this article is supported by the Critical Ecosystem Partnership Fund (CEPF), a joint initiative of l'Agence Française de Développement, Conservation International, the European Commission, the Global Environment Facility, the Government of Japan, the MacArthur Foundation and the World Bank.

INTRODUCTION

India is facing shortage of power (Singh 2006) and attempts are being made to address this problem through alternate and renewable energy sources. As a result, there is a rapid increase in the number of wind farms at suitable sites all over the country. As projected by the Ministry of Non-conventional Energy Sources, Government of India, 10% of the installed capacity of power requirement by the year 2012 (24,000MW) will come from renewable energy, of which 50% (12,000MW) is likely to come from wind power (Ghose 2006; Krithivasan 2006). India is the fifth largest producer of wind energy in the world with installed capacity of 10,891MW as in October 2009 (Meisen 2006, updated by Avinash & Timbadiya 2010). Some of the key sites where adequate wind velocities are encountered throughout the year are the plateaus on the Western Ghats (Ghosh 2006), which is identified as a global hotspot of biological diversity (Myers et al. 2000).

The rocky plateaus on the Western Ghats are described as terrestrial habitat islands facing extreme micro-environmental conditions, and even though it is documented that rocky outcrops such as inselbergs, barrens and others support rich and threatened floristic endemicity (Porembski et al. 1998), scant information is available on the ecology of these plateaus (Watve 2003). Considering the above scenario, we undertook a two-year study to document avian diversity and assess the impact of wind farms at Bhambarwadi Plateau on avian populations. To the best of our knowledge this is the first such study in India.

METHODS

Study area

The study area is situated on the Bhambarwadi Plateau (0.5km^2 area around 17^{0}8’90”N & 73^{0}54’96”E; 1053m) on the northern Western Ghats or the Sahyadri Mountains, near Gude-Pachgani Village, Satara District (Image 1). There was a proposal to construct 13 wind turbines in the study area, where ten wind turbines were previously constructed. The Chandoli Wildlife Sanctuary is approximately 5km to the west of the study area. The study area is a high level rocky plateau on the Sahyadris. It is composed of ferricrete duricrust, usually described as laterites, capping underlying basalt summits (Ollier & Sheth 2008). The soil cover ranges from few centimeters to less than one meter. The study area falls in the bio-geographic zone of Western Ghats and the agro-climatic zone is Western Plateau and Hills Region

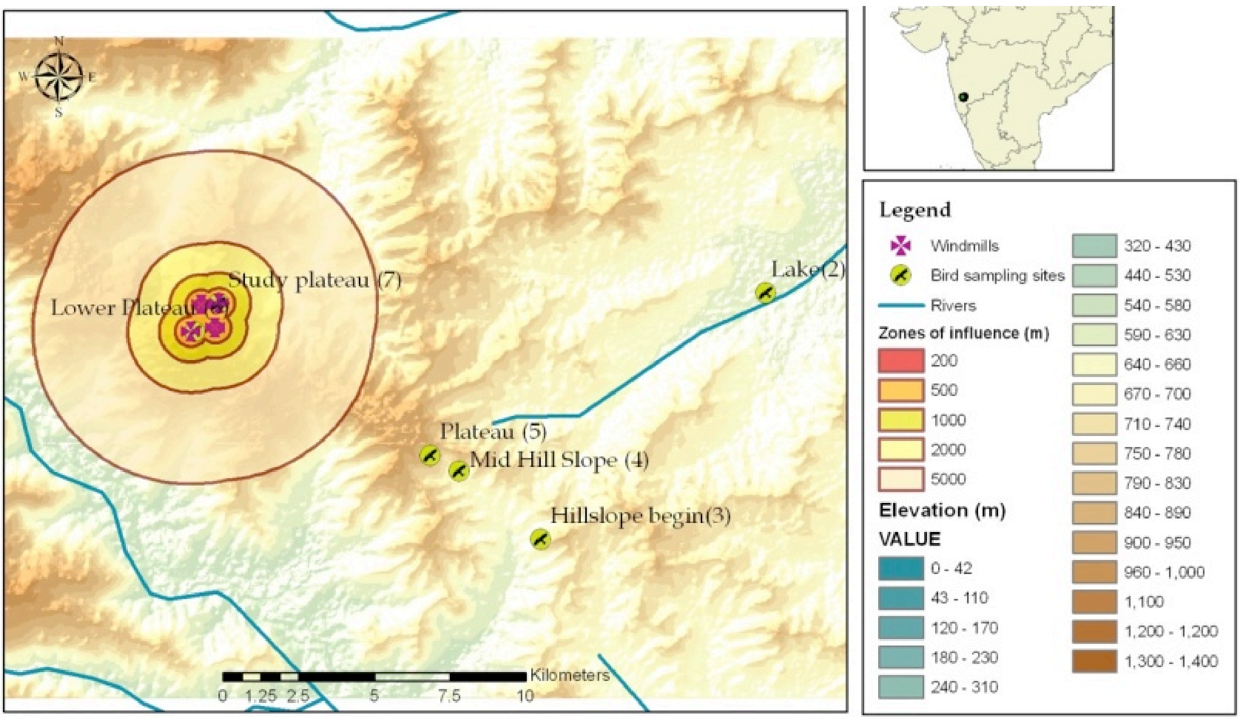

Image 1. Sketch Map Showing Point Count Sites in the Study Area. Region included by site marked from 2 to 3 is plains, from 3 to 5 is hill slope and from 5 to 7 is the plateau. The inner two circles comprise the study area where only point counts were taken.

