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A methodological framework integrating habitat suitability and landscape connectivity to identify optimal regions for insecticide application: a case study in Tongzhou, China

1 **Abstract**

2 Insecticide application is still a standard method in pest management. However, the current regions for
3 insecticide application usually focus on the host of the pest but ignore the migration pathways,
4 continually resulting in pests' periodic outbreaks. This research provides a valuable modeling
5 framework to identify optimal regions for insecticide application to solve this problem. This modeling
6 framework optimizes insecticide areas based on habitat suitability and landscape connectivity,
7 combining the MaxEnt and circuit theory. We conducted a case study in Beijing, China, to elucidate
8 the application of this modeling framework. The input data included 517 occurrence points of
9 *Semiothisa cinerearia* collected in the fieldwork and the environmental variables related to the eco-
10 physiological characteristics of this species. The results indicated that the Chinese scholar tree
11 (*Styphnolobium japonicum*) was the most vulnerable species. Increasing the pesticide region by 11.9%
12 at some crucial corridors of the target species, the pest management effectiveness increased by 27.7%,
13 compared with the pesticide applied only to the Chinese scholar trees. In summary, this study proposed
14 a convenient and efficient modeling methodology for planning optimal regions for insecticide
15 application.

16 **Keywords:** *Styphnolobium japonicum*, Pest control, Ecology model, Species distribution models,
17 Circuit theory, Invasive species management

18 **1   Introduction**

19   Pest outbreaks in natural and artificial forest ecosystems result in degradation of tree fitness, thus
20 significantly increasing rates of tree mortality (Ferrenberg, 2016; Marini et al., 2021). For example,
21 *Semiothisa cinerearia* (Bremer et Grey; Lepidoptera: Geometridae) has caused severe damage to the
22 Chinese scholar tree (*Styphnolobium japonicum*), a widely planted urban green tree species in China
23 and East Asia (Tang et al., 2014; X.-Y. Zhu et al., 2020). The *S. cinerearia* consumes the entire tree
24 leave in 2-3 days and causes disease and ultimately death to the host tree (Wu et al., 1998; Zhang et
25 al., 2013). In some cities, 50% to 100% of *S. japonicum* had been hosted by *S. cinerearia* (Zhang et
26 al., 2013) and therefore warrant special attention to control urban green trees loss, especially in like
27 Beijing where air pollution is a severe issue. Additionally, over the last decades, climate change has
28 triggered an increase in the range expansion and outbreaks of some pests (Fernandez-Carrillo et al.,
29 2020; Venäläinen et al., 2020). Forest insect pace with climate change are expected to be highly
30 propagative, due to shorter life cycle, and have higher fecundity and survival rate (Jactel et al., 2019).
31 Spraying insecticide is still a common practice in pest management, especially in the urban modified
32 forestry ecosystems (Meissle et al., 2010).

33   However, using insecticides could not wholly solve some pests' periodic/sporadic outbreaks. For
34 example, *Simulium chutteri* (a blackfly) broke out periodically in South Africa, even though some wide
35 insecticide control measures have been conducted (Rivers-Moore et al., 2008). Instead, unchecked and
36 excessive insecticides caused damage to the natural ecosystem and would be lethal for the pests' natural
37 predators (Frolov, 2015; Tang et al., 2008). The ever-growing list of pests is damaging natural and
38 artificial forest ecosystems worldwide (Aukema et al., 2010; Loo, 2008; Ramsfield et al., 2016; Santini

et al., 2013). Therefore, it is urgent to determine the efficient regions for pesticides to decrease the risk of periodic outbreaks and the damage of insecticides to the natural ecosystem.

The hypothesis that some insects occupy multiple niches (or hosts) during their life histories and migration processes could be the basis to explain these issues (Buckley et al., 2010; Melin et al., 2007; Singer, 1983). For instance, the Asian long-horned beetle (*Anoplophora glabripennis*) attack more than 15 families of tree species throughout their invasion pathways (Dodds and Orwig, 2011; Haack et al., 2010). Therefore, if the controlling measures had been conducted at the most suitable habitat (e.g., the food source of the pest), the other adjacent and suitable niches would still provide habitat to the survived individuals of the pests (Cowley et al., 2015; Demirozer et al., 2012; Dupas et al., 2014; Laćan and McBride, 2008). This hypothesis implied that if the spread pathways had not been cut off, the periodic outbreaks would possibly happen again (Tang et al., 2008). Therefore, not only the habitat suitability should be considered (Phillips et al., 2006)   , but the dispersal pathways should also be cut off by anthropogenic barriers to decrease the risk of secondary pest outbreaks (Dickson et al., 2019; Hlásny et al., 2016).

Previous studies (Marchioro and Krechemer, 2021; Reil et al., 2018; Schöneberg et al., 2020) merely estimated the habitat suitability or landscape connectivity to optimize the pest management regions. Habitat suitability and landscape connectivity are two critical requirements for periodic pest outbreaks (Zhu et al., 2020). Still, little has been done to integrate these two essential requirements to identify regions for efficiently applying insecticide for pest management (Elmes et al., 2019). On the one hand, habitat suitability quantifies the suitable niche of the targeted pest. Thus, the realized niche of this targeted species (specific environmental condition) would identify (Zhu et al., 2020). The MaxEnt model was a commonly used species distribution model (SDM) to estimate the habitat suitability (Phillips et al., 2017; Phillips and Dudík, 2008; Yang et al., 2018), especially for pest management (Kumar et al., 2014; Wang et al., 2010), which is based on a machine-learning algorithm to predict the suitable habitat distribution with the maximum entropy solution (Phillips et al., 2006). On the other hand, landscape connectivity measures the dispersal ability in the pest invasion pathways (Dickson et al., 2019). As a result, the potentially spatial movement patterns across their incontiguous and heterogeneous habitats can be simulated (Dupas et al., 2014; Viani et al., 2018). The circuit theory estimates the landscape connectivity of species based on the equivalence between graph theory representations of random flow of electrons in a circuit (McRae et al., 2008). Many studies applied this method on species invasion (Elmes et al., 2019; Falaschi et al., 2018), distribution range shift of endangered mammals (Puddu and Maiorano, 2016; Zhao et al., 2019), gene flow of a disease vector (Medley et al., 2015), and phylogeographic analysis (Dupas et al., 2014). Therefore, it is necessary to develop an integrated approach considering both habitat suitability and landscape connectivity, contributing to the prevention of periodic pest outbreaks.

This research provided a useful modeling framework integrating MaxEnt and the circuit theory to identify optimal regions for insecticide application of *S. cinerearia*, as a case study in Tongzhou district, Beijing, China. The result was a raster map representing the SDM-circuit values. This article aimed at 1) constructing a combine model, integrating MaxEnt and circuit theory using the field surveyed data points; 2) testing the hypothesis that *S. cinerearia* occupied multiple niches in an urban ecosystem, and 3) customizing the strategy for efficient and economical pest control in their inherent outbreak regions and dispersal pathways.

2   Materials and Methods

2.1   Study area

The study area was the entire region of Tongzhou District (39°36′-40°02′N, 116°32′-116°56′E, area 912.34 km^2, altitude 8.2-27.6 m) of Beijing, China (Figure 1). The mean annual temperature record in the area is 11.3°C, while the average annual precipitation is 620 mm, and the frost-free period is about 190 days per year. The outbreaks of *S. cinerearia* in 2013 had critically damaged the urban green trees in the study area (Tang et al., 2014). Some insecticides were subsequently adopted for pest control, but based on our fieldwork findings, the population of *S. cinerearia* persisted with periodic outbreaks in the area (Figure 1). The adverse impact in this sprawling city caused by the *S. cinerearia* was a heavy financial burden to the local government. A new city is in the construction and development phase here, as the Chinese capital sub-center (Wanghe et al., 2019). Therefore, it is essential to efficiently control pest outbreaks in the future, which is critical to the new city's development.

2.2 Sampling

We randomly set 24 quadrats (3km × 3km) in the urban and rural areas of Tongzhou District (Figure 1). To achieve random placement of those quadrats, we first divided the study areas into 101 grids. Secondly, 1,000 random points were generated on the grids. These random points were developed by the "Create Random Points" tool in the system toolbox of ArcGIS 10.2.2 software. After repeating the second step 10 times, the top 24 quadrats with the most randomly generated points were selected as the sampling quadrats. Fieldwork was conducted from June to August 2018. We searched and collected the target specimens S. cinerearia using the "Sweep Sampling Method" (Gadagkar et al., 1990) in each quadrat, in which we systematically swept all the ground level vegetation < 2.5m). The occurrence points were recorded with the help of a Global Position System (GPS) with the World Geodetic System 1984 (WGS 84) coordinate system. Five hundred seventeen individuals of *S. cinerearia* were collected in the fieldwork (Figure 1 and Table S1). The collected voucher specimens were deposited in the Natural Museum of Beijing Forestry University, Beijing, China.

