Global Ecology and Conservation 27 (2021) e01536

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: www.elsevier.com/locate/gecco

Effects of wind farms on the nest distribution of magpie (*Pica pica*) in agroforestry systems of Chongming Island, China

Ningning Song[a], Huan Xu[a], Shanshan Zhao[a], Ningning Liu[a], Shurong Zhong[a], Ben Li[a,c,*], Tianhou Wang[a,b,*]

[a] *School of Life Science, East China Normal University, Shanghai 200062, China*
[b] *Institute of Eco-Chongming, Shanghai 202162, China*
[c] *Shanghai Key Lab for Urban Ecological Processes and Eco-Restoration, Shanghai 200241, China*

ARTICLE INFO

Article history:
Received 11 January 2021
Received in revised form 4 March 2021
Accepted 5 March 2021

Keywords:
Magpie
Nest density variables
Nest character
Wind farm
Landscape

ABSTRACT

The use of wind turbines for energy generation has complex impacts on ecosystems, especially for flying wildlife. Given the importance of birds in many ecosystems and food webs, they are often used as ecological indicators to evaluate the direct (e.g., collision mortality) and indirect (e.g., habitat degradation and loss, low food available) impact of wind farms. To test the effect of wind farms on the nest distribution of magpie (*Pica pica*), a common bird species in agroforestry systems on Chongming Island, China, the differences in magpie nest density variables and character variables were compared between quadrats inside and outside a wind farm. The relationship between magpie nest character variables and density variables in each quadrat was also examined and the impacts of landscape variables on magpie nest density variables were clarified in each quadrat. From March to December 2019, nest density variables (including total and in-use nest density) were recorded in quadrats inside and outside a wind farm in an agroforestry system on Chongming Island, Shanghai. Three nest character variables and five landscape variables were also recorded in each quadrat. The total nest density and nesting height in the quadrats outside were significantly higher than those inside the wind farm. There was a significant negative correlation between the average nest size in the quadrats and the total nest density, and a significant positive correlation between the average nesting height in the quadrats and both nest density variables. Moreover, farmland shelterbelt network cover and the distance to the nearest wind turbine were significantly positively related to the total nest density, whereas the farmland shelterbelt network cover was significantly positively related to the in-use nest density. These results indicate a negative effect of wind turbines on the nest density of magpies, which could be addressed by the provision of more farmland shelterbelt networks inside the wind farms located in agroforestry systems on Chongming Island, China.

* Corresponding authors at: School of Life Science, East China Normal University, 3663 N. Zhongshan Rd., Shanghai 200062, China.
E-mail addresses: bli@bio.ecnu.edu.cn (B. Li), thwang@bio.ecnu.edu.cn (T. Wang).

https://doi.org/10.1016/j.gecco.2021.e01536
2351-9894/

1. Introduction

In recent decades, wind energy development has had a key role in efforts to reduce carbon emissions to meet the growing demand to mitigate climate change (Pryor and Barthelmie, 2010; Thaker et al., 2018). In 2018, the global wind power market capacity worldwide increased by 51 GW, and wind power is expected to provide 20% of the global energy demand by 2050. China was the first country to exceed a wind power capacity of 200 GW and ~21.1 GW was added in 2018 (19.5 GW onshore and nearly 1.7 GW offshore) to increase the total installed capacity to ~210 GW (Renewable Energy Policy Network for the 21st Century, 2019). Although wind energy is generally regarded as an environmentally friendly and alternative energy source, its continuous growth has led to concerns about its potential environmental impacts (Leung and Yang, 2012; Tabassum-Abbasi et al., 2014).

Wind farms have significant impacts on birds that inhabit the areas around wind farms and they may lead to displacement from wind farm locations given that birds are sensitive to environmental change (Fernandez-Bellon et al., 2019; Dohm et al., 2019; Gregory and Strien, 2010; Winder et al., 2014). Bird density and population dynamics are often used as important ecological indicators to evaluate the quality of the ecological environment (Canterbury et al., 2000), and research has indicated that wind farms have different impacts on different bird communities. For example, some birds suffer increased collision mortality around wind turbines (Sovacool, 2013; Graff et al., 2016; Aschwanden et al., 2018). For other bird species, the development of wind farms can lead to habitat loss/degradation (Gómez-Catasús et al., 2018), and habitat displacement (Marques et al., 2020; Dohm et al., 2019; Veltheim et al., 2019; Vignali et al., 2021), even reducing their fertility and reproductive success (Dahl et al., 2012; Sansom et al., 2016; Shaffer and Buhl, 2016).

Successful breeding is important in maintaining the ecosystem balance, insofar as it affects the population size (Komdeur, 1996; Pearce-Higgins et al., 2012; Zhao et al., 2019) and reflects the impact of any local environmental change (Natsukawa et al., 2019). Therefore, studies focusing on the relationship between wind farms and the reproduction of birds would further reflect the long-term impact of such farms on avian populations (Dahl et al., 2012; Flaspohler et al., 2001; Hatchett et al., 2013; Pearce-Higgins et al., 2009). Many studies have explored the influence of wind farms on bird offspring, with results indicating that wind farms have different influences on the reproduction of different bird species. For example, Dahl et al. (2012) reported that the construction of wind farms resulted in white-tailed eagles withdrawing from breeding sites around the wind farm, reducing the number of nestlings. By contrast, Sansom et al. (2016) revealed that the distance to the wind turbine had no effect on the hatching and flying success of golden plover, as also reported by McNew et al. (2014) for prairie-chickens and Gillespie and Dinsmore (2014) for red-winged blackbirds. Nests are important for avian reproduction, and variations in nest density can reflect the population dynamics of birds (Garcia et al., 2015). Previous studies showed that bird nest density can be influenced by the surrounding environment, such as forest cover, level of noise, food sources, human activities, and so on (Jokimäki et al., 2017). The construction and operation of wind turbines has been defined as an important human activity because they increase noise (Garcia et al., 2015), and change the surrounding land use (Fernandez-Bellon et al., 2019) and wind patterns (Leung and Yang, 2012), which would further influence nest density (Reynolds et al., 2019). However, fewer studies have focused on how wind farms impact bird nest density mechanistically.

The number, distribution pattern, usage, size, and other nest variables of nest affect avian breeding success (Zhao et al., 2019). High-quality nests provide increased protection, especially if they are at an increased height, and larger nests can hold bigger clutches, which can increase the population density (Nakahara et al., 2015). Additional research has also indicated that nest site selection is associated with land use around the nest site (Fernandez-Bellon et al., 2019; Yuan et al., 2014; Jokimäki et al., 2017). Thus, to determine how wind farms affect nest distribution, it is necessary to clarify the relationship between nest densities, nest qualities, and landscape variables around nesting sites within a wind farm.