(Rodgers & Panwar 1988). There are three seasons in the region. Summer is from March–May; monsoon from June–September; and winter is from October–February. Humidity ranges from almost 100% during the monsoon and around 45% in summer; the climate is monsoonal and the summer temperature rises up to 38^{0}C on a few days and the winter temperature dips to 5^{0}C; the average temperature is 24^{0}C (Lakshminarayana et al. 2001). Visibility is generally very good except during monsoon when there is a thick cloud cover on the plateau.

Data Collection

The data was collected from July 2008 to June 2010. Fortnightly visits were made during the study period. Data was collected for two years including the three seasons, summer, monsoon and winter during the daylight hours. The dimensions of the wind turbines required for further analysis, such as height of the wind turbines; length, width, pitch angle, thickness of the rotor blades; maximum cord width and dimensions of the nestle; were obtained from the wind farm company. The dynamic data regarding wind turbine revolutions per minute (rpm), direction of wind and wind velocity for each visit was obtained from the computerized system installed in the field office of the wind farm (only average values are provided by the wind farm company for the above three parameters for confidential reasons). Actual bird and mammal species found dead in the study area, due to collision with wind turbines, wind mast and overhead power lines, were also recorded. All observations were made during the entire study period by four trained observers.

Point counts were taken for the recording of avian activity in the study area. Point counts were made from the view point of an external observer with a 50m radius around the wind turbines. Each count lasted for the duration of 20 minutes. We recorded the following parameters: (i) avian species, (ii) number of individuals of each species (abundance) flying in the study area, (iii) whether the bird was flying in the risk zone, below it or above it, (iv) total flight time of each species in minutes (flight activity) and (v) the flight activity of birds in the risk zone (risk activity). Risk zone is the region between the lowest and top most points swept by the rotor blades or the aerial height band swept by the rotor blades (Image 2). The band span was 10–100 m above the ground level.

Known length of bird species (from the tip of the beak to the tip of the tail in meters) and known wing chord (from the wrist to the longest primary feather in flexion of the wing in meters) were taken from Ali & Ripley

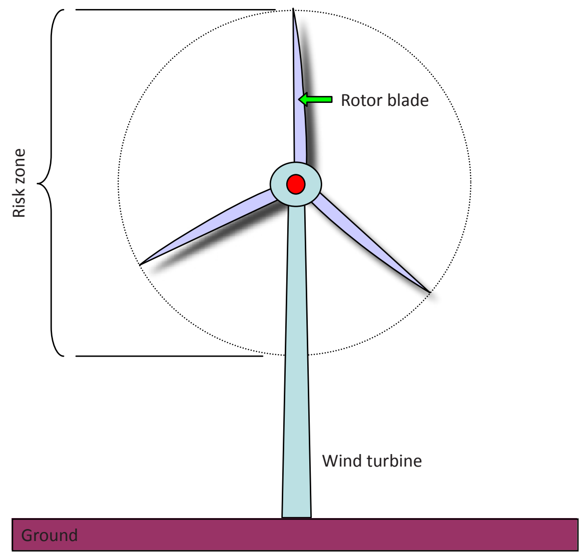

Image 2. Schematic drawing of a wind turbine showing the risk zone

(1969). The standard multiplier (the ratio of wing span to wing chord for that species) was taken from Fergusson-Lees & Christie (2005). The average flight speed for most of the species was taken from Bruderer & Boldt (2001) and Alerstam et al. (2007). For some species, bird length and wing chord were measured from rolled bird specimen in the collection of the Zoological Survey of India, Western Regional Center, Akurdi, Pune. The wing span in meters was calculated by multiplying the wing chord and standard multiplier. For some species, the average flight speed in meter/second and type of flight (0 = Fl. – Flapping, 1 = Gl. – Gliding) were recorded in the field. These parameters were used for calculation of hypothetical collision probability of all the bird species flying in the risk zone.

Calculation of collision risk

The assessment of the collision risk was done by the suitable modification of the Band Model (Anonymous 2000; Band et al. 2007), after taking into consideration the actual wind farm and rotor blade parameters in the study area.

Collision index for a species (CI) = Number of birds flying through rotor x Probability of bird flying through rotor being hit. Therefore,

$$\mathrm{CI} = \frac{n(Vr/Vw)}{v} \times 2\int_0^R p(r)\left(\frac{r}{R}\right)d\left(\frac{r}{R}\right)$$

where,

n= number of wind turbines;

Vr (the combined volume swept out by the wind farm rotors) = N x π x 2 x R x (d + l) = 21226.4 (d + l) cubic m.

