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Drivers of Electric Pylon Used as Nesting Sites by Birds in Baicheng City, China

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ZH and HTW conceived and designed the study. All authors participated in the field survey and data analysis. ZH wrote the first version of the manuscript. All authors read and approved the final manuscript.

Key words
Nesting birds, Power lines, Pylon use, Conservation planning, Random forest model, Landscape

ABSTRACT

Overhead power lines and associated infrastructure are expanding significantly worldwide. Though power lines are often considered to negatively affect bird populations due to electric collision and electrocution, pylons may serve as artificial perches, roosting sites, or nesting locations for various bird species. In this study, we first examined differences in surrounding habitat characteristics of occupied pylons among bird species in Baicheng City, northeastern China. Then we evaluated the relative importance of habitat variables on pylon selection by nesting birds. Among the 860 surveyed electric pylons in Baicheng, 56 nests of six bird species (Eurasian Magpie, Common Kestrel, Daurian Jackdaw, Amur Falcon, Little Owl, and Oriental White Stork) were detected. The percentage of pylons used as birds' nesting supports is approximately 6.51%. Bird species that occupy pylons exhibited nonrandom nest-placement patterns, they tend to nest on pylons characterized by a greater amount of grassland, water, and cropland in the surroundings. In addition, no significant differences were observed in the habitat characteristics between species pairs. Random Forest model highlighted nest occurrence on pylons was strongly influenced by NDVI and other landscape features, such as water proportion and grassland proportion in the pylon surroundings, and the intermediate value of NDVI, edge density, and patch richness can contribute to a relatively low pylon use rate. Our results provide evidence to identify and predict high-risk regions where high-voltage pylons and power lines might be located. It also has conservation implications when building artificial nesting platforms on suitable pylons to create new habitats for target species.

INTRODUCTION

The global demand for electricity in the last few decades has promoted a rapid deployment of power line networks (IRENA, 2017). Worldwide, tens of millions of birds die annually due to power lines (Scott *et al.*, 2014), and it has long been recognized as one of the most important negative impacts associated with overhead transmission and distribution systems (Bevanger, 1994; Lehman *et al.*, 2007; Bernardino *et al.*, 2018). Importantly, several studies have argued that overhead power lines and their support structures may increase the local bird diversity, especially in treeless landscapes or in intensive agricultural landscapes, as they provide alternative nesting, resting, and perching sites (Tryjanowski *et al.*, 2004, 2014; Mainwaring, 2015). Yet, most bird nests constructed on electric power line supports often pose a risk, as nest-building material increases the weight placed on the supports, and the excreta of nestling and adult birds deposited on pylons or the connection between energized conductors caused by nest materials may lead to fires and power outages (Moreira *et al.*, 2023). This will not only reduce the reliability of the electrical system, kill or injure birds but also bring significant financial losses to both the power supply and consumption sides (Moreira *et al.*, 2023).

The deforestation of many landscapes and the widespread distribution of power lines make them prone to being used as nest sites by a range of birds (Mainwaring, 2015), including species of conservation value such as raptors and vultures (Dixon *et al.*, 2013; Chevallier *et al.*, 2015). The likelihood of problematic pylon use by nesting birds can vary among species and is largely dependent

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upon the spatial distribution of power line structures (De Lucas *et al*., 2008; Ferrer *et al*., 2012). For example, large- or medium-sized birds, including raptors, cranes, storks, and passerines like ravens are more likely to nest on pylons (Bevanger, 1998; Schaub *et al*., 2010). Pylons that are placed on migratory pathways or in major congregation habitats (such as wetlands, and extensive steppes) tend to be more attractive to birds, as birds establish breeding or wintering colonies there, use them as potential stopover areas during migration, and consequently concentrate at high densities, which could increase the likelihood of pylon use. Conversely, birds may avoid using electric pylons that are distributed in the vicinity of roads, and other areas with intense human activities (Shaw *et al*., 2018). Additionally, pylon use has been found to intensify where food resources are more accessible (Moreira *et al*., 2018).

Understanding the drivers of pylon use by nesting birds can provide useful information for companies to mitigate against potential collisions and electrocutions. Nevertheless, there is still much uncertainty about such drivers, mainly because most studies are species-specific or site-specific, making it difficult to clarify what affects the likelihood of pylon use at a large spatial scale. Here, we characterized the use of transmission power line pylons by nesting birds in Baicheng City, an area for which this type of data was previously lacking. First, we examined differences in habitat characteristics of occupied pylons among species. Secondly, we evaluated the relative importance of habitat variables on pylon selection by nesting birds.