As a common species in East China (MacKinnon and Phillipps, 2000), the magpie (*Pica pica*) is a dominate species in agroforestry systems of Chongming Island, where wind farms have also been built. Magpies show strong adaptability to environments changing in response to human activity. They prefer tall, scattered trees for nesting (Nakahara et al., 2015; Jokimäki et al., 2017), and build nests at the start of each breeding season (March–May). The old nests are abandoned, but are easily located because of the thick leaf coverage surrounding them. Therefore, magpies are an ideal species to study the effect of wind farms on the breeding characteristics of resident birds in an agroforestry system on Chongming Island (Wang et al., 2008; Jokimäki et al., 2017).

The aim of the current study was to use quadrats inside and outside a selected wind farm to compare differences in nest density and nest characteristics of magpies, to examine the relationship between nest character variables (e.g., nest size and nesting height) and nest density, and to clarify the impact of landscape variables around nesting sites on the nest density of magpie. Therefore, we selected 32 quadrats (450 m * 450 m) inside the wind farm (within 1000 m of the closest wind turbine) and 34 control quadrats outside the wind farm (over 1000 m from the closest wind turbine) on Chongming Island, Shanghai, from March to December in 2019. We surveyed nest density variables (including the total and in-use nest densities) in the quadrats that are directly related to the success of bird reproduction (Nakahara et al., 2015). We also surveyed three character variables (nest size, nesting height, and wearing rate of the nest, which was defined by the percentage reduction in nest size in the non-breeding season versus the breeding season) and five landscape variables (cover by farmland, farmland shelterbelt network, building, and forest, and the distance to the nearest wind turbine) in the quadrats inside and outside the wind farm. We predicted the following.

(1) A lower nest density, nest size, and nesting height, and higher wearing rate for magpie nests in the quadrats inside the wind farm compared with those in the quadrats outside the wind farm given that the existing wind turbine was a human disturbance factor that changed the surrounding environment.
(2) A lower nest size and nesting height would be influenced by the wind farm to decrease the magpie nest density due to the poor nest quality with a smaller nest size and reduced safety with a lower nesting height.
(3) The magpie nest density would respond positively and significantly to the cover by farmland, farmland shelterbelt network, and forest, which are the important magpie habitats, and negatively and significantly to building cover and the distance to the nearest wind turbine, which represent higher human activity.

2. Methods

2.1. Study area

Chongming Island (121°09′ 30″–121° 54′ 00″E, 31° 27′ 00″N–31° 51′ 15″N), located in Yangtze River estuary, is a suburban area of Shanghai city. The total land area of Chongming Island is 1185.49 km^2, with a population of 688,000 (Shanghai Municipal Statistics Bureau, 2020). Farmland and forest cover 506.52 km^2 and 308.44 km^2, respectively accounting for 38.79% and 23.62% of all land-use types on Chongming Island (Shanghai Municipal Statistics Bureau, 2020); the island is thus characterized by an agroforestry system that mainly comprises forest and farmland. The forested land includes woodland patches and timberlines, with the farmland being used to grow wheat from December to May and rice from June to November. This multilevel artificial ecosystem is inhabited by diverse wildlife, especially birds (Li et al., 2020b).

Chongming Island is an important wind resource for Shanghai, with an average annual wind power density of 339.1 W/m^2; 145 wind turbines have been established since 2005, mainly concentrated in the eastern and northeastern coastal areas (Li et al., 2020a). North Lake (121° 31′ 27″E, 31° 43′ 56″N-121° 39' 47'E, 31° 37' 50'N) was chosen as the study area, with 30 established wind turbines; the wind power density in the agroforestry system around the North Lake is 300–330 W/m^2 (Yu et al., 2008). The North Lake wind farm (60 MW) was constructed in 2012 and it comprises 30 monopole wind turbines in a line in the agroforestry system (Fig. 1). The distance between adjacent wind turbines is ~450 m. The turbine hub is about 90 m high with a rotor blade of about 45 m.

2.2. Quadrat selection

Magpies usually collect food for nestlings in areas no further than 75 m from the nest site (Jokimäki et al., 2017), with previous studies indicating the potential scale to test the effect of wind farms on forest birds to be no more than 1 km (Fernandez-Bellon et al., 2019; Hatchett et al., 2013); therefore, the area inside the wind farm (≤ 1 km) and outside the wind farm (> 1 km) was defined by the distance to the closest wind turbine. We selected two agroforestry systems with similar main land cover types (such as farmland, farmland shelterbelt network, building, and forest) (Supplementary Material, Table S1), except they differed in terms of the presence and absence of wind turbines in the areas inside and outside wind farm, respectively (Fig. 1, Fig. 2). The areas inside and outside the wind farm in this study were constructed and managed by the same farm manager and these two areas were far from the village. In addition, the main human activity was cultivation and few vehicles were observed during our survey in the areas inside and outside wind farm. Therefore, we consider that there were no significant differences in land cover and human activity between the areas inside and outside the wind farm. The areas inside and outside the wind farm were measured 49.38 km^2 and 18.20 km^2, respectively. The distance between the edge of the areas inside and outside the wind farm was 2.60 km.

Given the different sizes of these areas, quadrats were used to compare the differences in nest distribution of magpies inside and outside the wind farm. According to the distance between adjacent wind turbines in North Lake, a quadrat size of 450 m × 450 m was selected to ensure that no more than one wind turbine was located in each quadrat inside the wind farm. Quadrats with a high proportion of forest and farmland shelterbelt network (≥ 10%) for nesting sites were selected (Jokimäki et al., 2017). To ensure the spatial independence of each quadrat, the minimum distance between each one was at least 50 m. In total, 66 quadrats were selected, with 32 inside the wind farm (experimental groups) and 34 outside the wind farm (control groups) (Fig. 1).

2.3. Magpie nest surveys

From March to May in 2019 (i.e., the magpie breeding season), any magpie nests in each quadrat were located and the following information recorded: nest number, nest condition (currently in use or used in previous breeding season), nest size, and nesting height. To measure the wearing rate of the nest recorded during the 2019 breeding season, nest size was compared with that measured during December 2019 (i.e., during the non-breeding season of magpies). Three investigators observed the nests on a sunny day between 08:00 and 16:00 (Jokimäki et al., 2017) with 8–42 × binoculars, and then went to the nest site to record the location of each nest in the quadrat, used a GPS receiver to locate the exact nest position, recording the latitude and longitude, and marking it in Google Earth Pro 7.3.2 (Google LLC) (Wang et al., 2015). All the nests recorded were located in