2.3 The scope, assumption, and framework of the modeling

Figure 2 illustrates the modeling framework of this study. A combine model, integrating MaxEnt and the circuit theory was applied. The scope of this combination was to predict the dispersal ability of the target pest relating to the original habitat suitability without any control measurements and the changes of habitat suitability after some control measures were conducted. This study was based on certain assumptions. First, we assumed that the results of MaxEnt represent the present habitat suitability before pest control. Second, we assumed that the control measures change the current habitat suitability of the pest. By comparing the SDM-circuit values among those different scenarios (explained in Section 2.8), the pest management effectiveness among the scenarios was identified.

2.4 Environmental variables

Eight environmental variables (Table 1) were selected to model habitat suitability based on current knowledge of the eco-physiological characteristics of targeted species (Jiang et al., 2018; Lozier and Mills, 2011), especially in the urban areas (Godefroid et al., 2020) Additionally, our study area landscape is plain and relatively small, without apparent altitude and climate differences, so we did not select altitude and climate as the environmental variables.

The environmental variables were extracted from the forest resource inventory database and the land-use dataset (Table 1). The forest resource inventory database in 2015 was a polygon shapefile provided by the Beijing Tongzhou Forestry Bureau. The locations of *S. japonicum* (the primary host of *S. cinerearia*), the percentage coverages of forests, and shrubs and meadows in a cell were extracted from this database as raster maps at the resolution of 10m × 10m. The land-use dataset in 2015 was

126 interpreted from a series of Gaofen-2 satellite images (resolution = 0.80 m) (Wanghe et al., 2020b,
127 2020a, 2019). Subsequently, four environmental variables, the distance from a raster to the nearest
128 building, road, cropland, and water, were derived from the land-use dataset using the Euclidean
129 Distance System Toolboxes of ArcGIS 10.2 software (Environmental Systems Research Institute Inc.,
130 Redlands, USA).

2.5 Species distribution model (SDM)

2.5.1 Correlation analyses of the environmental variables

To avoid model overfitting in calibration caused by multicollinearity among predictors (Warren and
Seifert, 2011), we conducted the pairwise correlation (*r*) analyses among the environmental variables
by the Band Collection Statistics Tool of ArcGIS 10.2 software, Following Dormann *et al., (2013)*
suggestion (conservative threshold of *r* = |0.7|) All eight environmental variables exhibited low
bivariate correlation coefficients < |0.7| (Table S2) in the current study. Therefore, all eight variables
were retained for further analyses.

2.5.2 Parameter setting of MaxEnt model

The MaxEnt model version 4.4.1 (Phillips et al., 2006) was used to estimate the habitat suitability from
the 517 surveyed occurrence points of *S. cinerearia* and the eight derived environmental variables of
these occurrence points. The model was submitted to 10 repetitions, and for each repetition, cross-
validation was performed. The occurrence dataset was randomly split into ten equal parts; each was
employed as the model built with the remnants nine test dataset. Accordingly, all records were
practiced nine times for training and one for testing the model, and all the observations were equally
weighted in the training and testing of the model (Merow et al., 2013). A convergence threshold of
0.00001 was inputted, with 500 interactions and 10,000 background points. The Jack-Knife test
quantified the participation of each environmental variable in the modeling. To avoid overfitting,
MaxEnt was operated, allowing only "linear", "product" and "quadratic" features (Falaschi et al., 2018).
The accuracy of the final result was assessed by the area under the receiver operating characteristics
curve (AUC). The range of AUC was from 0 to 1, and the relatively high value of AUC indicated that
the model's prediction result was relatively accurate and agreeable (Figure S1) (Phillips et al., 2006).
This approach produced a raster habitat suitability map with values ranging from 0 to 1.

2.6 Connectivity model

The connectivity model was built using Circuitscape version 4.0.5 (McRae and Shah, 2014), a software
designed to model habitat connectivity using the electrical circuit theory (McRae et al., 2008). The
input was a conductance map from the habitat suitability map estimated by the MaxEnt model. The
standard conductance of each cell was defined by rescaling the habitat suitability map between 0
(minimum suitability) to 1 (maximum suitability). Circuitscape ran in advanced mode to allow for the
use of arbitrary current sources and grounds. The cells at the host location were set as current sources
of one ampere. The cells at the perimeter of the study areas represented the ground of one ohm,
following Falaschi *et al., (2018)*. Thus, the model could predict the possible spread of *S. cinerearia*,
considering all possible directions in one fell swoop (Cowley et al., 2015). The current densities of the
cells estimated by this connectivity model were defined as the SDM-circuit values. The higher SDM-
circuit indicated cells with more necessary net passage probabilities for random movement, moving
from one raster to another (McRae et al., 2008). The movement boundaries and the "pinch points"
among populations were identified by Kernel Density analyses (Silverman, 2018) based on the SDM-
circuit values, using the Kernel Density Tool (Silverman, 2018) of ArcMap 10.2 software (ESRI,
2011).

2.7   Scenario developments

The SDM and connectivity model identified the regions of suitable habitat and corridors of *S. cinerearia*. However, widely spraying insecticide at all those regions was costly and would further impose some unfavorable impacts on the ecosystem, such as damaging the pests' natural enemies Therefore, a cost-effective solution was to detect the significant and economical regions/areas for chemical control. To determine that cost-effective solution, we developed five scenarios and compared the pest management effectiveness of those scenarios.

Firstly, we defined that part A was the host's location and part B was the location of other tree species except for the host. Secondly, part B was divided into five sub-parts based on the SDM-circuit values ranked by Jenks natural breaks method (Chen et al., 2013): top 20% (sub-part B20), top 40% (sub-part B40), top 60% (sub-part B60), top 80% (sub-part B80), and top 100% (sub-part B100). Those natural break classifications were in terms of natural groupings inherent to their SDM-circuit values, whose class breaks were identified that the best group was similarly valued and that maximizes the differences between classes (ESRI, 2011). Thirdly, the regions for insecticides of scenario B*n* were defined as the union of part A and sub-part B*n* (*n* = 20, 40, 60, 80, and 100, respectively) (Figure S2). Based on the second and third assumptions described in section 2.3, the habitat suitability of the regions for insecticides was modified to a value approaching zero. The habitat suitability of the regions without insecticides remained unchanged. Finally, the five scenarios were independently inputted to the connectivity model.

2.8   Scenario comparisons

To examine pest management performance/effectiveness, those five scenarios were compared with the connectivity model's original result (without the assumptive scenario). The "fuzzy numerical" algorithm (Jiang and Chen, 2003) (Equations 1 and 2) was implemented, allowing a cell-to-cell comparison between two raster maps. In Equations 1 and 2, map A was the initial result of the connectivity model, and map B was one of the scenarios. The raster maps A and B were in the same location with the same rows and columns. The a_i and b_i were one cell on the maps A and B in the same location, and *j* was the total number of cells. Consequently, $S_{(ai,bi)}$ depicted a new map highlighting the divergences between maps A and B. $S_{(A,B)}$ referred to the average differentiation between the entire maps of A and B, ranging from zero to one: one meaning two completely different maps, and zero representing an identical pair. Therefore, a higher $S_{(A,B)}$ indicated a better pest management performance of a sub-scenario than the original result (Visser and De Nijs, 2006). Those calculations were programmed by Python 2.2 using the ArcPy site package (ESRI, 2011).

$$S_{(a_i,b_i)} = 1 - \frac{|a_i - b_i|}{\max(|a_i|, |b_i|)} \qquad \text{Equation 1}$$

$$S_{(A,B)} = 1 - \frac{\sum_{a_i=b_i=1}^{j} S_{(a_i,b_i)}}{j} \qquad \text{Equation 2}$$

Ultimately, a regression model between the two variables, $S_{(A, B)}$ and the control area of sub-part B*n*, was conducted by the basic Trendline R package. The computer device executing all analyses was a Mac Pro (2019) graphic workstation with 3.5GHz Intel Xeon W CPU, 32 GB RAM, and Windows 10 Professional operating system.