MATERIALS AND METHODS

The occurrence of bird nests on electricity pylons of the overhead transmission network was surveyed from 2021 to 2023 in Baicheng City, northeastern China. The city covers an area of 25758 km^2 and extends from 121°38′E to 124°22′E and 44°13′N to 46°18′N, and the human population density is ca.71 inhabitants/km^2. The terrain from the northwest to the southeast of the region is low mountains, hills, and plains. It has a typical temperate monsoon climate, with sufficient light time and less rainfall. The mean annual precipitation and temperature are around 400mm and 5.2°C, respectively (Peng *et al*., 2023).

We consulted with the local electric power company for information about existing power lines (e.g. distribution, voltage, and technical characteristics). During March–July, coinciding with the birds peak breeding season, we covered a total of 260 km 220-kV power lines and checked 860 pylons to record active bird nests. We considered the nest as active (i.e., being used by a breeding pair) if we observed eggs, nestlings, or an incubating/brooding bird (Andrew, 2013). The field observation was conducted with binoculars from vehicles or on foot. If the visibility condition is favorable, we drove a car along the routes of the power lines with a speed of 15–20 km/h. In places with less visibility or accessibility (e.g., dense vegetation), the search was carried out on foot (Orihuela-Torres *et al*., 2021). Based on the major surrounding habitat, we roughly assigned each pylon to one of five main land cover types: Village (272 pylons), farmland (226 pylons), forest (215 pylons), grassland (79 pylons), and wetland (68 pylons).

For each electricity pylon, we obtained a set of nine landscape-scale habitat variables within a 300-m buffer radius: water proportion, grassland proportion, cropland proportion, forest proportion, impervious surface proportion, edge density, patch richness, and Shannon diversity of land cover types. These metrics were calculated by the "landscapemetric" R package (Hesselbarth *et al*., 2019), from a Landsat-derived annual China land cover dataset (CLCD) with a 30-m resolution in 2020, in which land cover was grouped into nine categories: cropland, forest, shrub, grassland, water, snow and ice, barren, impervious, and wetland. The overall accuracy of CLCD reached 79.31 %, more details on the land cover dataset itself can be found in (Yang and Huang, 2021). We used a buffer radius of 300 m to minimize the spatial overlap between two adjacent buffered areas and consequently to avoid high redundancy of landscape attributes for two adjacent pylons. Based on the location of each pylon, we obtained the annual maximum normalized difference vegetation index (NDVI) to represent the best status that vegetation can achieve in a single growing season (Cuomo *et al*., 2001). NDVI has been proven to be closely related to the coverage of vegetation and reliable for monitoring vegetation dynamics of the land surface (Xue and Su, 2017). The NDVI dataset has a resolution of 30m, and spans from 2000 to 2022, we chose the year 2020 to match that of the CLCD dataset (Yang *et al*., 2019).

Because power-line pylons are used as nesting structures by different bird species, we used non-metric multidimensional scaling (NMDS) to identify linear combinations of habitat features that best identified structure differences among species nest sites. NMDS is widely used to simplify multivariate data into a few important axes to facilitate the recognition and interpretation of patterns and differences among groups. Unlike other ordination techniques that rely on (primarily Euclidean) distances, NMDS uses rank orders and thus is an extremely flexible technique that can accommodate a variety of different kinds of data. NMDS was performed using the first two dimensions and random starting iterations to obtain the lowest stress value. NMDS was complemented by a permutational analysis of variance

(PERMANOVA) to determine whether the habitat features statistically differed between pairs of species. We used the Holm method to correct for the mass significance that can arise when performing multiple comparisons. This method rejects hypotheses sequentially until no further rejections can be done and adjusts the p values according to the number of tested hypotheses (Holm, 1979). The NMDS and PERMANOVA analysis was carried out by the "vegan" R package (Oksanen *et al*., 2022).