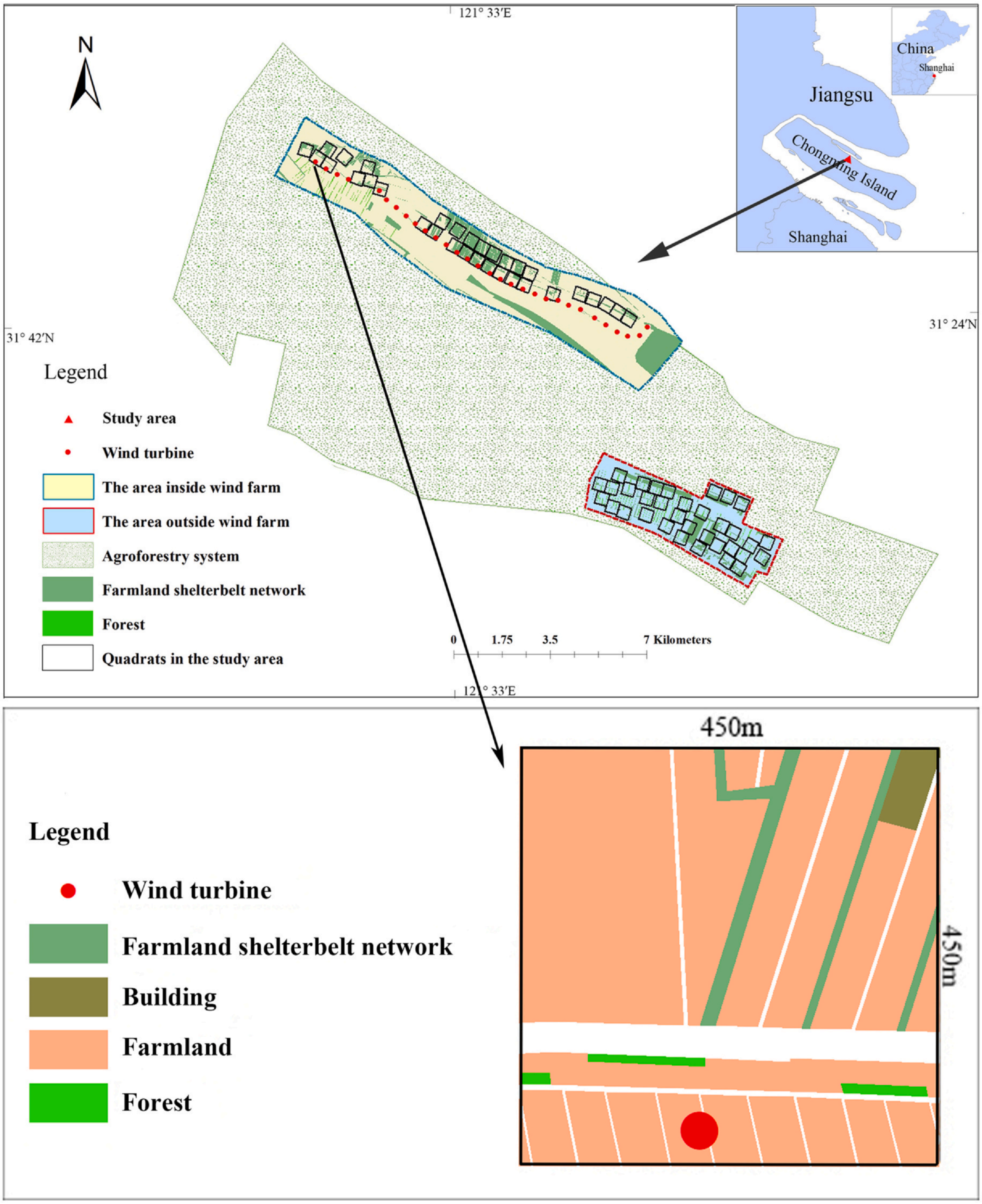

Fig. 1. Map of the study area (a) and four land cover types (farmland, farmland shelterbelt network, building, and forest) in each quadrat (b) on Chongming Island, China. Blue and red boxes represent the areas inside and outside the wind farm, respectively; black boxes represent quadrats and red dots represent wind turbines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

natural sites (i.e., in trees) rather than anthropogenic sites (e.g., located on anthropogenic objects, such as telegraph poles) to understand magpie nest distributions in natural rather than artificial sites (Lancaster and Rees, 1979; Wang et al., 2008, 2010; Nakahara et al., 2015).

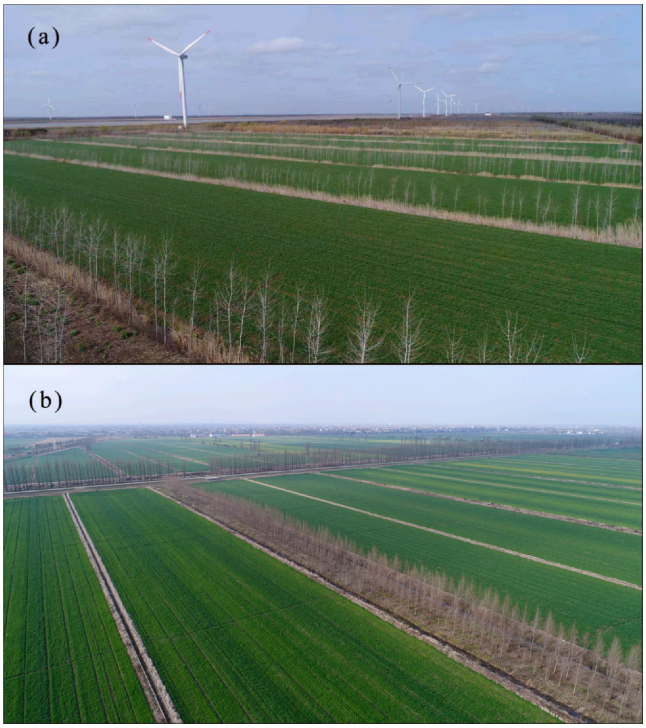

Fig. 2. The areas inside (a) and outside (b) the wind farm on Chongming Island, China.

The number of nests in each quadrat represented the nest density variable in each quadrat. Based on the breeding behaviors of magpie (including nest building, distraction displays, incubation feeding, and nestling provisioning) within 5 m of each nest, the nest density variables were divided into two categories: total nest density and in-use nest density.

2.4. Predictor variables

2.4.1. Nest character variables

During the initial investigation, the cross- and longitudinal sections of each nest were measured to reflect the nest size (Table 1). An unmanned aerial vehicle flew from the ground to the bottom of the nest to measure the nesting height (Jokimäki et al., 2017) (Table 1). The wearing rate of the nest was defined as the decrease in the nest size during the non-breeding season compared with the same nest during breeding expressed as a percentage difference (Table 1).

2.4.2. Landscape variables

According to the landscape variables related to magpie nesting in current studies (Jokimäki et al., 2017), four land cover types (farmland, farmland shelterbelt network, building, and forest) were classified within each quadrat and examined further to understand their effects on total nest density and in-use nest density (Fig. 3, Table 2). The distance to the nearest wind turbine was also measured (Table 2). Land cover data were obtained from Formosat-2 (June 2012; 2 m resolution).

Table 1
Descriptions of nest character variables for each nest in this study.