3   Results

3.1 *S. cinerearia* habitat suitability

The AUC value (0.895 ± 0.018, mean ± standard deviation) indicated that the results of SDM had a receivable result (Figure S1). The high AUC value (compared to the possible maximum 1.0) indicated that the quality of habitat suitability map derived by the MaxEnt models was high and the sampling quadrats were sufficient (Phillips et al., 2006) . The relative importance of environmental variables was assessed by the Jack-Knife test (Figure 3), which implied that forests and hosts appeared to have the most useful statistical information. The contributions of environmental variables are in Table S3. The habitat suitability map of *S. cinerearia* (Figure 4) illustrated that the average suitability in the entire study was 0.1231 (SD = 0.1791). Comparably, the mean suitability in the location with *S. japonicum* was 0.5315 (SD = 0.1468), while the average suitability in the regions without *S. japonicum* was 0.1101 (SD = 0.1640). Our results indicated that the places of *S. japonicum* were ordinarily more suitable for *S. cinerearia* than other land-use types.

We compared the habitat suitability among the top ten widely planted tree species in Tongzhou District (Figure 5). *S. japonicum*, the host of *S. cinerearia*, provided the most suitable habitat for this pest insect. In other words, *S. japonicum* was the most vulnerable species to *S. cinerearia*, compared with the other nine tree species, which was also widely planted in the study area. The genus *Populus* (*P. tomentosa* and *P. canadensis*) presented the least suitable habitat to *S. cinerearia* compared to the other eight species.

3.2 *S. cinerearia* habitat connectivity

The map of current densities/SDM-circuit values (Figure 6) indicated the passage probabilities of the target pest. A cell with a high current density value implied that it would provide great landscape connectivity to *S. cinerearia* (McRae et al., 2008). Our results showed that the mean current density of the host tree species (*S. japonicum*) was 39.268 (SD = 30.456), while the average current density of other tree species was 25.973 (SD = 25.892).

Six populations with high current densities were distinguished (Figure 6). Our results recognized some "pinch points" (Figure 6). The "pinch points" were narrow linear pathways of *S. cinerearia* between or within those populations.

3.3 Scenarios comparisons

The area of part A is 27.03km^2, and the areas of sub-parts B20, B40, B60, B80, and B100 (the red patches in Figure S2) are 3.22, 20.55, 65.47, 137.90, and 253.28km^2, respectively. Figure 7 describes the differences in management performances among these scenarios. While the effectiveness of pest management on the host was similar from scenarios B20 to B100, by increasing the area of chemical control, the passage probabilities of *S. cinerearia* in the other tree species were decreasing.

Figure 8 displays the regression model results between two variables, $S_{(A, B)}$ and A (the area of the sub-part Bn). The most suitable model was the polynomial regression, whose $R^2 = 0.9937$. This result indicated that management effectiveness increased while enlarging the regions of chemical control when $A < 200$ km^2. The marginal benefit of scenario B20 was the maximum among all scenarios. Therefore, scenario B20 was the most efficient one to conduct chemical prevention, in which the areas of chemical application were increased only by 3.22 km^2 (11.9%). At the same time, the connectivity of the other trees species was decreased by 27.7%.

4 Discussion

4.1 The implications for pest management

The list of forests being damaged by pests is growing worldwide (Aukema et al., 2010; Loo, 2008; Ramsfield et al., 2016; Santini et al., 2013). Compared with natural forests, urban trees are more vulnerable to pest incursions (Paap et al., 2017). The limited tree diversity in the urban ecosystem further predisposes urban forests to potentially devastating pest outbreaks (Laćan and McBride, 2008; Paap et al., 2017). For example, ash is a widely planted city street tree in the United States, consisting primarily of a limited number of cultivars of white and green ash (*Fraxinus americana* and *Fraxinus pennsylvanica*) (MacFarlane and Meyer, 2005). This situation resulted in low genetic diversity and enhanced the risk of pest incursions to urban plants. As a result, extensive damage occurred in urban greening of the northeastern United States with the accidental incursions of the emerald ash borer (*Agrilus planipennis*) (Kovacs et al., 2010) In the current study, the urban forests were composed of dozens of different tree species (Figure 5). However, the periodic outbreaks of *S. cinerearia* have been causing significant disruption to the urban forests, although some chemical control focused on the host. Similarly, *Simulium chutteri* broke out periodically in South Africa, even though some integrated control measures have been adopted (Rivers-Moore et al., 2008) . The issues remained as neither increasing the diversity of urban forest nor host-specific pest management measures may completely solve periodic pest outbreaks, which could be explained by the theory of island biogeography and landscape ecology (Simberloff, 1974; Zimmerman and Bierregaard, 1986). Our study focused on an area of the urban ecosystem at the local scale, where the urban trees were always isolated by some artificial surfaces and infrastructures, such as road networks and buildings (Wanghe et al., 2019). Consequently, each isolated land unit of urban greenery (e.g., an urban park) could be regarded as an analogous island (Zimmerman and Bierregaard, 1986). Because of the homogenous environment at the local scale, these widely planted urban greening trees (Figure 5) in each island likely occupied similar niches (Shushan et al., 2016), whose community structure would adapt itself to a dynamic equilibrium among the parasitoid and host, as well as their habitat (Zimmerman and Bierregaard, 1986).

Our results highlighted that the targeted insect's connectivity and migration should be considered a significant component within pest management. In many cases (Dodds and Orwig, 2011; Haack et al., 2010; Paap et al., 2017; Santini et al., 2013; Smith et al., 2007), some clear evidence proposed that after the arrival of these pests into urban areas, their subsequent spread into natural or planted forest landscapes was through multiple means and migratory pathways. For example, the invasive pathways of Asian long-horned beetles contained more than 15 families of trees, which remained in the urban settings until the 2008 outbreak in the natural forest in Massachusetts, the United States (Dodds and Orwig, 2011; Haack et al., 2010). In the current study, although *S. japonicum* was the primary host and provided the most suitable habitat to *S. cinerearia*, other tree species might still provide multiple niches to the moth (Zhang et al., 2013). The current study identified 42.9% of the occurrence points near but not located in *S. japonicum*. This result indicated that the imago of *S. cinerearia* could migrate and select multiple niches (tree species) other than its primary host (Figure 5). In addition, the result of the connectivity model (Figure 6) identified that not only the host tree species of *S. cinerearia* helped the pest to migrate, but other tree species also served the same purpose. We built and tested different scenario comparisons, suggesting that there would be multiple migratory pathways of *S. cinerearia* if the most suitable habitat (i.e., the primary host) had been removed. Those representations possibly supported the hypothesis of insects' multiple niches because of their migration and adaptation abilities.

We presumed that decreasing the pests' connectivity at some momentous pathways (e.g., the pinch points in Figure 6) might sufficiently alleviate the probability of periodic outbreaks and consequential spread. *S. japonicum* was the most vulnerable to the incursion of *S. cinerearia*, compared with the other widely planted nine tree species found in the area. A study suggested that *S. japonicum* was not the only food source of *S. cinerearia* (Tang et al., 2014). The pest prevalence in other plant species indicated that it could survive at different habitats in an urban ecosystem. Therefore, spraying pesticides only in its favorable habitat (*S. japonicum*) would not eliminate the outbreak, as some

survivors with resistance genes could move to the other niches through some high connectivity corridors (Feng et al., 2019; Tang et al., 2019). As a result, there would always be a risk of a secondary pest outbreak. Those representations might explain the reasons for periodic pest outbreaks in our study area, even if some chemical control had been conducted on the most vulnerable tree (i.e., *S. japonicum*). The other habitat providing critical landscape connectivity, such as sub-part B20 (Figure S2a), was also the potential and efficient pest management region (Figure 9). Our results showed that the genus *Populus* (*P. tomentosa* and *P. canadensis*) presented the most miniature habitat suitability. In other words, it was more resistant to *S. cinerearia* than the other eight species. Therefore, planting *P. tomentosa* and *P. canadensis* at "pinch points" would probably halt the outbreak and migration of *S. cinerearia*. Moreover, some anthropogenic barriers should be built in the "pinch points" to decrease the connectivity. For example, although the Sixth Ring Road isolated the Populations B and C (Figure 6), some "pinch points" between the two populations still acted as corridors for *S. cinerearia*. Thus, cutting off those "pinch points" could minimize the probability of migration between Populations B and C.