[where, N is the number of wind turbines (N=10), d is the depth of the rotor back to front, l is the length of the bird, π is Pythagoras constant (3.14159) and R is radius of rotor (26m)];

Vw [flight risk volume which is the area of the wind farm ($5x10^6$ sq.m) multiplied by the risk height of the turbines 90m) = $45000000m^3$].

p(r) is the probability p of collision for a bird at a radius r from hub.

$$p(r) = \begin{cases} (b\Omega/2\pi v)\left[K|\pm c\sin y + \alpha c\cos y| + l\right] & \alpha < \beta \\ (b\Omega/2\pi v)\left[K|\pm c\sin y + \alpha c\cos y| + w\alpha F\right] & \alpha > \beta \end{cases}$$

where,

α = v/rΩ; β = aspect ratio of bird i.e. l / w; b = number of blades in rotor; Ω = angular velocity of rotor (radians/sec); v = velocity of bird through rotor; K = 0 for one-dimensional model (rotor with no zero chord width); K = 1 for three-dimensional model (rotor with real chord width); c = chord width of blade; γ = pitch angle of blade; w = wingspan of bird; F = 1 for a bird with flapping wings (no dependence on φ); F = (2/π) for a gliding bird; l = length of bird; r = radius of point of passage of bird.

Yearly average collision rate = Sum of collision Index for each species / number of turbines.

Several approximations and assumptions were involved in the study. The bird was assumed to be of simple cruciform shape, with the wings at the halfway point between nose and tail. The turbine blade is assumed to have a width and a pitch angle (relative to the plane of the turbine), but to have no thickness. It was also assumed that no avoiding action was taken by the bird. Hence, the calculated collision risks should be held as an indication of the risk (±10%). It was also assumed that bird flight velocity is likely to be the same relative to the ground, both upwind and downwind. We have separately calculated collision indices for upwind and downwind flight speeds as suggested by Band et al. (2007).

RESULTS

A. Point Count

In all, 89 species were recorded during point count, of which 27 were recorded in the risk area. Seasonal flight activity (in minutes) of each species in the study area during Monsoon, winter and summer, irrespective of the number of individuals was recorded. The maximum flight activity of 191 minutes was presented by Red-rumped Swallow *Hirundo daurica*. Red-vented Bulbul *Pycnonotus cafer* - 162 minutes, Wire-tailed Swallow *Hirundo smithii* - 123 minutes and Malabar Lark *Galerida malabarica* - 102 minutes were the other species who showed total flight activity of over 100 minutes (Table 1).

Total avian flight activity, as recorded in the study area, irrespective of the number of species and number of individuals, was 1604 minutes; while total seasonal flight activity was maximum during summer (645 minutes) followed by monsoon (548 minutes). Flight activity was the least in winter which was 411 minutes. Out of 1604 minutes of the total avian flight activity, flight activity in the risk area was 1067 minutes. Seasonal flight activity in the risk area showed the same trend with maximum flight activity in the risk area during summer (449 minutes) followed by monsoon (324 minutes). Flight activity in the risk area was the least in winter which was 294 minutes (Fig. 1).

Analysis of monthwise total avian flight activity and flight activity in the risk area during the entire study period depicted that overall pattern of avian flight activity and the flight activity in risk area corresponded to each other (Fig. 2). Activity was high in July 2008, when there was minimal disturbance in the study area. It peaked again in March 2009, mainly due to a forest

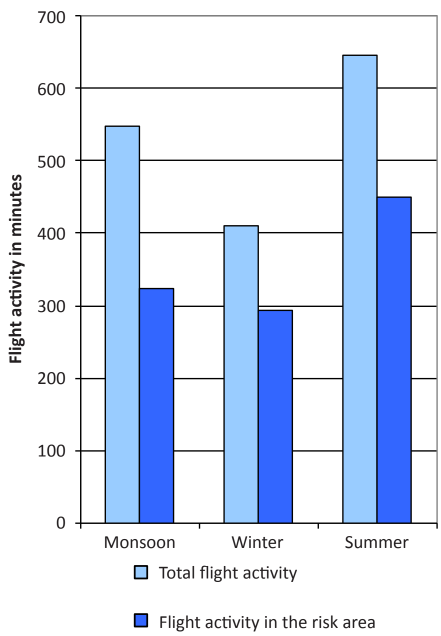

Figure 1. Seasonal flight activity, as recorded in the entire study area on the plateau as well as in the risk area, irrespective of the number of species and number of individuals (Monsoon: June–September; Winter: October–February; Summer: March–May).

Table 1. Species wise seasonal flight activity in minutes during Monsoon (June to September), Winter (October to February) and Summer (March to May) in the study area on the plateau irrespective of the number of individuals. Those recorded flying in the risk area (RA) swept by the rotor blades are also indicated. Those marked with * are Indian endemics.