Variable	Unit	Description
Nest size	Score	Score 5: cross- or longitudinal section of nest ≥ 120 cm Score 4: cross-section 85–120 cm or longitudinal section 70–120 cm Score 3: cross-section 60–85 cm or longitudinal section 50–70 cm Score 2: cross section 35–60 cm, or longitudinal section 30–50 cm Score 1: cross-section < 35 cm, or longitudinal section < 30 cm
Nesting height	m	Height from nest bottom to ground
Wearing rate of the nest	%	Percentage reduction in nest size in non-breeding versus breeding season: $\frac{V1-V2}{V1}*100\%$ V1 = Nest size in breeding season (March–May, 2019), V2 = Nest size in non-breeding season (December, 2019).

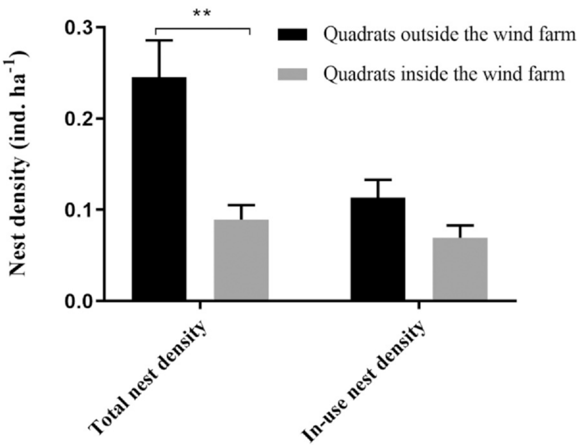

Fig. 3. Differences in the total nest density and in-use nest density of magpies in the quadrats inside and outside the wind farm on Chongming Island, China (mean ± SE). **, $P < 0.01$.

Table 2
Descriptions of landscape variables in the quadrats inside and outside the wind farm in this study.

Landscape variable	Unit	Description
Farmland cover	%	Percentage of area of farmland covered by crops (mainly rice and wheat) in each quadrat
Farmland shelterbelt network cover	%	Percentage of area of tree belt in farmland in each quadrat, comprising one or two rows of trees
Building cover	%	Percentage of area of buildings (mainly houses) in each quadrat
Forest cover	%	Percentage of area of forest or roadside trees in each quadrat
The distance to nearest wind turbine	m	Distance from the quadrat center to the nearest wind turbine in each quadrat

The percentage of each land cover type in each quadrat and the distance to the nearest wind turbine were calculated using ArcMap 10.2 (ESRI 2016) and Fragstats 4.2 (McGarigal et al., 2012).

2.5. Data analyses

2.5.1. Differences in magpie nest density and nest character variables in quadrats inside and outside the wind farm

Total nest density and in-use nest density were compared between quadrats inside and outside the wind farm. Nest size, nesting height, and nest wearing rate were used to compare differences in nest character variables in quadrats inside and outside the wind farm. Normality was tested using Shapiro–Wilk tests. Any non-normally distributed variables were logarithmically or square root transformed; however, all five variables remained non-normally distributed. Therefore, the Mann–Whitney *U* test was used to compare the differences in nest density variables and nest character variables in quadrats inside and outside the wind farm.

2.5.2. Relationship between magpie nest character variables and nest density in each quadrat

To test the effects of nest character variables (i.e., nest size and nesting height) on nest density variables (i.e., total and in-use nest density) in the quadrat, these two nest character variables were first transformed to the average nest size and average nesting height in the quadrat. A simple linear regression was used to test the relationship between nest size and nesting height and total nest density and in-use nest density in each quadrat. To clarify the linear relationship between nest character variables and nest density, all data were $\log_{10}$ transformed.

2.5.3. Impacts of landscape variables on magpie nest density in each quadrat

To test the impacts of landscape variables on total nest density and in-use nest density, the latter two variables were used as response variables, and five landscape variables (the covers of building, forest, farmland, farmland shelterbelt network, and the distance to the nearest wind turbine) were used as predictor variables. Given that total nest density and in-use nest density were count data, generalized linear models (GLMs) were run with a Poisson distribution.

To assess the collinearity among the predictor variables, their variance inflation factors (VIFs) were estimated, with $VIF > 4$ indicating a possible collinearity (Neter et al., 1996; Chatterjee and Hadi, 2006). To further check the potential spatial autocorrelation of response variables (i.e., total nest density and in-use nest density), Moran's I was calculated using ArcMap 10.2 (ESRI 2016) and GeoDa 1.14 software (Anselin et al., 2006).

A multi-model inference approach using Akaike's Information Criterion corrected for small sample sizes (AIC_C) was used to estimate and compare standardized model-weight mean coefficients of the direction and relative importance of the predictor

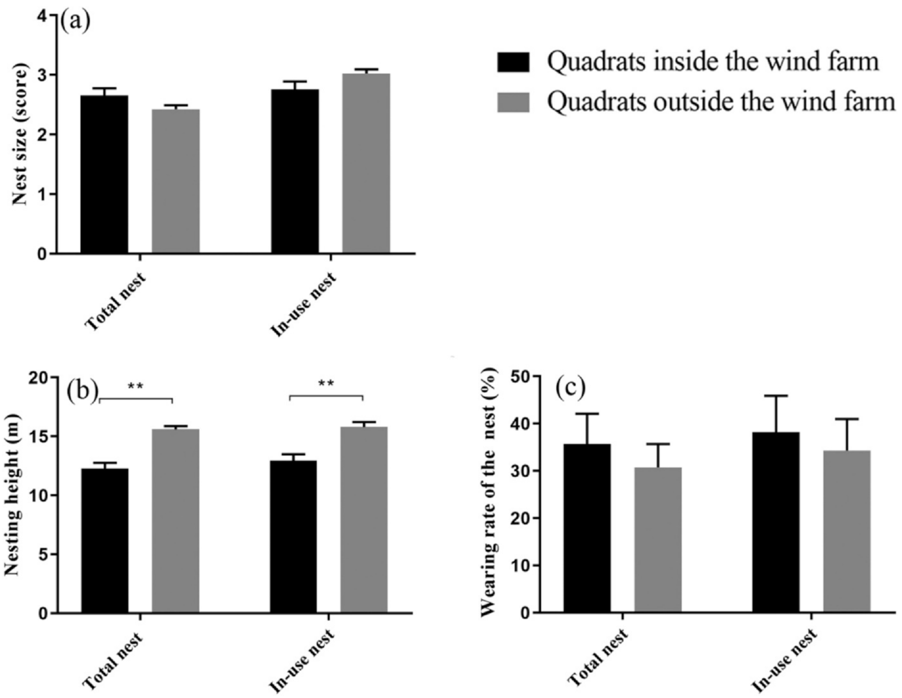

Fig. 4. Differences in nest size (a), nesting height (b), and wearing rate of the nest (c) of total and in-use nests of magpies in the quadrats inside and outside the wind farm on Chongming Island, China (mean ± SE). **, P < 0.01.

variables on each response variable. Differences in AIC_C ($\triangle AIC_C$) were used to choose the set of candidate models. All models with $\triangle AIC_C < 4$ were considered to be equally suitable for making inferences (Burnham and Anderson, 2004; Burnham et al., 2011). Akaike weights (w_i) were also calculated to further estimate whether any model was clearly the best among the candidate models ($w_i > 0.9$) (Anderson et al., 2001). The global model of total nest density and in-use nest density with the predictor variables was used to perform model selection, and model averaging of all candidate models was performed to provide model coefficients and variances.