4.2 The availability and limitation of this combinational model for pest management

Many studies (Fischbein et al., 2019; Jiang et al., 2018; Müller et al., 2019) recognized potential habitat aimed at pest management by SDM without analyzing landscape connectivity. Thus, some significant pathways of the target species could not be identified (Cowley et al., 2015). For example, the potential dispersal of the Asian long-horned beetle was predicted using (but not combining) SDM and the circuit theory (Elmes et al., 2019), but the relationship between habitat suitability and landscape connectivity was ignored. However, few studies used this associated method on pest insect management (Elmes et al., 2019). Nonetheless, combining these two methods could identify a more practical pest management strategy without increasing the fieldwork labor and data input. In the current study, we illustrated a straightforward working procedure of this combinational modeling (Figures 2 and 9). This integrated method has also been empirically applied to predict the expansion of species invasion (Elmes et al., 2019; Falaschi et al., 2018), distribution range shift of endangered mammals (Puddu and Maiorano, 2016; Zhao et al., 2019), the process of gene flow of a disease vector (Medley et al., 2015), and phylogeographic analysis (Dupas et al., 2014). These case studies identified that this combination model was available to different ecological processes.

Geographic information system (GIS) has grown in popularity in recent years, and it has realized the integration of various types of data and algorithms, providing sophisticated tools for analyzing, editing, mapping, and performing spatial queries on data (Günen, 2021a). Meanwhile, some integrated GIS-based spatial models have improved the decision support processes in many research fields, such as energy planning (Günen, 2021b), urban greening planning (Pelorosso et al., 2014), endangered animal conservation (Ahmad et al., 2020b, 2020a), and even helping to clarify the extent and impact of the COVID-19 pandemic (Franch-Pardo et al., 2020). In this paper, we proposed an integrated GIS-based modeling framework to improve research and applications focused on pest management. Three advantages were concluded as follows. Firstly, the researcher easily acquired the input data, only including the occurrence points (Figure 1) and eco-physiological environment layers (Table 1) of the targeted pest. Secondly, the results explicitly determined the relationship between the pest and the environment of its habitat (Table S3), as well as the potential regions for pest management. These results mapped the pests' vulnerable regions for forestry managers (e.g., the suitable habitat in Figure 4 and the pinch points and corridors in Figure 6). Thirdly, the management effectiveness (Figures 7 and 8) of different scenarios were reasonably quantified. Thus, customized solutions could be proposed in various pest situations (scenario B20 in Figure 9).

We concluded that our model has great potential in designing pest management policies and strategies in other similar situations around the world. Nonetheless, this approach had some limitations, which could be eliminated in further studies. For example, the spatial autocorrelation and pseudo-replicates may decrease the results' confidence (e.g., AUC value). Because our occurrence points were only obtained by our fieldwork at the local scale, whose spatial autocorrelation and pseudo-replicates were likely ignorable (Guisan et al., 2017), we did not examine the spatial autocorrelation in model residuals. Instead, if the occurrence points were from different sources at a large scale, the spatial autocorrelation should be detected by the Moran's I test on the generalized linear models (Guisan et al., 2017). Additionally, our results lacked validation. In a future study, we would experimentally implement scenario B20 to validate this model.

5   Conclusions

Tree being damaged by pest is global problem, especially in metropolitan cities. To eradicate pest and manage its outbreak, it is necessary to identify suitable habitat, corridors, and cut off the migratory pathway rather than only insecticide application. Because the only chemical eradication is not only expensive, laborious but also disturb the biological control mechanism and alleviate ecosystem function. Landscape connectivity has been defined as the degree to which the landscape facilitates or impedes movement among different patches, is a critical component of ensuring healthy ecosystems.

In the current study, we proposed a spatially explicitly GIS-based modeling framework, including MaxEnt and circuit theory to identify optimal regions for insecticide application. The AUC value indicated the parsimony results of SDM. The high AUC value indicated that the quality of habitat suitability map (derived by the MaxEnt models) was high and the sampling quadrats were sufficient.

This modelling framework can minimize damage to the natural ecosystem related to the unchecked and excessive use of pesticides and decrease the risk of periodic outbreaks. These optimal locations were targeted on potentially suitable habitat and the critical migration pathways, supporting precise insecticide application to save operation costs (e.g., travel and human efforts). Furthermore, this proposed modeling framework could be rerun for different parameters and newly collected points data to apply to similar urban areas for pest management.

6   Conflict of Interest

The research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

7   Acknowledgments

8   Author Contributions

XG, WK, and KL contributed to conception and design of the study. XG and KZ investigation and sample collection. XG, SA and WK performed the statistical analysis and wrote the first draft of the

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manuscript. IIS, GN, KL wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

9   Supplementary Material

Table S1: The occurrences database of *Semiothisa cinerearia*, Table S2: The detail results of Pearson correlation analyses among the eight environmental variables, Table S3: The relative contributions of eco-physiological variables used in the MaxEnt model for habitat suitability of *Semiothisa cinerearia*, Figure S1: The area under the receiver operating characteristics curve (AUC) of the MaxEnt model, Figure S2. The pest management locations of Scenario B*n* (red and grey patches). The grey patches are the locations of hosts (sub-part A described in section 2.7 of the main body). The red patches are the locations of the other trees (sub-part B*n* described in section 2.7 of the main body). From scenarios B20 to B100, the pest management locations are enlarging based on the range of landscape connectivity ranked by Jenks natural breaks.

References

Adjemian, J.C.Z., Girvetz, E.H., Beckett, L., Foley, J.E., 2006. Analysis of Genetic Algorithm for Rule-Set Production (GARP) modeling approach for predicting distributions of fleas implicated as vectors of plague, Yersinia pestis, in California. Journal of medical entomology 43, 93–103.

Ahmad, S., Khan, T.U., Hacker, C., Yang, L., Nabi, G., Ullah, S., Wanghe, K., Shah, S., Chen, M., Saeed, S., Luan, X., 2020a. Critical assessment of Asiatic ibex (Capra ibex sibirica) for sustainable harvesting in northern areas of Pakistan. Global Ecology and Conservation 22. https://doi.org/10.1016/j.gecco.2020.e00907

Ahmad, S., Yang, L., Khan, T.U., Wanghe, K., Li, M., Luan, X., 2020b. Using an ensemble modelling approach to predict the potential distribution of Himalayan gray goral (Naemorhedus goral bedfordi) in Pakistan. Global Ecology and Conservation 21. https://doi.org/10.1016/j.gecco.2019.e00845

Aukema, J.E., McCullough, D.G., Von Holle, B., Liebhold, A.M., Britton, K., Frankel, S.J., 2010. Historical accumulation of nonindigenous forest pests in the continental United States. BioScience 60, 886–897.

Buckley, T.R., Marske, K., Attanayake, D., 2010. Phylogeography and ecological niche modelling of the New Zealand stick insect Clitarchus hookeri (White) support survival in multiple coastal refugia. Journal of Biogeography 37, 682–695.

Chen, J., Yang, S., Li, H., Zhang, B., Lv, J., 2013. Research on geographical environment unit division based on the method of natural breaks (Jenks). Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci 3, 47–50.

Cowley, D.J., Johnson, O., Pocock, M.J.O., 2015. Using electric network theory to model the spread of oak processionary moth, Thaumetopoea processionea, in urban woodland patches. Landscape Ecology 30, 905–918.

Demirozer, O., Tyler-Julian, K., Funderburk, J., Leppla, N., Reitz, S., 2012. Frankliniella occidentalis (Pergande) integrated pest management programs for fruiting vegetables in Florida. Pest Management Science 68, 1537–1545.

421 Dickson, B.G., Albano, C.M., Anantharaman, R., Beier, P., Fargione, J., Graves, T.A., Gray, M.E.,
422   Hall, K.R., Lawler, J.J., Leonard, P.B., 2019. Circuit-theory applications to connectivity science
423   and conservation. Conservation Biology 33, 239–249.

424 Dodds, K.J., Orwig, D.A., 2011. An invasive urban forest pest invades natural environments—Asian
425   longhorned beetle in northeastern US hardwood forests. Canadian Journal of Forest Research
426   41, 1729–1742.

427 Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J.R.G., Gruber, B.,
428   Lafourcade, B., Leitao, P.J., 2013. Collinearity: a review of methods to deal with it and a
429   simulation study evaluating their performance. Ecography 36, 27–46.