Name	Scientific Name	Monsoon	Winter	Summer	Total	RA
Ashy Prinia	*Prinia socialis*	7	1	6	14	No
Ashy-crowned Finch Lark	*Eremopterix griseus*	3	5	4	12	No
Baya Weaver	*Ploceus philippinus*	19	0	0	19	No
Bay-backed Shrike	*Lanius vittatus*	0	1	8	9	No
Blue Rock-thrush	*Monticola solitarius*	0	8	0	8	No
Brahminy Kite	*Haliastur indus*	0	1	1	2	No
Brahminy Starling	*Temenuchus pagodarum*	2	0	0	2	No
Common Blackbird	*Turdus merula*	7	0	10	17	No
Common Iora	*Aegithina tiphia*	0	0	1	1	No
Common Stonechat	*Saxicola torquatus*	0	6	0	6	No
Crested Bunting	*Melophus lathami*	19	0	10	29	No
Eurasian Collared Dove	*Streptopelia decaocto*	1	0	1	2	No
Eurasian Coot	*Fulica atra*	0	0	1	1	No
Greater Coucal	*Centropus sinensis*	0	1	0	1	No
Grey Wagtail	*Motacilla cinerea*	0	0	1	1	No
House Crow	*Corvus splendens*	2	0	11	13	No
House Sparrow	*Passer domesticus*	16	2	16	34	No
Indian Bush-Lark	*Mirafra erythroptera*	3	1	2	6	No
Indian Great Reed-Warbler	*Acrocephalus stentoreus*	0	0	1	1	No
Indian Grey Hornbill	*Ocyceros birostris*	3	0	0	3	No
Indian Peafowl	*Pavo cristatus*	0	4	11	15	No
Indian Robin	*Saxicoloides fulicatus*	5	2	3	10	No
Indian Roller	*Coracias benghalensis*	0	10	15	25	No
Indian Silverbill	*Euodice malabarica*	2	3	0	5	No
Isabeline Shrike	*Lanius isabellinus*	0	1	0	1	No
Jacobian Cuckoo	*Clamator jacobinus*	3	0	1	4	No
Jungle Babbler	*Turdoides striata*	12	8	4	24	No
Jungle Myna	*Acridotheres fuscus*	0	0	3	3	No
Jungle Prinia	*Prinia sylvatica*	0	0	3	3	No
Lesser Pied Kingfisher	*Ceryle rudis*	0	0	4	4	No
Little Brown Dove	*Streptopelia senegalensis*	37	0	12	49	No
Little Cormorant	*Phalacrocorax niger*	0	0	1	1	No
Little Egret	*Egretta garzetta*	0	0	4	4	No
Long-billed Pipit	*Anthus similis*	0	3	0	3	No
Long-tailed Shrike	*Lanius schach*	4	23	8	35	No
Oriental Magpie-Robin	*Copsychus saularis*	3	2	5	10	No
Painted Francolin	*Francolinus pictus*	2	0	1	3	No
Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	2	3	2	7	No
Plain Prinia	*Prinia inornata*	0	1	1	2	No
Plum-headed Parakeet	*Psittacula cyanocephala*	0	1	0	1	No
Purple Sunbird	*Cinnyris asiaticus*	6	2	2	10	No
Purple-rumped Sunbird	*Leptocoma zeylonica*	0	1	0	1	No
Rain Quail	*Coturnix coromandelica*	1	5	0	6	No
Red Spurfowl*	*Galloperdix spadicea*	0	0	4	4	No
Red-whiskered Bulbul	*Pycnonotus jocosus*	9	0	0	9	No

Name	Scientific Name	Monsoon	Winter	Summer	Total	RA
Rock Bush-Quail*	*Perdicula argoondah*	11	0	2	13	No
Rock Pigeon	*Columba livia*	0	1	0	1	No
Rose-ringed Parakeet	*Psittacula krameri*	0	2	0	2	No
Rufous-tailed Lark	*Ammomanes phoenicura*	1	8	8	17	No
Scaly-breasted Munia	*Lonchura punctulata*	29	0	0	29	No
Shikra	*Accipiter badius*	1	2	1	4	No
Small Minivet	*Pericrocotus cinnamomeus*	2	0	0	2	No
Spotted Dove	*Streptopelia chinensis*	6	0	2	8	No
Sykes's Lark*	*Galerida deva*	0	1	3	4	No
Tree Pipit	*Anthus trivialis*	0	2	2	4	No
Cattle Egret	*Bubulcus ibis*	0	2	0	2	No
White-browed Wagtail	*Motacilla maderaspatensis*	0	1	0	1	No
White-cheeked Barbet*	*Megalaima viridis*	1	0	0	1	No
White-throated Fantail	*Rhipidura albicollis*	0	0	1	1	No
White-throated Kingfisher	*Halcyon smyrnensis*	2	0	1	3	No
Yellow-eyed Babbler	*Chrysomma sinense*	2	2	13	17	No
Zitting Cisticola	*Cisticola juncidis*	1	1	6	8	No
Black Drongo	*Dicrurus macrocercus*	8	50	4	62	Yes
Black Kite	*Milvus migrans*	15	13	12	40	Yes
Black-winged Kite	*Elanus caeruleus*	0	2	3	5	Yes
Bonelli's Eagle	*Hieraaetus fasciatus*	3	0	4	7	Yes
Booted Eagle	*Hieraaetus pennatus*	0	2	0	2	Yes
Changeable Hawk-Eagle	*Spizaetus cirrhatus*	3	1	2	6	Yes
Common Kestrel	*Falco tinnunculus*	0	43	11	54	Yes
Common Myna	*Acridotheres tristis*	18	4	22	44	Yes
Common Sandpiper	*Actitis hypoleucos*	4	4	0	8	Yes
Crested Serpent-Eagle	*Spilornis cheela*	0	0	3	3	Yes
Dusky Crag-martin	*Ptyonoprogne concolor*	24	4	24	52	Yes
House (Little) Swift	*Apus affinis*	8	0	6	14	Yes
Indian Jungle Crow	*Corvus culminatus*	1	0	11	12	Yes
Indian Spot-billed Duck	*Anas poecilorhyncha*	0	0	0	0	Yes
Little Green Bee-eater	*Merops orientalis*	3	8	2	13	Yes
Malabar Lark*	*Galerida malabarica*	27	19	56	102	Yes
Montagu's Harrier	*Circus pygargus*	0	2	0	2	Yes
Oriental Honey-Buzzard	*Pernis ptilorynchus*	0	2	0	2	Yes
Paddyfield Pipit	*Anthus rufulus*	8	6	20	34	Yes
Pallid Harrier	*Circus macrourus*	0	1	0	1	Yes
Pied Bushchat	*Saxicola caprata*	18	28	43	89	Yes
Red-rumped Swallow	*Hirundo daurica*	28	61	102	191	Yes
Red-vented Bulbul	*Pycnonotus cafer*	49	20	93	162	Yes
Red-wattled Lapwing	*Vanellus indicus*	14	4	7	25	Yes
River Tern	*Sterna aurantia*	0	0	2	2	Yes
Tawny Eagle	*Aquila rapax*	2	7	3	12	Yes
Wire-tailed Swallow	*Hirundo smithii*	91	13	19	123	Yes