All data processing was analyzed using R 3.6.2 (R Core Team, 2019). The 'glmulti' (Calcagno, 2019) and 'MuMIn' (Bartoń, 2019) packages were used for model selection and averaging, respectively. No problems were identified with overdispersion or heterogeneity of variance upon examination of the dispersion parameters and residuals from the models.

3. Results

3.1. Differences in magpie nest density and nest character variables in quadrats inside and outside the wind farm

In total, 227 magpie nests were found in the 30 quadrats outside the wind farm (N = 169) and 22 in the quadrants inside the wind farm (N = 58). These included 123 in-use nests and 104 used nests. In total, 166 magpie nests in 20 quadrats outside the wind farm (N = 117) and 26 quadrats inside the wind farm (N = 49) were recorded during the non-breeding season.

The total nest density in the quadrats outside the wind farm was significantly higher than in the quadrats inside the wind farm (P < 0.01) (Fig. 3); however, there was no significant difference in the in-use nest density in the quadrats inside and outside the wind farm (Fig. 3).

Although there was no significant difference in nest size and wearing rate of total nest and in-use nest in the quadrats inside and outside wind farm (Fig. 4a, c), the nesting heights of total nest and in-use nests in the quadrats outside wind farm were significantly higher than in the quadrats inside wind farm (P < 0.01) (Fig. 4b).

3.2. Relationship between magpie nest character variables and nest density in each quadrat

There were a significant negative correlation between the average nest size in the quadrats and total nest density (R^2 = 0.1138, P = 0.0144, Fig. 5a), a significant positive correlation between the average nesting height in the quadrats and total nest density (R^2 = 0.1602, P = 0.0033, Fig. 5c), and a significant positive correlation between the average nesting height in the quadrats and in-use nest density (R^2 = 0.1687, P = 0.0034, Fig. 5d). However, there was no significant relationship between the average nest size in the quadrats and in-use nests (R^2 = 0.0294, P = 0.2385, Fig. 5b).

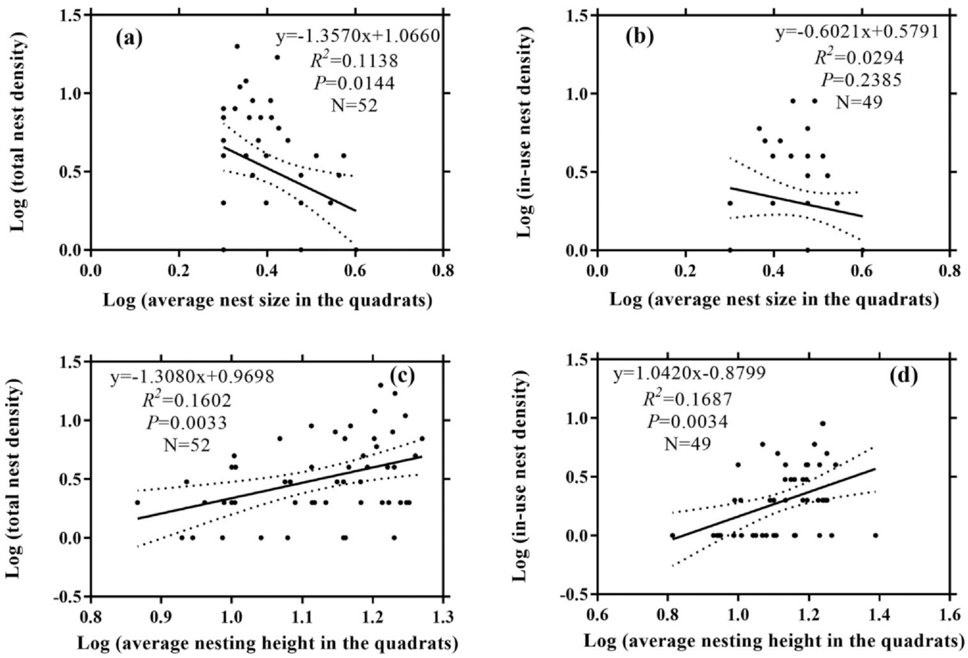

Fig. 5. Simple linear regression of total nest density and in-use nest density with nest size (a, b) and nesting height (c, d) in the quadrats inside and outside the wind farm on Chongming Island, China. The upper and lower limits of the 95% CIs are shown by dotted lines.

3.3. Impacts of landscape variables on magpie nest density in each quadrat

The VIFs for the five predictor variables were all < 4 (Supplementary Material, Table S2), which suggested no severe collinearity between the five predictor variables in the analysis. No significant spatial autocorrelations were determined for the response variables ($P > 0.1$) (Supplementary Material, Table S3).

The distance to the nearest wind turbine and farmland shelterbelt network cover were the most important predictors in the top 12 models ($\triangle AIC_C < 4$) for total nest density (Supplementary Material, Table S4). The average results of the model showed that there was a significant positive correlation between the distance to the nearest wind turbine and the total nest density [estimated mean ± standard error (SE); 0.0005 ± 0.0002, 95% confidence interval (CI) = 0.0001–0.0008]. There was also a significant positive correlation between the farmland shelterbelt network cover and the total nest density (estimate mean ± SE = 0.0705 ± 0.0350, 95% CI = 0.0019–0.1390) (Fig. 6, Supplementary Material, Table S5).

Farmland shelterbelt network cover was also the most important predictor in the top eight models ($\triangle AIC_C < 4$) for in-use nest density (Supplementary Material, Table S6). The average results of the model showed that there was a significant positive correlation between the farmland shelterbelt network cover and the in-use nest density (estimate mean ± SE = 0.1040 ± 0.0347, 95% CI = 0.0360–0.1720) (Fig. 7, Supplementary Material, Table S7).

4. Discussion

4.1. Differences in magpie nest density and nest character variables in quadrats inside and outside the wind farm

The total nest density in the quadrats inside the wind farm was significantly lower than that in those outside the wind farm (Fig. 3), which was consistent with our hypothesis and the results reported by Drewitt and Langston (2006) who showed that the construction and operation of wind turbines can reduce the nest density of birds. The total nest density can also reflect the breeding propensity (Catlin et al., 2019); the current results showed that there were more nests in the quadrats outside the wind farm, which suggested that magpies preferred to nest in areas without wind turbines. Thus, the noise and wind power created by the wind turbines might influence magpie nesting, resulting in the lower total nest density in quadrats inside the wind farm. The in-use nest could reflect magpie reproduction during the study the year; moreover, the in-use nest density can reflect the breeding propensity of magpie more accurately than the total nest density. In the current study, there were more in-use nests in quadrats outside than inside the wind farm, but there the difference was not significant; this suggests that the actual effect of wind turbines on magpie reproduction was less than expected during the study year. Given that magpies show an ability to adapt to a changing environment (Nakahara et al., 2015) and the wind farm had been in operation for 7 years, the magpies in the local area might have adapted to the presence of the wind farm, reflected by the distribution of in-use nests in the current study.