430 Dupas, S., Le Ru, B., Branca, A., Faure, N., Gigot, G., Campagne, P., Sezonlin, M., Ndemah, R.,
431   Ong'Amo, G., Calatayud, P., 2014. Phylogeography in continuous space: coupling species
432   distribution models and circuit theory to assess the effect of contiguous migration at different
433   climatic periods on genetic differentiation in B usseola fusca (L epidoptera: N octuidae).
434   Molecular ecology 23, 2313–2325.

435 Elmes, A., Rogan, J., Williams, C., Ratick, S., Nowak, D., 2019. Modeling the Potential Dispersal of
436   Asian Longhorned Beetle Using Circuit Theory. The Professional Geographer 71, 580–594.

437 ESRI, 2011. ArcGIS 10.2 for Desktop. Redlands: ESRI.

438 Falaschi, M., Mangiacotti, M., Sacchi, R., Scali, S., Razzetti, E., 2018. Electric circuit theory applied
439   to alien invasions: a connectivity model predicting the Balkan frog expansion in Northern Italy.
440   Acta Herpetologica 13, 33–42.

441 Feng, C., Zhou, W., Tang, Y., Gao, Y., Chen, J., Tong, C., Liu, S., Wanghe, K., Zhao, K., 2019.
442   Molecular systematics of the Triplophysa robusta (Cobitoidea) complex: extensive gene flow in
443   a depauperate lineage. Molecular phylogenetics and evolution 132, 275–283.

444 Fernandez-Carrillo, A., Patočka, Z., Dobrovolný, L., Franco-Nieto, A., Revilla-Romero, B., 2020.
445   Monitoring Bark Beetle Forest Damage in Central Europe. A Remote Sensing Approach
446   Validated with Field Data. Remote Sensing 2020, Vol. 12, Page 3634 12, 3634.
447   https://doi.org/10.3390/RS12213634

448 Fischbein, D., Lantschner, M.V., Corley, J.C., 2019. Modelling the distribution of forest pest natural
449   enemies across invaded areas: Towards understanding the influence of climate on parasitoid
450   establishment success. Biological Control 132, 177–188.

451 Franch-Pardo, I., Napoletano, B.M., Rosete-Verges, F., Billa, L., 2020. Spatial analysis and GIS in
452   the study of COVID-19. A review. Science of The Total Environment 739, 140033.
453   https://doi.org/10.1016/J.SCITOTENV.2020.140033

454 Frolov, A.N., 2015. The beet webworm Loxostege sticticalis L. (Lepidoptera, Crambidae) in the
455   focus of agricultural entomology objectives: I. The periodicity of pest outbreaks. Entomological
456   Review 95, 147–156. https://doi.org/10.1134/S0013873815020013

457 Godefroid, M., Meurisse, N., Groenen, F., Kerdelhué, C., Rossi, J.-P., 2020. Current and future
458   distribution of the invasive oak processionary moth. Biological Invasions 22, 523–534.

459 Guisan, A., Thuiller, W., Zimmermann, N.E., 2017. Habitat suitability and distribution models: with
460   applications in R. Cambridge University Press.

461 Günen, M.A., 2021a. A comprehensive framework based on GIS-AHP for the installation of solar
462   PV farms in Kahramanmaraş, Turkey. Renewable Energy 178.
463   https://doi.org/10.1016/j.renene.2021.06.078

464 Günen, M.A., 2021b. Determination of the suitable sites for constructing solar photovoltaic (PV)
465   power plants in Kayseri, Turkey using GIS-based ranking and AHP methods. Environmental
466   Science and Pollution Research 28, 57232–57247. https://doi.org/10.1007/S11356-021-14622-
467   X/TABLES/6

468 Haack, R.A., Hérard, F., Sun, J., Turgeon, J.J., 2010. Managing invasive populations of Asian
469   longhorned beetle and citrus longhorned beetle: a worldwide perspective. Annual review of
470   entomology 55.

471 Hlásny, T., Trombik, J., Holuša, J., Lukášová, K., Grendár, M., Turčáni, M., Zúbrik, M., Tabaković-
472   Tošić, M., Hirka, A., Buksha, I., 2016. Multi-decade patterns of gypsy moth fluctuations in the
473   Carpathian Mountains and options for outbreak forecasting. Journal of Pest Science 89, 413–
474   425.

475 Jactel, H., Koricheva, J., Castagneyrol, B., 2019. Responses of forest insect pests to climate change:
476   not so simple. Current Opinion in Insect Science 35, 103–108.
477   https://doi.org/https://doi.org/10.1016/j.cois.2019.07.010

478 Jiang, D., Chen, S., Hao, M., Fu, J., Ding, F., 2018. Mapping the potential global codling moth
479   (Cydia pomonella L.) distribution based on a machine learning method. Scientific reports 8, 1–
480   8.

481 Jiang, Q., Chen, C.-H., 2003. A numerical algorithm of fuzzy reliability. Reliability Engineering &
482   System Safety 80, 299–307.

483 Kovacs, K.F., Haight, R.G., McCullough, D.G., Mercader, R.J., Siegert, N.W., Liebhold, A.M.,
484   2010. Cost of potential emerald ash borer damage in US communities, 2009–2019. Ecological
485   Economics 69, 569–578.

486 Kumar, S., Graham, J., West, A.M., Evangelista, P.H., 2014. Using district-level occurrences in
487   MaxEnt for predicting the invasion potential of an exotic insect pest in India. Computers and
488   Electronics in Agriculture 103, 55–62.

489 Laćan, I., McBride, J.R., 2008. Pest Vulnerability Matrix (PVM): A graphic model for assessing the
490   interaction between tree species diversity and urban forest susceptibility to insects and diseases.
491   Urban Forestry & Urban Greening 7, 291–300.

492 Liu, C., Luo, W., Li, F., Wang, X., 2004. Purification and characterization of polyphenol oxidase
493   from {\sl Semiothisa cinerearia Bremer {\sl et} Grey (Lepidoptera: Geometridae). Kun Chong
494   xue bao. Acta Entomologica Sinica 47, 184–188.

495 Loo, J.A., 2008. Ecological impacts of non-indigenous invasive fungi as forest pathogens, in:
496   Ecological Impacts of Non-Native Invertebrates and Fungi on Terrestrial Ecosystems. Springer,
497   pp. 81–96.

498 Lozier, J.D., Mills, N.J., 2011. Predicting the potential invasive range of light brown apple moth
499   (Epiphyas postvittana) using biologically informed and correlative species distribution models.
500   Biological Invasions 13, 2409.

501 MacFarlane, D.W., Meyer, S.P., 2005. Characteristics and distribution of potential ash tree hosts for
502   emerald ash borer. Forest Ecology and Management 213, 15–24.

503 Marchioro, C.A., Krechemer, F.S., 2021. Prevention is better than cure: Integrating habitat suitability
504   and invasion threat to assess global biological invasion risk by insect pests under climate
505   change. Pest Management Science.

506 McRae, B.H., Dickson, B.G., Keitt, T.H., Shah, V.B., 2008. Using circuit theory to model
507   connectivity in ecology, evolution, and conservation. Ecology 89, 2712–2724.

508 McRae, B.H., Shah, V.B., 2014. Circuitscape user's guide. The University of California, Santa
509   Barbara.

510 Medley, K.A., Jenkins, D.G., Hoffman, E.A., 2015. Human-aided and natural dispersal drive gene
511   flow across the range of an invasive mosquito. Molecular Ecology 24, 284–295.

512 Meissle, M., Mouron, P., Musa, T., Bigler, F., Pons, X., Vasileiadis, V.P., Otto, S., Antichi, D., Kiss,
513   J., Pálinkás, Z., Dorner, Z., van der Weide, R., Groten, J., Czembor, E., Adamczyk, J., Thibord,
514   J.B., Melander, B., Nielsen, G.C., Poulsen, R.T., Zimmermann, O., Verschwele, A., Oldenburg,
515   E., 2010. Pests, pesticide use and alternative options in European maize production: Current
516   status and future prospects. Journal of Applied Entomology 134, 357–375.
517   https://doi.org/10.1111/j.1439-0418.2009.01491.x

518 Melin, A.D., Fedigan, L.M., Hiramatsu, C., Sendall, C.L., Kawamura, S., 2007. Effects of colour
519   vision phenotype on insect capture by a free-ranging population of white-faced capuchins,
520   Cebus capucinus. Animal Behaviour 73, 205–214.

521 Merow, C., Smith, M.J., Silander Jr, J.A., 2013. A practical guide to MaxEnt for modeling species'
522   distributions: what it does, and why inputs and settings matter. Ecography 36, 1058–1069.