fire of unknown cause in the study area when there was a sudden increase in the activity of Black Drongos, *Dicrurus macrocercus*. It increased again in June 2009 (early monsoon) and then in November–December 2009 (during the winter), when there was an influx of the migratory Common Kestrels *Falco tinnunculus*. However, by June 2010, there was a definite reduction in overall avian activity in the study area as compared to activity in July 2008, even though the wind turbine erection and road construction activities had ceased and human presence was minimized to maintenance work. We consider this as the species displacement effect.

b. Bird Collision Indices

The average annual wind velocity was 7.6m/s; the wind direction was variable with average of 261 degrees with respect to North. The average windmill rotor RPM was 23.6. The lowest RPM were seen during the March of each year and the peak was seen in December and July. The monthly variation is shown in Figure 3.

Assuming that the birds do not take any preventive action so as to avoid collision with the rotor blades, the yearly average collision rate was 1.9 birds per turbine. Considering the presence of 13 wind turbines in the study area the total collision rate is 24.9 birds annually. The biometric parameters used for the calculation of hypothetical collision probability of all 27 bird species flying in the risk area are given in Table 2. The

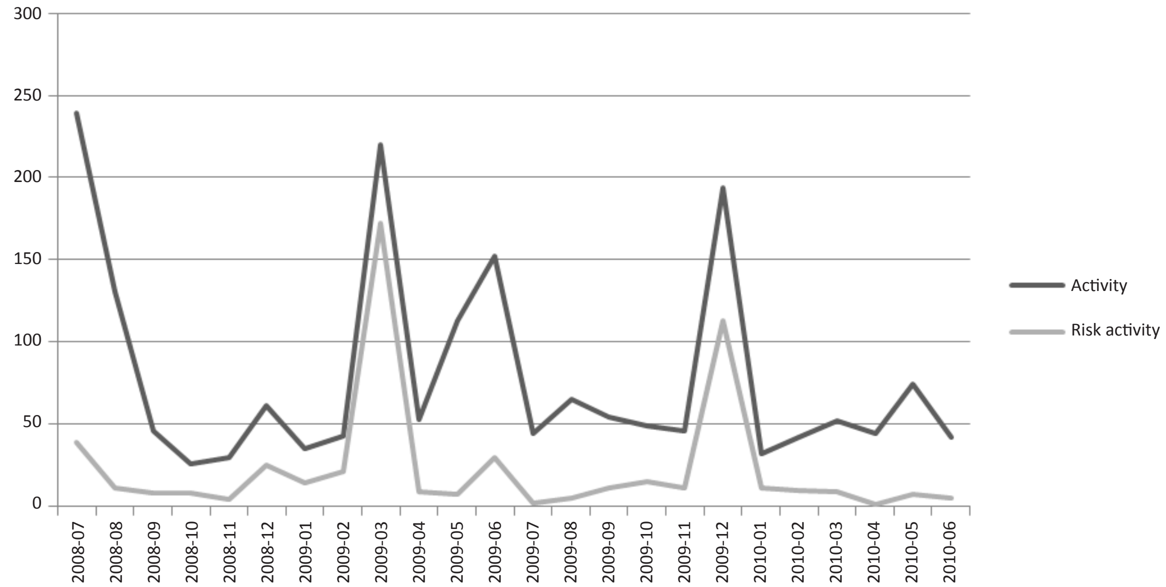

Figure 2. Month wise total avian flight activity in bird minutes (y-axis) and flight activity in the Risk Area swept by the rotor blades, in the study area on the plateau during the entire study period (July2008-June2010).