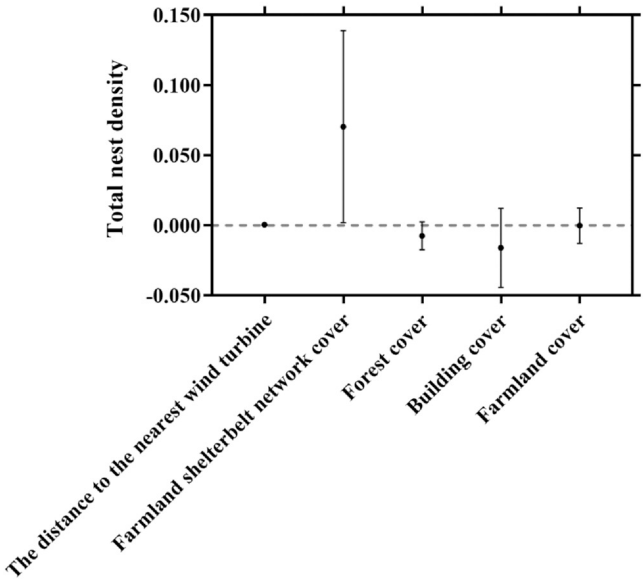

Fig. 6. Model-weighted mean standardized coefficients and 95% CIs for the direction and relative magnitude of the effects of five landscape variables (cover by farmland, farmland shelterbelt network, buildings, and forest, and the distance to the nearest wind turbine) from the top models (ΔAICc < 4) based on the total nest density of magpies in the quadrats inside and outside the wind farm on Chongming Island, China. The models for the total nest density of magpies are based on GLMs.

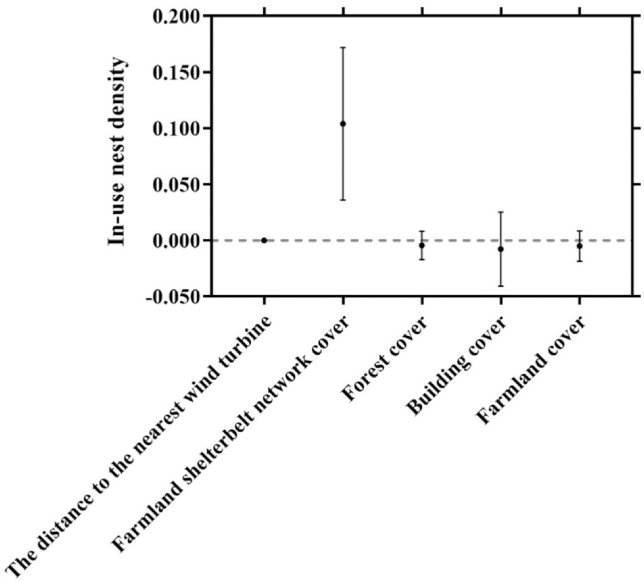

Fig. 7. Model-weighted mean standardized coefficients and 95% CIs for the direction and relative magnitude of the effect of five landscape variables (cover by farmland, farmland shelterbelt network, buildings, and forest, and the distance to the nearest wind turbine) from the top models (ΔAICc < 4) based on using the in-use nest density of magpies in the quadrats inside and outside the wind farm on Chongming Island, China. The models for the in-use nest density of magpies are based on GLMs.

The results of nest character variables showed that the nesting height of total nests and in-use nests in the quadrats inside the wind farm were both significantly lower than in quadrats outside the wind farm. Previous research showed that magpies reduce the height of their nest with a reduction in the surrounding risks, including decreases in the number of predators and the level of human disturbance (Wang et al., 2008; Jokimäki et al., 2017; Xu et al., 2020). In the current study, there were no significant differences in the quadrats inside and outside the wind farm in terms of the available nest sites (i.e., height, type, and age of trees), except for the effects of the wind turbine; for example, the wind turbine rotor generates an air vortex, which could increase the strength of the wind further up a tree (Huang et al., 2016), which would not result in a safe nest site, thus reducing the height at which the magpies site their nests (Jokimäki et al., 2017). The nesting height can also reflect reproductive success (Jokimäki et al., 2017; Catlin et al., 2019; Xu et al., 2020). The higher nesting height outside the wind farm than inside the wind farm suggests that magpie nests outside wind farm were more secure and, thus, more likely to result in successful breeding attempts. This hypothesis is supported by the fact that the in-use nests in the quadrats inside the wind farm were smaller than the quadrats outside the wind farm, a pattern not shown by the total number of nests (Fig. 4a); however, the wearing rate of the nest in the quadrats inside the wind farm was higher than that outside the wind farm (Fig. 4c), although the differences were not significant, which suggests that the wind farm does not impact this nest characteristic.

4.2. Relationship between magpie nest character variables and nest density in each quadrat

The linear regressions showed that higher magpie nesting height was correlated with nest density (both total nest and in-use nest density). Magpies prefer to nest in taller trees, and their nests need at least three to five forks to support their weight (Xu et al., 2020). The nests in the wind farm were placed lower down the trees (Fig. 4b), where fewer branching forks occurred, and thus, fewer nest sites were available, thereby decreasing the nest density. Therefore, the construction and operation of wind turbines could decrease magpie nest density inside wind farms because of this change in nesting height.

Unexpectedly, bigger nest sizes were negatively correlated with the total density of magpie nests. In agroforestry systems, magpies usually build more than one nest in the breeding season to defend against predators and parasites (Nakahara et al., 2015); however, building more than one nest requires significant energy resources, which can limit the breeding success. Therefore, multiple nests built by the same birds might be smaller than single nests to enable the bird to conserve energy. However, there were no significant differences in nest size inside and outside the wind farm, so it is unclear whether the wind farm affected nest density by influencing nest size in this study site.

4.3. Impacts of landscape variables on magpie nest density in each quadrat

The average model results of landscape variables in the quadrats showed that the total nest density increased with the distance of the quadrat from the wind turbine and with the percentage of farmland shelterbelt network in the quadrat (Fig. 6); by contrast, the in-use nest density increased only with the percentage of farmland shelterbelt network in the quadrat (Fig. 7).

Previous research showed that distance to a wind farm influences avian density (Drewitt and Langston, 2006; Gómez-Catasús et al., 2018), which was consistent with the results of the current study. This suggests that magpies are more likely to nest away from wind turbines, which would reduce the impact of the wind farm on their breeding success (Dahl et al., 2012). As a bird nesting in the canopy layer, the land-use types around the nest site can affect nest-site selection by magpies (Jokimäki et al., 2017). The current study found that magpies preferred to nest at the forest edge and in the farmland shelterbelt network, consistent with a previous report (Flaspohler et al., 2001); thus, the magpie nest density might have increased because of the higher farmland shelterbelt network cover in the study site, as also found in a study of the reproductive performance of skylarks on intensive farmland (Kuiper et al., 2015).