523 Müller, F.A., Dias, N.P., Gottschalk, M.S., Garcia, F.R.M., Nava, D.E., 2019. Potential distribution
524   of Bactrocera oleae and the parasitoids Fopius arisanus and Psyttalia concolor, aiming at
525   classical biological control. Biological Control 132, 144–151.

526 Paap, T., Burgess, T.I., Wingfield, M.J., 2017. Urban trees: bridge-heads for forest pest invasions and
527   sentinels for early detection. Biological Invasions 19, 3515–3526.

528 Pelorosso, R., Gobattoni, F., Geri, F., Monaco, R., Leone, A., 2014. Bio-Energy Connectivity and
529   Ecosystem Services. An assessment by PANDORA3.0 model for land use decision making.
530   Journal of Land Use, Mobility and Environment.

531 Phillips, S.J., Anderson, R.P., Dudík, M., Schapire, R.E., Blair, M.E., 2017. Opening the black box:
532   an open-source release of Maxent. Ecography 40, 887–893. https://doi.org/10.1111/ecog.03049

533 Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species
534   geographic distributions. Ecological modelling 190, 231–259.

535 Phillips, S.J., Dudík, M., 2008. Modeling of species distributions with Maxent: New extensions and a
536   comprehensive evaluation. Ecography 31, 161–175. https://doi.org/10.1111/j.0906-
537   7590.2008.5203.x

538 Puddu, G., Maiorano, L., 2016. Combining multiple tools to provide realistic potential distributions
539   for the mouflon in Sardinia: species distribution models, spatial pattern analysis and circuit
540   theory. Hystrix 27.

541 Ramsfield, T.D., Bentz, B.J., Faccoli, M., Jactel, H., Brockerhoff, E.G., 2016. Forest health in a
542   changing world: effects of globalization and climate change on forest insect and pathogen
543   impacts. Forestry 89, 245–252.

544 Reil, J.B., Doorenweerd, C., San Jose, M., Sim, S.B., Geib, S.M., Rubinoff, D., 2018. Transpacific
545   coalescent pathways of coconut rhinoceros beetle biotypes: Resistance to biological control
546   catalyses resurgence of an old pest. Molecular ecology 27, 4459–4474.

547 Rivers-Moore, N.A., Hughes, D.A., De Moor, F.C., 2008. A model to predict outbreak periods of the
548   pest blackfly Simulium chutteri Lewis (Simuliidae, Diptera) in the Great Fish River, Eastern
549   Cape province, South Africa. River research and applications 24, 132–147.

550 Santini, A., Ghelardini, L., De Pace, C., Desprez-Loustau, M.-L., Capretti, P., Chandelier, A., Cech,
551   T., Chira, D., Diamandis, S., Gaitniekis, T., 2013. Biogeographical patterns and determinants of
552   invasion by forest pathogens in Europe. New Phytologist 197, 238–250.

553 Schöneberg, T., Arsenault-Benoit, A., Taylor, C.M., Butler, B.R., Dalton, D.T., Walton, V.M.,
554   Petran, A., Rogers, M.A., Diepenbrock, L.M., Burrack, H.J., 2020. Pruning of small fruit crops
555   can affect habitat suitability for Drosophila suzukii. Agriculture, Ecosystems & Environment
556   294, 106860.

557 Shushan, Y., Portugali, J., Blumenfeld-Lieberthal, E., 2016. Using virtual reality environments to
558   unveil the imageability of the city in homogenous and heterogeneous environments. Computers,
559   Environment and Urban Systems 58, 29–38.

560 Silverman, B.W., 2018. Density estimation: For statistics and data analysis. Density Estimation: For
561   Statistics and Data Analysis. https://doi.org/10.1201/9781315140919

562 Simberloff, D.S., 1974. Equilibrium theory of island biogeography and ecology. Annual review of
563   Ecology and Systematics 5, 161–182.

564 Singer, M.C., 1983. Determinants of multiple host use by a phytophagous insect population.
565   Evolution 389–403.

566   Smith, R.M., Baker, R.H.A., Malumphy, C.P., Hockland, S., Hammon, R.P., Ostojá-Starzewski, J.C.,
567   Collins, D.W., 2007. Recent non-native invertebrate plant pest establishments in Great Britain:
568   origins, pathways, and trends. Agricultural and Forest Entomology 9, 307–326.

569   Su, B., Liu, L., Tong, Z., Song, J., 2010. The study on occurrence regularity of Semiothisa cinerearia
570   in Shenyang. Chinese Bulletin of Entomology 47, 1194–1200.

571   Tang, H., Li, J., Wu, J., Gao, H., Zhang, S., 2014. Development Characteristics and Control
572   Measures for Semiothisa cineraria Bremer & Grey. Agricultural Science & Technology 15, 933.

573   Tang, S., Xiao, Y., Cheke, R.A., 2008. Multiple attractors of host–parasitoid models with integrated
574   pest management strategies: Eradication, persistence and outbreak. Theoretical Population
575   Biology 73, 181–197.

576   Tang, Y., Li, C., Wanghe, K., Feng, C., Tong, C., Tian, F., Zhao, K., 2019. Convergent evolution
577   misled taxonomy in schizothoracine fishes (Cypriniformes: Cyprinidae). Molecular
578   phylogenetics and evolution 134, 323–337.

579   Townsend Peterson, A., Papeş, M., Eaton, M., 2007. Transferability and model evaluation in
580   ecological niche modeling: a comparison of GARP and Maxent. Ecography 30, 550–560.

581   Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O.P., Viiri, H., Ikonen, V.P.,
582   Peltola, H., 2020. Climate change induces multiple risks to boreal forests and forestry in
583   Finland: A literature review. Global Change Biology 26, 4178–4196.
584   https://doi.org/10.1111/GCB.15183

585   Viani, R.A.G., Braga, D.P.P., Ribeiro, M.C., Pereira, P.H., Brancalion, P.H.S., 2018. Synergism
586   between payments for water-related ecosystem services, ecological restoration, and landscape
587   connectivity within the Atlantic Forest hotspot. Tropical Conservation Science 11,
588   1940082918790222.

589   Visser, H., De Nijs, T., 2006. The map comparison kit. Environmental Modelling & Software 21,
590   346–358.

591   Wang, X.Y., Huang, X.L., Jiang, L.Y., Qiao, G.X., 2010. Predicting potential distribution of chestnut
592   phylloxerid (Hemiptera: Phylloxeridae) based on GARP and Maxent ecological niche models.
593   Journal of Applied Entomology 134, 45–54.

594   Wanghe, K., Guo, X., Hu, F., Ahmad, S., Jin, X., Khan, T.U., Xiao, Y., Luan, X., 2020a. Spatial
595   coincidence between mining activities and protected areas of giant panda habitat: The
596   geographic overlaps and implications for conservation. Biological Conservation 247, 108600.

597   Wanghe, K., Guo, X., Luan, X., Li, K., 2019. Assessment of Urban Green Space Based on Bio-
598   Energy Landscape Connectivity: A Case Study on Tongzhou District in Beijing, China.
599   Sustainability 11, 4943.

600   Wanghe, K., Guo, X., Wang, M., Zhuang, H., Ahmad, S., Khan, T.U., Xiao, Y., Luan, X., Li, K.,
601   2020b. Gravity model toolbox: An automated and open-source ArcGIS tool to build and
602   prioritize ecological corridors in urban landscapes. Global Ecology and Conservation e01012.

603   Warren, D.L., Seifert, S.N., 2011. Ecological niche modeling in Maxent: the importance of model
604   complexity and the performance of model selection criteria. Ecological applications 21, 335–
605   342.

606   Wu, L., Zhao, Y., Tang, Y., 1998. Forecast on the fourth and fifthgeneration ovipositing amount and
607   pupal stage of Semiothisa conerearia Bremer et Grey. Forest Pest and Disease 2, 9–11.

608   Xu, H., 2017. Control Effect of Different Insecticides against Semiothisa cinerearia. Protection
609   Forest Science and Technology 12.

610   Yang, Li, Zhang, C., Chen, M., Li, J., Yang, Lei, Huo, Z., Ahmad, S., Luan, X., 2018. Long-term
611   ecological data for conservation: Range change in the black-billed capercaillie (Tetrao
612   urogalloides) in northeast China (1970s–2070s). Ecology and Evolution 8, 3862–3870.
613   https://doi.org/10.1002/ece3.3859

614   Zhang, Z., Yang, L.P., Zhou, C., Liu, G.C., 2013. Potential Distribution Prediction of Semiothisa
615   cinerearia in China Based on GARP Ecological Niche Model, in: Advanced Materials Research.
616   Trans Tech Publ, pp. 4678–4681.