Random Forest (RF) was then employed to model the influence of explanatory variables on nest occurrence on pylons and to assess their relative importance. RF is a non-linear classification and regression tree analysis that can handle many inputs, including redundant or irrelevant variables, as well as continuous and categorical data types (Breiman, 2001). RF creates many internal training/testing data subsets and aggregates the predictors, resulting in stable and consistent results that generally do not overfit the data and can be evaluated through validation processes. RF is easy to tune and has been successfully incorporated into ecological studies (Simon *et al*., 2023). We categorized each pylon as either nest present or absent and considered it as the response variable. We further evaluated multi-collinearity between explanatory habitat variables via the Pearson correlation coefficient and variance inflation factor (VIF) analysis with R package 'car' (Fox and Weisberg, 2011). The process excluded two habitat variables, which are core area and Shannon diversity of land cover types. VIF values (all < 3.5) and pairwise correlation between the remaining explanatory variables (all $|r|<0.70$) were low.

We then assessed spatial autocorrelation in the RF model's residuals using the "plot_moran" function based on Moran's I index. The predictive performance of RF was evaluated by Area under the receiver operator characteristic curve (AUC). We run RF by the "random Forest SRC" package with the default setting, except the number of trees was set as 5000 to make sure enough trees were fitted. We measured and plotted the relative importance of each habitat variable, with higher values indicating a stronger influence (Ishwaran and Lu, 2019). Partial dependence plots were also derived to display the effect of a variable on the response while controlling for the average effect of all other variables in the model. All analyses were performed in the R statistical environment (R Core Team, 2023).

RESULTS

A total of 860 different electric pylons were surveyed, the distance between two adjacent pylons ranges from 250m to 530m, with the median and standard deviation as 300m and 68m, respectively. 56 nests of six bird species were detected on pylons in Baicheng city. The Eurasian Magpie *Pica pica* is the species that used such structures the most, occupying 50.0% of the total pylons, followed by the common kestrel *Falco tinnunculus* (19.6%). The other four species, Daurian jackdaw *Corvus dauuricus*, Amur falcon *Falco amurensis*, little owl *Athene noctua,* oriental white stork *Ciconia boyciana* used 14.3%, 8.9%, 3.6%, and 3.6% pylons, respectively.

Table I. PER MANOVA analysis to determine the pylons' habitat difference between pairs of nesting birds. The degrees of freedom (Df), sums of squares (SS), pseudo-*F* statistic (F), partial R2 (R^2), and *P*-value for each term (Pr(>F)) along with the adjusted *P*-value (adjusted sig) also shown.

Species pairs	Df	SS	F	R^2	p. value	Adjusted sig
Eurasian magpie vs Common kestrel	1	412.58	0.06	0.00	0.889	1.000
Eurasian magpie vs Oriental white stork	1	24368.67	3.54	0.11	0.055	0.825
Eurasian magpie vs Amur falcon	1	4604.65	0.76	0.02	0.418	1.000
Eurasian magpie vs Little owl	1	2640.77	0.39	0.01	0.652	1.000
Eurasian magpie vs Daurian jackdaw	1	141.46	0.02	0.00	0.966	1.000
Common kestrel vs Oriental white stork	1	20354.67	2.63	0.19	0.093	1.000
Common kestrel vs Amur falcon	1	2301.84	0.41	0.03	0.577	1.000
Common kestrel vs Little owl	1	2036.14	0.28	0.02	0.799	1.000
Common kestrel vs Daurian jackdaw	1	29.92	0.00	0.00	0.992	1.000
Oriental white stork vs Amur falcon	1	11819.92	2.77	0.36	0.183	1.000
Oriental white stork vs Little owl	1	6055.99	0.55	0.22	0.667	1.000
Oriental white stork vs Daurian jackdaw	1	19849.22	1.72	0.18	0.201	1.000
Amur falcon vs Little owl	1	1323.03	0.41	0.08	0.663	1.000
Amur falcon vs Daurian jackdaw	1	2471.59	0.32	0.03	0.680	1.000
Little owl vs Daurian jackdaw	1	2044.57	0.19	0.02	0.869	1.000

The low stress value (less than 0.2) indicated the first two NMDS axis provided a good representation of reduced habitat dimensions. On the NMDS ordination diagram, the convex hulls of pylon site characteristics largely overlapped (Fig. 1). PERMANOVA confirmed that no significant differences were observed in the used pylon site characteristics among species pairs (Table I).