5. Conclusions

The results showed that wind turbines directly influence magpie nest density, and that they can change the nest characteristics (i.e., nesting height), which can, in turn, further influence nest density. Thus, developers should consider providing more favorable nesting sites for magpies (and other species with similar nesting habits) in areas inside wind farms by increasing the farmland shelterbelt network around potential nest sites and the distance to the wind turbine (Benton et al., 2003). We described possible mechanisms by which wind turbines influence magpie nest density in terms of the landscape and nest characteristics. However, whether environmental factors resulting from wind power generation (e.g., noise, and magnetic and electric fields) impact magpie nesting requires further study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This study was financially supported by the Science and Technology Commission of Shanghai Municipality (No. 18DZ1205000), the Institute of Eco-Chongming, Shanghai (No. ECNU-IEC-201902), Natural Science Foundation of China (No. 31901099), and the Fundamental Research Funds for the Central Universities. We also thank Dr. H.B. Xie and Dr. W. Zhang for help with nest research.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at 10.1016/j.gecco.2021.e01536.

References

Anderson, D.R., Link, W.A., Johnson, D.H., Burnham, K.P., 2001. Suggestions for presenting the results of data analyses. J. Wildl. Manag. 65, 373–378.
Anselin, L., Syabri, I., Kho, Y., 2006. GeoDa: an introduction to spatial data analysis. Geogr. Anal. 38, 5–22.
Aschwanden, J., Stark, H., Peter, D., Steuri, T., Schmid, B., Liechti, F., 2018. Bird collisions at wind turbines in a mountainous area related to bird movement intensities measured by radar. Biol. Conserv. 220, 228–236.
Bartoń, K., 2019. MuMIn: Multi-Model Inference. 〈https://cran.r-project.org/web/packages/MuMIn/index.html〉.
Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18, 182–188.
Burnham, K.P., Anderson, D.R., 2004. Multimodel inference - understanding AIC and BIC in model selection. Sociol. Methods Res. 33, 261–304.
Burnham, K.P., Anderson, D.R., Huyvaert, K.P., 2011. AIC model selection and multimodel inference in behavioral ecology: some background, observations, and comparisons. Behav. Ecol. Sociobiol. 65, 23–35.
Calcagno, V., 2019. glmulti: Model Selection and Multimodel Inference Made Easy. 〈https://cran.r-project.org/web/packages/glmulti/index.html〉.
Canterbury, G.E., Martin, T.E., Petit, D.R., Petit, L.J., Bradford, D.F., 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conserv. Biol. 14, 544–558.
Catlin, D.H., Gibson, D., Hunt, K.L., Friedrich, M.J., Weithman, C.E., Karpanty, S.M., Fraser, J.D., 2019. Direct and indirect effects of nesting density on survival and breeding propensity of an endangered shorebird. Ecosphere 10, e02740.
Chatterjee, S., Hadi, A.S., 2006. Regression Analysis by Example, fourth ed. John Wiley & Sons, Inchttps://doi.org/10.1002/0470055464
Dahl, E.L., Bevanger, K., Nygård, T., Røskaft, E., Stokke, B.G., 2012. Reduced breeding success in white-tailed eagles at Smøla windfarm, western Norway, is caused by mortality and displacement. Biol. Conserv. 145, 79–85.
Dohm, R., Jennelle, C.S., Garvin, J.C., Drake, D., 2019. A long-term assessment of raptor displacement at a wind farm. Front. Ecol. Environ. 17, 433–438.
Drewitt, A.L., Langston, R.H.W., 2006. Assessing the impacts of wind farms on birds. Ibis 148, 29–42.
Fernandez-Bellon, D., Wilson, M.W., Irwin, S., O'Halloran, J., 2019. Effects of development of wind energy and associated changes in land use on bird densities in upland areas. Conserv. Biol. 33, 413–422.
Flaspohler, D.J., Temple, S.A., Rosenfield, R.N., 2001. Species-specific edge effects on nest success and breeding bird density in a forested landscape. Ecol. Appl. 11, 32–46.
Garcia, D.A., Canavero, G., Ardenghi, F., Zambon, M., 2015. Analysis of wind farm effects on the surrounding environment: assessing population trends of breeding passerines. Renew. Energy 80, 190–196.
Gillespie, M.K., Dinsmore, S.J., 2014. Nest survival of Red-winged Blackbirds in agricultural areas developed for wind energy. Agric. Ecosyst. Environ. 197, 53–59.
Gómez-Catasús, J., Garza, V., Traba, J., 2018. Wind farms affect the occurrence, abundance and population trends of small passerine birds: the case of the Dupont's lark. J. Appl. Ecol. 55, 2033–2042.
Graff, B.J., Jenks, J.A., Stafford, J.D., Jensen, K.C., Grovenburg, T.W., 2016. Assessing spring direct mortality to avifauna from wind energy facilities in the Dakotas. J. Wildl. Manag. 80, 736–745.
Gregory, R.D., Strien, A.V., 2010. Wild bird indicators: using composite population trends of birds as measures of environmental health. Ornithol. Sci. 9, 3–22.
Hatchett, E.S., Hale, A.M., Bennett, V.J., Karsten, K.B., 2013. Wind turbines do not negatively affect nest success in the Dickcissel (Spiza americana). Auk 130, 520–528.
Huang, Z.J., Pan, Z.Y., Hu, Y.G., Wang, X.B., Wu, W.Y., 2016. Research on 3D wind field and temperature variation based on tea antifrost fan. Chin. J. Agric. Mech. 37, 75–79.
Jokimäki, J., Suhonen, J., Vuorisalo, T., Kövér, L., Kaisanlahti- Jokimäki, M.L., 2017. Urbanization and nest-site selection of the Black-billed Magpie (Pica pica) populations in two Finnish cities: from a persecuted species to an urban exploiter. Landsc. Urban Plan. 157, 577–585.
Komdeur, J., 1996. Breeding of the Seychelles Magpie Robin Copsychus sechellarum and implications for its conservation. Ibis 138, 485–498.
Kuiper, M.W., Ottens, H.J., van Ruijven, J., Koks, B.J., de Snoo, G.R., Berendse, F., 2015. Effects of breeding habitat and field margins on the reproductive performance of Skylarks (Alauda arvensis) on intensive farmland. J. Ornithol. 156, 557–568.
Lancaster, R.K., Rees, W.E., 1979. Bird communities and the structure of urban habitats. Can. J. Zool. 57, 2358–2368.
Leung, D.Y.C., Yang, Y., 2012. Wind energy development and its environmental impact: a review. Renew. Sustain. Energy Rev. 16, 1031–1039.
Li, B., Yuan, X., Chen, M., Bo, S.Q., Xia, L., Guo, Y., Zhao, S.S., Ma, Z.J., Wang, T.H., 2020a. How to strive for balance of coastal wind energy development with waterbird conservation in the important coastal wetlands, a case study in the Chongming Islands of East China. J. Clean. Prod. 263, 121547.
Li, B.C., Wang, J.F., Liu, W., Xie, H.B., Zhang, W., Ma, S., Yang, G., Yin, J.F., 2020b. Analyzing community stability of terrestrial breeding bird in greenspaces and agricultural ecosystems in Shanghai. J. Ecol. Rural Environ. 36, 567–572.
MacKinnon, J., Phillipps, K., 2000. A Field Guide to the Birds of China. Oxford University Press.
Marques, A.T., Santos, C.D., Hanssen, F., Muñoz, Antonio-Román, Onrubia, A., Wikelski, M., Moreira, F., Palmeirim, J.M., Silva, J.P., 2020. Wind turbines cause functional habitat loss for migratory soaring birds. J. Anim. Ecol. 89, 93–103.
McGarigal, K., Cushman, S., Ene, E., 2012. FRAGSTATS v4: Spatial pattern analysis program for categorical and continuous maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. 〈http://www.umass.edu/landeco/research/fragstats/fragstats.html〉. (Accessed 9 July 2020).
McNew, L.B., Hunt, L.M., Gregory, A.J., Wisely, S.M., Sandercock, B.K., 2014. Effects of wind energy development on nesting ecology of Greater Prairie-Chickens in fragmented grasslands. Conserv. Biol. 28, 1089–1099.
Nakahara, T., Kuroe, M., Hasegawa, O., Hayashi, Y., Mori, S., Eguchi, K., 2015. Nest site characteristics of the newly established Eurasian Magpie Pica pica population in Hokkaido, Japan. Ornithol. Sci. 14, 99–109.
Natsukawa, H., Mori, K., Komuro, S., Shiokawa, T., Umetsu, J., Ichinose, T., 2019. Environmental factors affecting the reproductive rate of Urban Northern Goshawks. J. Raptor Res. 53, 377–386.
Neter, J., Kutner, M.H., Nachtsheim, C.J., Wasserman, W., 1996. Applied Linear Statistical Models. Irwin Press, Chicago.
Pearce-Higgins, J.W., Stephen, L., Langston, R.H.W., Bainbridge, I.P., Bullman, R., 2009. The distribution of breeding birds around upland wind farms. J. Appl. Ecol. 46, 1323–1331.
Pearce-Higgins, J.W., Stephen, L., Douse, A., Langston, R.H.W., 2012. Greater impacts of wind farms on bird populations during construction than subsequent operation: results of a multi-site and multi-species analysis. J. Appl. Ecol. 49, 386–394.
Pryor, S.C., Barthelmie, R.J., 2010. Climate change impacts on wind energy: a review. Renew. Sustain. Energy Rev. 14, 430–437.
R Core Team, 2019. R: A language and environment for statistical computing. R foundation for statistical computing. 〈https://www.r-project.org〉.
Renewable Energy Policy Network for the 21st Century, 2019. Renewables 2018 global status report. 〈http://www.ren21.net/status-of-renewables/global-statusreport/〉. (Accessed 9 July 2020).
Reynolds, S.J., Ibanez-Alamo, J.D., Sumasgutner, P., Mainwaring, M.C., 2019. Urbanisation and nest building in birds: a review of threats and opportunities. J. Ornithol. 160, 841–860.
Sansom, A., Pearce-Higgins, J.W., Douglas, D.J.T., 2016. Negative impact of wind energy development on a breeding shorebird assessed with a BACI study design. Ibis 158, 541–555.
Shaffer, J.A., Buhl, D.A., 2016. Effects of wind-energy facilities on breeding grassland bird distributions. Conserv. Biol. 30, 59–71.