617   Zhao, X., Ren, B., Li, D., Garber, P.A., Zhu, P., Xiang, Z., Grueter, C.C., Liu, Z., Li, M., 2019.
618   Climate change, grazing, and collecting accelerate habitat contraction in an endangered primate.
619   Biological Conservation 231, 88–97.

620   Zhu, G., Illan, J.G., Looney, C., Crowder, D.W., 2020. Assessing the ecological niche and invasion
621   potential of the Asian giant hornet. Proceedings of the National Academy of Sciences 117,
622   24646–24648.

623   Zhu, X.-Y., Xu, J.-W., Li, L.-L., Wang, D.-Y., Zhang, M.-L., Yu, N.-N., Purba, E.R., Zhang, F., Li,
624   X.-M., Zhang, Y.-N., 2020. Analysis of chemosensory genes in Semiothisa cinerearia reveals
625   sex-specific contributions for type-II sex pheromone chemosensation. Genomics 112, 3846–
626   3855.

627   Zimmerman, B.L., Bierregaard, R.O., 1986. Relevance of the equilibrium theory of island
628   biogeography and species-area relations to conservation with a case from Amazonia. Journal of
629   biogeography 133–143.

630

631

632   **Table**

633

634   **Table 1.** List of the environmental variables.

Sources	Names	Descriptions	Ranges
The forest resource inventory database	Host	The distance to the nearest tree *Styphnolobium japonicum* (the primary host of *S. cinerearia*)	0 – 2,084 m
	Forest	The percentage coverage of forests in a raster	0 – 100%
	Shrub	The percentage coverage of shrubs in a raster	0 – 100%
	Meadow	The percentage coverage of meadows in a raster	0 – 100%
The land-use dataset	Building	The distance from a raster to the nearest buildings	0 – 1,086 m
	Road	The distance from a raster to the nearest roads	0 – 1,694 m
	Cropland	The distance from a raster to the nearest croplands	0 – 3,569 m
	Water	The distance from a raster to the nearest water	0 – 2,381 m

635

636

637   **Figures**
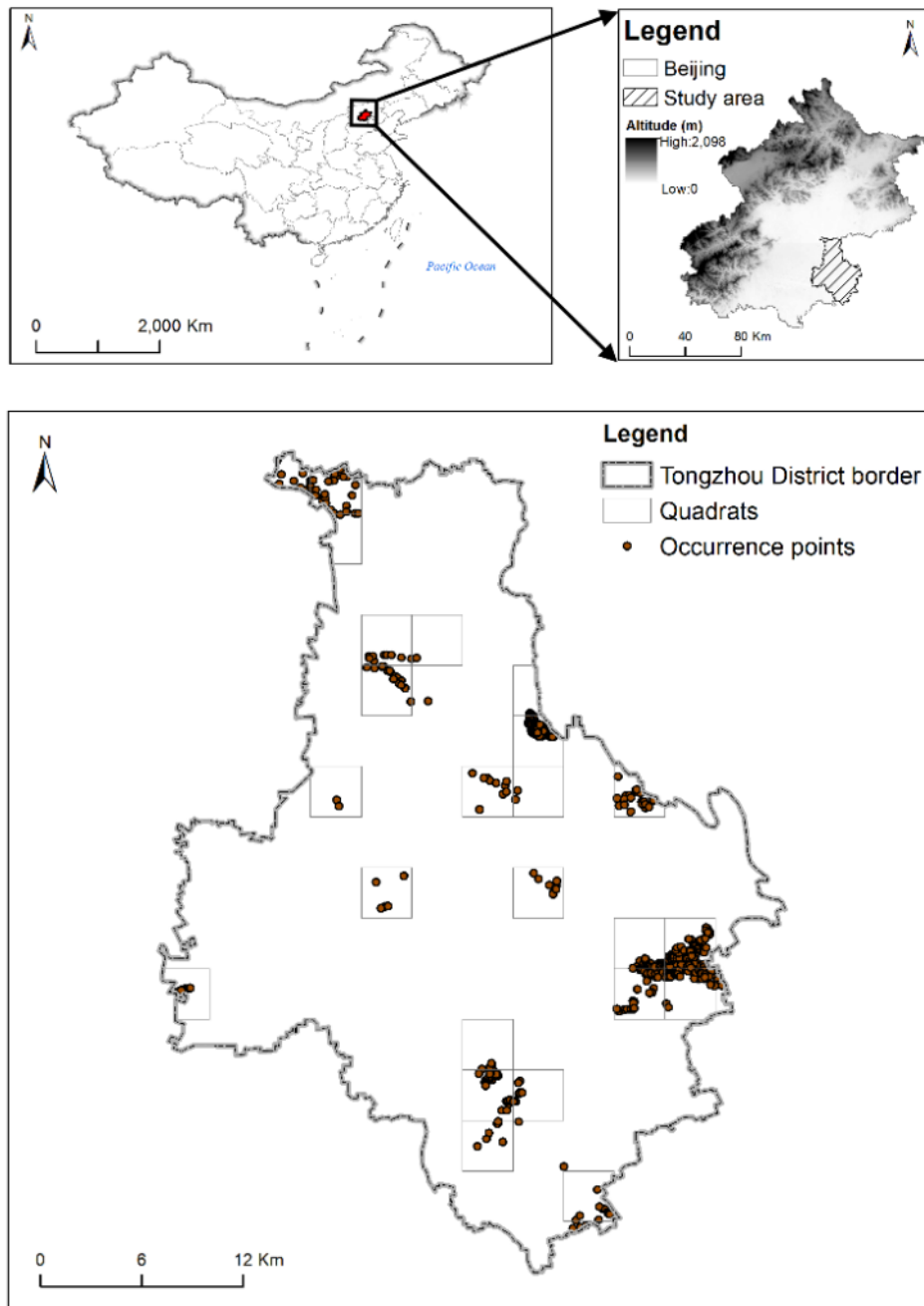
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639

640   **Figure 1.** Locations of our study area and the quadrats selected randomly, as well as *S. cinerearia*
641   occurrence points surveyed.

18

642
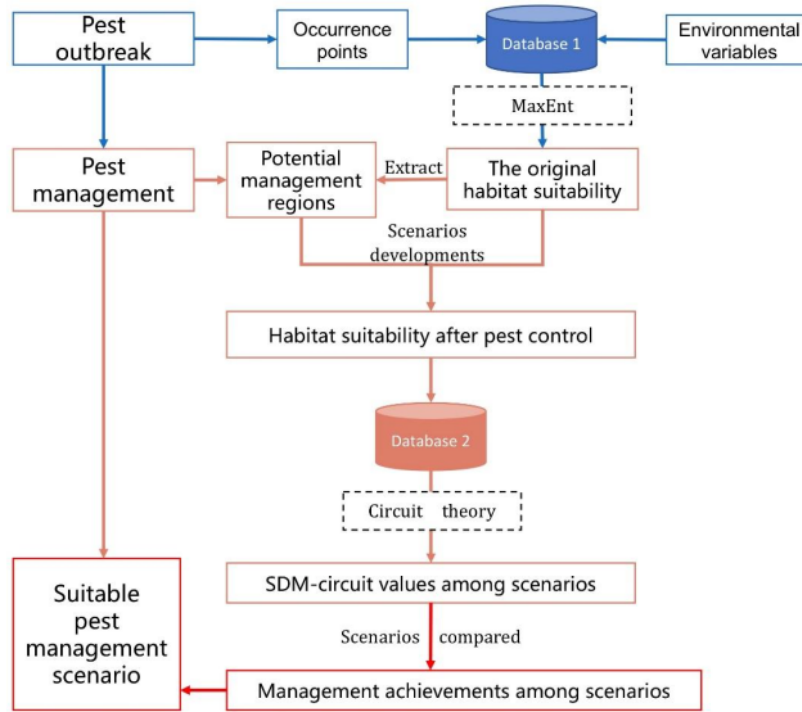
Figure 2. Modeling framework of the study.