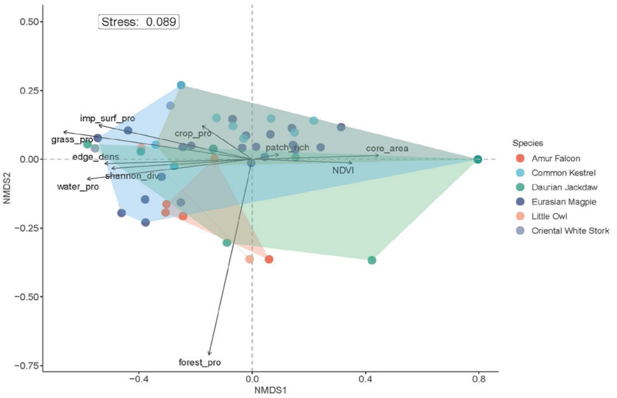

Fig. 1. Non-metric multidimensional scaling plot based on the Bray–Curtis dissimilarity matrix for surrounding habitat features of occupied pylons by nesting birds. The proximity of species to arrows and their perpendicular distance along an arrow are measures of the relative influence of explanatory variables. Convex hulls connecting the vertices of the points showed how species cluster based on their occupied pylons' habitat features.

The random forest model had a good performance (AUC over 0.72). There was no significant spatial autocorrelation in the model's residuals (Supplementary Fig. S1). Birds tend to build nests at pylons with high NDVI values, or surrounding habitat of which has a high proportion of water, grassland, and cropland. Conversely, pylons with greater edge density and patch richness were mostly linked with nest absence. Overall, edge density, grassland, and forest proportion were the three most important drivers affecting pylon use by nesting birds, with patch richness and cropland proportion having lower importance (Fig. 2).

The partial response plots showed that pylons located in areas with a high proportion of grassland were preferentially selected by nesting birds (Fig. 3). The likelihood of pylon use increased steeply when water occupied over 10% of the buffer. Although both have lower importance, cropland and forest proportion in the 300-m buffer around each pylon also increased pylon use (Fig. 3). The response trends of nest occurrence to NDVI, patch richness and Shannon diversity were roughly similar, as the likelihood first decreased then got greater towards the increases of these habitat gradients, while the change points were substantially different (Fig. 3).

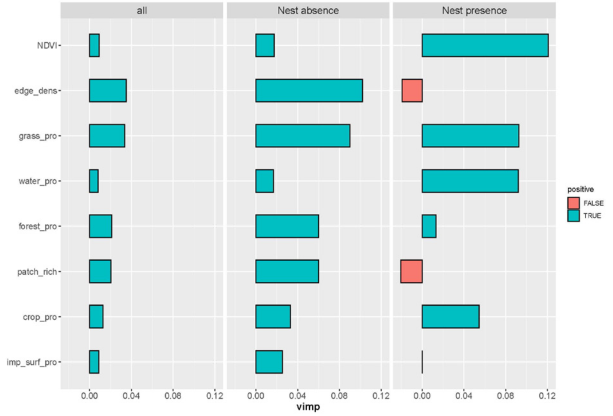

Fig. 2. The variable importance (VIMP) plot for each habitat variable when predicting the presence and absence of nesting birds on electric pylons using random forest models.

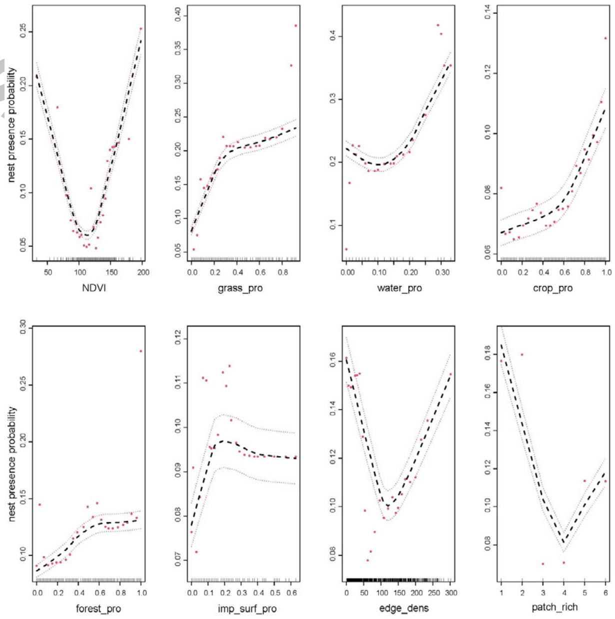

Fig. 3. Partial dependence plots (representing estimated marginal effects when the remaining variables are held at their average) for eight environmental variables used in the Random Forest model. Variables are sorted by their relative importance in predicting nest presence on electric pylons.