Shanghai Municipal Statistics Bureau, 2020. ⟨http://ss.shanghai.gov.cn/⟩.
Sovacool, B.K., 2013. The avian benefits of wind energy: a 2009 update. Renew. Energy 49, 19–24.
Tabassum-Abbasi, Premalatha, M., Abbasi, T., Abbasi, S.A., 2014. Wind energy: increasing deployment, rising environmental concerns. Renew. Sustain. Energy Rev. 31, 270–288.
Thaker, M., Zambre, A., Bhosale, H., 2018. Wind farms have cascading impacts on ecosystems across trophic levels. Nat. Ecol. Evol. 2, 1854–1858.
Veltheim, I., Cook, S., Palmer, G.C., Hill, F.A.R., McCarthy, M.A., 2019. Breeding home range movements of pre-fledged brolga chicks, Antigone rubicunda (Gruidae) in Victoria, Australia – implications for wind farm planning and conservation. Glob. Ecol. Conserv. 20, e00703.
Vignali, S., Lörcher, F., Hegglin, D., Arlettaz, R., Braunisch, V., 2021. Modelling the habitat selection of the bearded vulture to predict areas of potential conflict with wind energy development in the Swiss Alps. Glob. Ecol. Conserv. 25, e01405.
Wang, Y.P., Chen, S.H., Jiang, P.P., Ding, P., 2008. Black-billed Magpies (Pica pica) adjust nest characteristics to adapt to urbanization in Hangzhou, China. Can. J. Zool. 86, 676–684.
Wang, Y.P., Huang, Q., Lan, S.S., Zhang, Q., Chen, S.H., 2015. Common blackbirds Turdus merula use anthropogenic structures as nesting sites in an urbanized landscape. Curr. Zool. 61, 435–443.
Wang, Z., Wang, Y., Jerzak, L., Zhang, Z., 2010. Nest site selection of the Magpie Pica pica sericea in Beijing of China. Biol. Stud. 4, 71–82.
Winder, V.L., McNew, L.B., Gregory, A.J., Hunt, L.M., Wisely, S.M., Sandercock, B.K., 2014. Space use by female Greater Prairie-Chickens in response to wind energy development. Ecosphere 5, art3.
Xu, Y., Cao, Z.Y., Wang, B., 2020. Effect of urbanization intensity on nest-site selection by Eurasian Magpies (Pica pica). Urban Ecosyst. 23, 1099–1105.
Yu, H.M., Zhou, H.Z., Xin, W., 2008. Analysis and assessment on wind energy resource in Chongming Islands. Renew. Energy Res. 26, 76–79.
Yuan, Y.J., Zeng, G.M., Liang, J., Li, X.D., Li, Z.W., Zhang, C., Huang, L., Lai, X., Lu, L.H., Wu, H.P., Yu, X., 2014. Effects of landscape structure, habitat and human disturbance on birds: a case study in East Dongting Lake wetland. Ecol. Eng. 67, 67–75.
Zhao, J.M., Yang, C., Lou, Y.Q., Shi, M., Fang, Y., Sun, Y.H., 2019. Nesting season, nest age, and disturbance, but not habitat characteristics, affect nest survival of Chinese grouse. Curr. Zool. 66, 29–37.