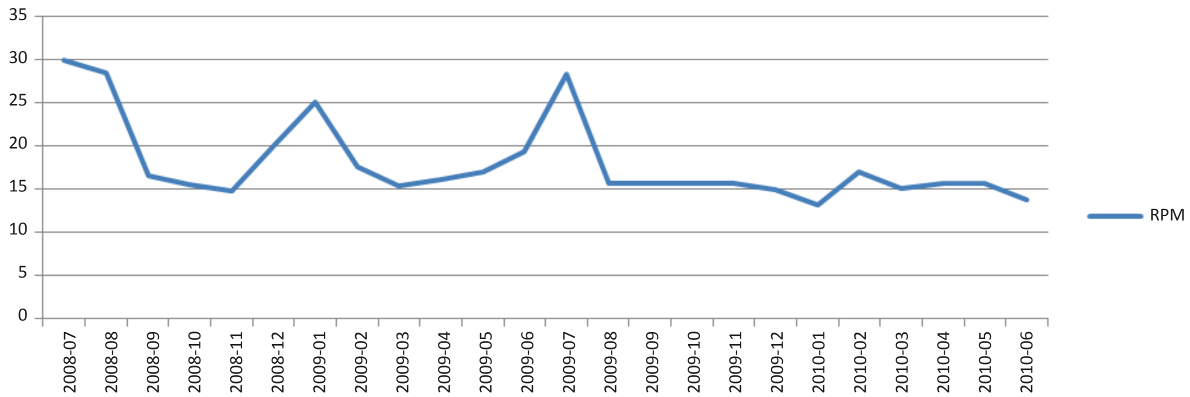

Figure 3. The RPM (revolutions per minute) on the day of the study for all the wind turbines (Y-axis) in the study area are plotted for each month during the entire study period (X-axis). (Data from Enercon India Ltd.)

hypothetical probability of bird collision and the collision index indicating probable bird hits per year for all 27 bird species is given in Table 3. Season wise bird collision assessment studies revealed that the maximum collision risk was in winter while it was the minimum in monsoon (Fig. 4). Amongst all the species, raptors were at the maximum collision risk. Season wise collision risks for each species is given in Table 4.

During the study period, 19 birds and mammals were found dead due to collision with the rotor blades (n=10) or electrocution (n=9) due to contact with overhead transmission lines or transformers. Asian Palm Civets *Paradoxurus hermaphroditus* were found dead in the transformers built for transmitting windmill power to the base stations. Maximum collisions of raptors were seen during the monsoon months. Swallows and martins were found dead in post monsoon period. In addition, we also noticed that two Black Kites *Milvus migrans* and one Changeable Hawk Eagle *Spizaetus cirrhatus* collided with wind masts. Actual bird and mammal species found dead in the study area and their respective numbers are listed in Table 5.

DISCUSSION

The study area assumes special significance because it lies in the Western Ghats, which are listed as one of the global biodiversity hotspots (Myers et al. 2000).

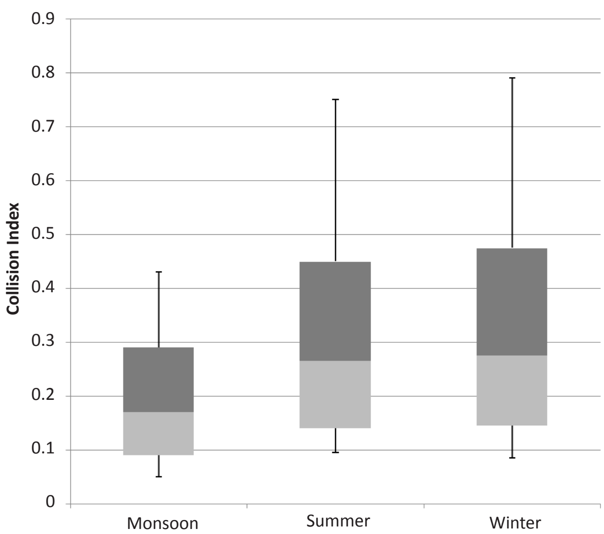

Figure 4. Box plot showing seasonal variation in the collision Indices in monsoon, summer and winter irrespective of the species. The minimum and maximum values are shown by crossbars on the vertical line. The frequency distribution within 75 percentile is shown by dark grey box and within 25 percentile is shown by light grey box. The median is indicated by the confluence of the boxes.

Table 2. Biometric parameters (length of bird from the tip of the beak to the tip of the tail in meters, known wing chord measured from the wrist to the longest primary feather in flexion of the wing in meters, standard multiplier, calculated Wing Span by multiplying the wing chord and Multi-multiplier in meters, average flight speed in m/sec, and type of flight (0 = Flapping, 1 = Gliding) used for calculation of hypothetical collision probability of all the 27 bird species flying in the risk zone swept by the rotor blades.

Species	Length (m)	Wing Chord (m)	Multi	Wing Span (m)	Av. Speed-(m/s)	Flight type
Black Drongo	0.31	0.155	2.48	0.3844	12	0
Black Kite	0.61	0.4475	3.1	1.38725	11.7	1
Black-winged Kite	0.33	0.269	3.1	0.8339	11.5	1
Bonelli's Eagle	0.7	0.504	3.2	1.6128	11.3	1
Booted Eagle	0.7	0.504	3.2	1.6128	11.3	1
Changeable Hawk-Eagle	0.7	0.419	3.2	1.3408	11.3	1
Common Kestrel	0.36	0.2485	2.8	0.6958	10.1	1
Common Myna	0.23	0.1455	2.6	0.3783	16.2	0
Common Sandpiper	0.21	0.11	2.48	0.2728	12.3	0
Crested Serpent Eagle	0.74	0.478	3.2	1.5296	11.5	1
Dusky Crag-Martin	0.13	0.109	2.4	0.2616	33.3	1
House Swift	0.15	0.1285	2.4	0.3084	33.3	1
Indian Jungle Crow	0.5	0.3445	3	1.0335	13.5	0
Indian Spot-billed Duck	0.61	0.265	2.6	0.689	18.5	0
Little Green Bee-eater	0.21	0.093	2.48	0.23064	12.2	0
Malabar Lark	0.15	0.098	2.48	0.24304	15.1	0
Montague's Harrier	0.48	0.3695	3.1	1.14545	14	1
Oriental Honey-Buzzard	0.68	0.4575	3.1	1.41825	12.5	1
Paddyfield Pipit	0.17	0.0955	2.48	0.23684	12.7	0
Pallid Harrier	0.48	0.3695	3.1	1.14545	14	1
Pied Bushchat	0.13	0.076	2.48	0.18848	15	0
Red-rumped Swallow	0.19	0.119	2.4	0.2856	33.3	1
Red-vented Bulbul	0.2	0.105	2.48	0.2604	14	0
Red-Wattled Lapwing	0.33	0.2275	3	0.6825	12.8	0
River Tern	0.42	0.27	2.48	0.6696	12.1	0
Tawany Eagle	0.67	0.533	3.2	1.7056	7.7	1
Wire-tailed Swallow	0.14	0.1175	2.4	0.282	33.3	1