DISCUSSION

The electric pylons have been widely used as nesting supports by a range of birds, while these structures can sometimes act as ecological traps, as birds can be more easily hurt by collision or electrocution (Martin and Shaw, 2010), and the temporary nature of pylons also means that they can be dismantled and thus, lost as suitable nesting sites fast (Mainwaring, 2015). In this study, we assessed the drivers of pylon selection by nesting birds, such information could help to detect high-risk regions that high-voltage pylons and power lines might locate. Power companies can use it to account for the likelihood of conflict-prone use of pylons when siting future power lines. It also has conservation implications for building artificial nesting platforms on suitable pylons to provide new habitats for target species (Tryjanowski *et al*., 2009; Guil and Pérez-García, 2022).

The percentage of pylon use as birds' nesting supports in Baicheng city (6.51%) is slightly higher than the percentage of approximately 4.99% reported in central Spain (Infante and Peris, 2003). This is probably due to the difference in the local bird population density or the survey region size. The six bird species in this study exhibited nonrandom nest-placement patterns. They tend to nest on pylons characterized by a greater amount of grassland, water, and cropland, which may provide greater environmental resources for their own requirements (such as forging) and those of their offspring in the breeding season. This pattern was also observed in other transmission networks used by storks and other large birds (Ding *et al*., 2021; Moreira *et al*., 2023). Eurasian magpie, common kestrel, and Daurian jackdaw were the most frequently detected nesting birds on pylons, they have been well demonstrated to utilize such anthropogenic structures frequently (Howe *et al*., 2014; Mahmood *et al*., 2020; Xu *et al*., 2020). These species have large body sizes and high wing loadings, along with other raptors, waterfowl, and waders are always of particular concern for power line collision and electrocutions (Hernández-Matías *et al*., 2015; McClure *et al*., 2018; Guil and Pérez-García, 2022). In addition, no significant difference was found in the surrounding habitat characteristics of used pylons among species pairs, this would indicate a relatively low level of specificity in their pylon site choice. Another reason could be in regions with a large proportion of grassland or cropland, pylons are probably the only alternative nesting substrates due to the lack of natural ones (Mainwaring, 2015). Amur falcon was known to use usurped or old nests (Andrew, 2013), though it was generally difficult to determine which species had originally built these nests. The similarity of nesting site preferences may facilitate pylon use, but it can lead to negative biotic interactions (e.g., stronger competition for the best sites) between them (Barrero *et al*., 2023).

The partial plots reveal that the likelihood of pylon use was positively associated with the proportion of different landscape features (i.e., grassland, water, cropland, forest and impervious surface) in the pylon surroundings, these features have been previously described as preferred foraging or perching habitats for storks (Kaługa *et al*., 2011), raptors (Carrascal *et al*., 1993), vultures (Phipps *et al*., 2013), and passerines (Lesiński, 2000; Howe *et al*., 2014). Several studies have shown the presence of wetlands can largely increase feeding habitat suitability for nesting storks (Tryjanowski *et al*., 2009; Gadenne *et al*., 2014; Janiszewski *et al*., 2014; Tomasz *et al*., 2014), it is reasonable to assume that the higher amount of natural habitats can provide more food supply, therefore can promote the likelihood of pylons being used for nesting. The impervious surface around each pylon can act as an open habitat, making the nesting birds easier to detect prey or predators. Another possibility is the impervious surface is generally linked with human settlements where garbage or trash is more accessible, which can be used as extra food resources for crows (Vuorisalo *et al*., 2003) or storks (Gilbert *et al*., 2016).