Table 3. The Hypothetical Probability of Bird Collision (Hypo. Prob.) and the Collision Index indicating probable bird hits per year are given for all the 27 bird species that were recorded flying in the risk zone swept by the rotor blades in the study area. The species are arranged in the decreasing order of their collision index. It is assumed that the birds do not take any preventive action so as to avoid collision with the rotor blades. In fact they actually do so and the actual hits are expected to be less than the calculated index.

Species	Bird seconds	Hypo. Prob.	Collision Index
Falco tinnunculus	11799.69	0.11	5.91
Hirundo daurica	12682.66	0.06	3.78
Milvus migrans	3050.26	0.12	1.94
Hieraaetus fasciatus	1525.13	0.13	1.03
Spizaetus cirrhatus	1444.86	0.13	0.96
Ptyonoprogne concolor	2969.99	0.06	0.87
Hirundo smithii	2648.91	0.06	0.78
Galerida malabarica	1444.86	0.07	0.7
Aquila rapax	642.16	0.17	0.58
Anas poecilorhyncha	722.43	0.09	0.55
Pycnonotus cafer	561.89	0.07	0.27
Anthus rufulus	481.62	0.08	0.22
Corvus culminatus	321.08	0.1	0.21
Dicrurus macrocercus	401.35	0.09	0.2
Acridotheres tristis	321.08	0.07	0.18
Apus affinis	561.89	0.06	0.16
Vanellus indicus	240.81	0.09	0.13
Spilornis cheela	160.54	0.13	0.11
Saxicola caprata	240.81	0.07	0.11
Circus macrourus	160.54	0.09	0.1
Elanus caeruleus	160.54	0.09	0.08
Actitis hypoleucos	160.54	0.08	0.07
Sterna aurantia	160.54	0.1	0.06
Hieraaetus pennatus	80.27	0.13	0.05
Circus pygargus	80.27	0.09	0.05
Pernis ptilorynchus	80.27	0.11	0.05
Merops orientalis	80.27	0.08	0.04

Being situated at higher altitudes, these areas receive high and year round wind velocities required for wind power generation; hence these plateaus are increasingly utilized for wind farm erections. However, these plateaus with unique geographical features, are poorly studied (Lakshminarayana 2001; Watve 2003).

In the current study, we enlisted the avian diversity and species that are at risk due to collision with turbines, transformers, wind-masts and at risk of electrocution due to power lines, for the first time for this unique bio-geographical region. Albeit unintentional, birds die as

Table 4. The Season wise Bird Collision Index indicating probable bird hits per year are given for all the 27 bird species that were recorded flying in the risk zone.

Bird	Monsoon	Summer	Winter
Black Drongo	0.18	0.28	0.29
Black Kite	0.32	0.48	0.51
Black-winged Kite	0.2	0.3	0.32
Bonelli's Eagle	0.37	0.55	0.59
Booted Eagle	0.37	0.55	0.59
Changeable Hawk-Eagle	0.37	0.55	0.59
Common Kestrel	0.24	0.35	0.37
Common Myna	0.12	0.2	0.21
Common Sandpiper	0.13	0.21	0.22
Crested Serpent Eagle	0.38	0.57	0.6
Dusky Crag-Martin	0.1	0.15	0.16
House Swift	0.12	0.18	0.19
Indian Jungle Crow	0.26	0.42	0.44
Indian Spot-billed Duck	0.22	0.35	0.37
Little Green Bee-eater	0.13	0.2	0.21
Malabar Lark	0.09	0.15	0.16
Montague's Harrier	0.22	0.34	0.36
Oriental Honey-Buzzard	0.33	0.49	0.52
Paddyfield Pipit	0.11	0.18	0.18
Pallid Harrier	0.22	0.34	0.36
Pied Bushchat	0.08	0.14	0.14
Red-rumped Swallow	0.13	0.19	0.21
Red-vented Bulbul	0.12	0.18	0.19
Red-Wattled Lapwing	0.2	0.31	0.33
River Tern	0.24	0.37	0.39
Twany Eagle	0.43	0.75	0.79
Wire-tailed Swallow	0.11	0.16	0.17

Table 5. Actual bird and mammal species found dead in the study area and their respective numbers.

Species	July-2008 to June 2009	July-2009 to June 2010
Black Kite	01 M	02 M
Bonelli's Eagle	0	01 M
Changeable Hawk Eagle	01 M	0
Red-rumped Swallow	02 (M-n=1)	01
Dusky Crag-Martin	01	01 M
Slaty-legged Crake	0	01* M
Common Crow	01* M	0
Flying Fox	01*	01*
Hanuman Langur	01**	0
Asian Palm Civet	02** M	02**
TOTAL	**10**	**09**

* electrocuted in the transmission wires; ** electrocuted near the transformer; M = recorded during monsoon (n = 10).

a result of collisions with wind turbines (Banks 1979; Drewitt & Langston 2008; Rothery et al. 2009; Martin 2011), collisions with power lines (Manville 2005) and subsequent electrocutions can threaten survival of certain avian populations such as juveniles (Schaub & Pradel 2004), migrants (Christensen et al. 2004; Kahlert et al. 2004) or endangered species (ESKOM 2008; Shaw et al. 2010).

Our observation of reduction in the avian activity status in the study area with progression of wind farm erection activity is in accordance with similar bird displacement effect of wind farms reported by others (Anderson et al. 1999). Even after the wind turbines erection and other related human activities had ceased after commissioning of the wind farms, the avian displacement effect was conspicuous. Though the footprint of an individual wind turbine is small, the associated infrastructure development activities like road construction, establishment of power substations, and laying of power cables cause an effectively greater level of habitat destruction and modification, which could explain this displacement effect.

We did not observe the presence of an avian winter migratory corridor in the study area. Our study showed only one seasonal influx of Common Kestrels in winter, in contrast to well known avian migratory movements along coastal areas (Ali & Ripley 1969; Pande et al. 2003; Fox et al. 2006) and a few locations in the northern Western Ghats (Padhye et al. 2007), that are potential wind farm sites.

We recorded 27 bird species flying in the risk zone in the study area out of which 11 were raptors. Out of the 12 birds (belonging to seven species) that were found dead, five were raptors belonging to three species. This indicates that raptors are at a higher risk of collision as compared to other species. Moreover, the seasonal variation in collision index was highest in raptors. The overall risk of collision for all species, including raptors, was highest in winter. Such high risk of raptor collisions with turbine rotors and overhead power lines has also been reported by Madders & Whitfield (2006). Further, out of five Indian avian endemic species observed in the study area, Malabar Crested Lark *Galerida malabarica* (endemic to the Western Ghats) was recorded in the risk zone.

In addition to the risk zones created by the turbines, the wind masts are supported by very thin steel wires that are not visible from a distance, which lead to avian collisions and subsequent mortality. We strongly recommend that the supporting wires of the wind mast and the mast itself should be marked in bright colours or flags to make the wires and the mast prominently visible from a distance.

Modeling collision risk can help to determine the approximate level of mortality likely to result from particular developments such as wind farms, which enables us to explore the consequences for local and regional populations (Madders & Whitfield 2006). There is a mismatch between theoretical and actual collision risks due to several reasons (Richardson 2000). The theoretical risk can be an overestimate because the birds in practice take active collision avoidance measures. On the other hand, the actual number of birds found dead in the field can be underestimated because these birds can be scavenged before they are recorded by investigators. It is agreed that the reliability of collision models is limited by difficulties in gathering appropriate field data and by the large number of assumptions necessary during the modeling process, notably for the levels of collision avoidance (Madders & Whitfield 2006). Higher wind velocities and subsequent higher RPM of the turbine blades were recorded in July and December that may lead to a higher risk, when the visibility in the study area is low due to clouds and fog. However, the overall flight activity may also be underestimated during this period as a consequence of poor visibility.

We found highest number of dead birds during monsoon (9 out of 12 birds), and this could be due to the carcasses being left for longer time in monsoon due to absence of scavengers in these months, when the weather conditions are harsh in the study area. Carcasses due to collision are more likely to be scavenged immediately in winter and summer months. Further, we would also like to mention that we have collected the field data twice in a month which itself can be a reason of the underestimate of the dead birds; though the efforts were significant considering the remoteness of the study area. Therefore, it is evident that the search for dead birds alone may be inadequate to assess the true effects of wind farms on birds.

There are few published studies describing the activity budgets of upland bird species and potentially influential factors globally (Collopy & Edwards 1989) and Western Ghats is not an exception. Hence our study assumes special importance. The number of hours per day that birds are potentially active, and the influence of factors such as weather, time of year as well as the breeding status are poorly understood (Madders & Whitfield 2006).

It is suggested that due to their unique nature the plateaus of Western Ghats need protection by limiting human activities. None the less, many of the plateaus adjoining the study area are mushrooming with wind farms and associated infrastructure development activities. Such activities can lead to immense loss of local biodiversity (Lakshminarayana et al. 2001).

It is accepted that hydropower and thermal power generation by burning of fossil fuels have their own environmental and biological risks (Huntley et al. 2006), so also, it is increasingly recognized that 'Green Energy' providing wind farms do impact wildlife and environment (Drewitt & Langston 2006). In view of the above avifaunal risks, we feel that wind farm erections in strategic locations such as biodiversity hotspots should be subject to prior strategic environmental assessments (SEA) as well as environmental impact assessment (EIA) studies. The need for such SEA's and EIA's have been emphasized elsewhere (Fox et al. 2006). There is a need for 'site-based approach' for detailed biodiversity assessment studies of the plateaus of Western Ghats that are potential wind farm locations, so as to effectively enforce conservation measures during erection of wind farms in future.

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