We found NDVI strongly influenced pylon use, the likelihood of which decreased at first but then increased shapely along the NDVI gradient. NDVI is an indicator of vegetation cover and net primary productivity (Pettorelli *et al*., 2005), previous studies have shown high NDVI values promoted species diversity (Haedo *et al*., 2017; Leveau and Isla, 2021). However, in our case, the high pylon use rate occurred at relatively low or high levels of greenness, which may reflect birds' nesting preference for open or enclosed habitats, or represent the trade-off in selection between habitat type and productivity. Bird species usually avoid using breeding or nesting habitat within their home ranges near edges (Winter *et al*., 2000; Coppes *et al*., 2017), as nests may experience higher rates of human disturbance and predation or brood parasitism in smaller habitat fragments or closer to edges (Winter and Faaborg, 1999; Benson *et al*., 2013). This may explain why the pylon use decreased with the increasing edge density and patch richness. However, the reason behind the positive relationship between them after a certain threshold is not well understood, some unmeasured variables (e.g., food resource, biotic interaction) may offset the magnitude and direction of edge effects.

When inappropriately designed, high-voltage pylons and power lines are threatening many birds due to collision and electrocution (Bevanger, 1994; Lehman *et al*., 2007). We highlighted nest occupation on pylons was strongly influenced by NDVI and other landscape features, such as water proportion and grassland proportion in the pylon surroundings, and the intermediate value of NDVI, edge density, and patch richness can contribute to a relatively low pylon use rate. It is possible that variables not measured in our study (e.g., weather conditions, food resources, human disturbance, and pylon technical features) could be responsible for unaccounted variability in the pylon use, but we argue that our approach contributes to developing useful tools to mitigate potential bird collision proactively. It allows power companies to identify and predict priority infrastructures where to take mitigation measures to prevent birds from nesting. To conserve birds better, further research on the costs and benefits of pylon structures as nesting sites (e.g. breeding success and mortality) for target birds would be useful. Continuous monitoring of bird spatial distribution during breeding, migratory, or wintering periods, along with timely supervision of distribution lines, can also decrease bird incidence rates of electrocution and collision.

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Supplementary material

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Statement of conflict of interest

The authors have declared no conflict of interest.

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Supplementary Material

Drivers of Electric Pylon Used as Nesting Sites by Birds in Baicheng City, China

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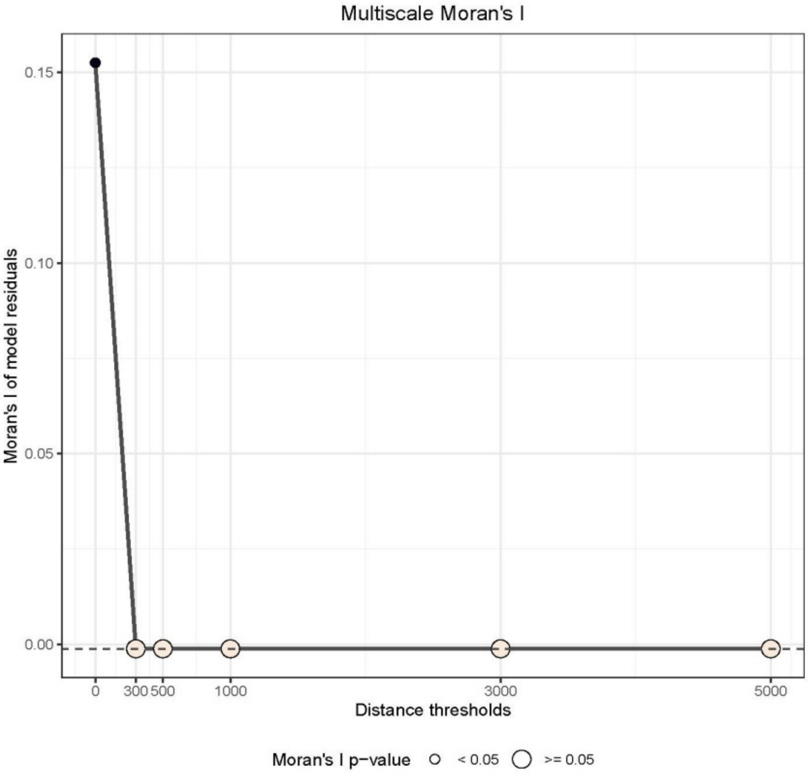

Supplementary Fig. S1. The results of spatial autocorrelation in the residuals of the random forest model. The y-axis represents Moran's I estimate, and the x-axis contains the values of the distance thresholds. The dot sizes represent the p-values of the Moran's I estimate, and the black dashed line represents the theoretical null value of the Moran's I estimate. The spatial autocorrelation is weak and non-significant for neighborhood distances larger than 300m.

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