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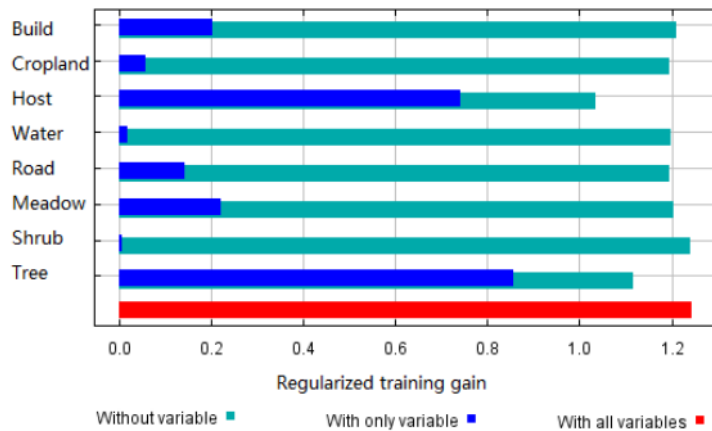
645

646   **Figure 3.** Relative importance of environmental variables (training gains) in MaxEnt models by the
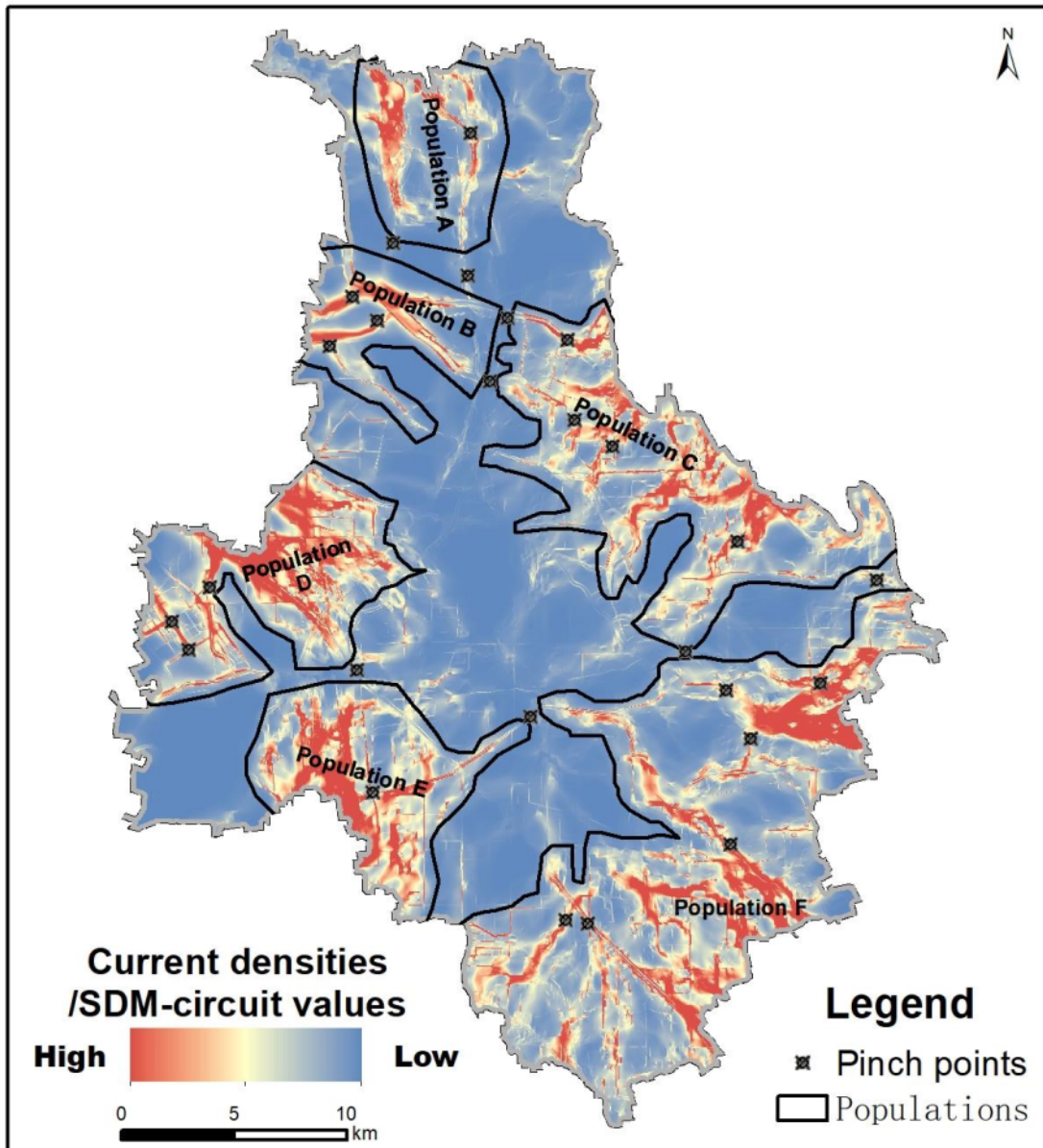647   Jack-knife test. The names and descriptions of those environmental variables see Table 1.

648
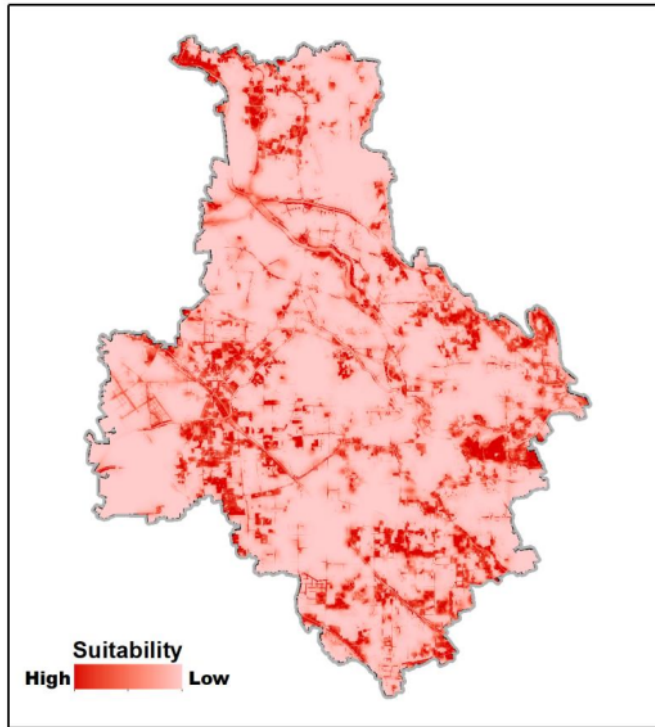
649

650   **Figure 4.** Habitat suitability map for *S. cinerearia*.

651
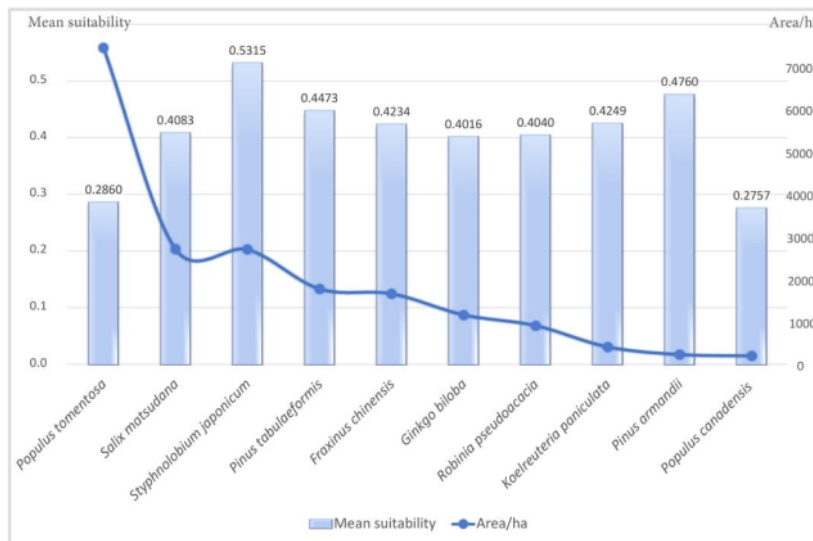
652   **Figure 5.** Comparison of habitat suitability providing to *S. cinerearia* among the top ten widely
653   planned urban greening tree species.

654

Figure 6. Map of the current densities/SDM-circuit values of *S. cinerearia*. Higher current densities indicate cells with higher net passage probabilities for random walkers moving from one patch to the other. The map highlights "pinch points", which are in some linear narrow pathways but providing critical habitat connections between or within two populations.

659
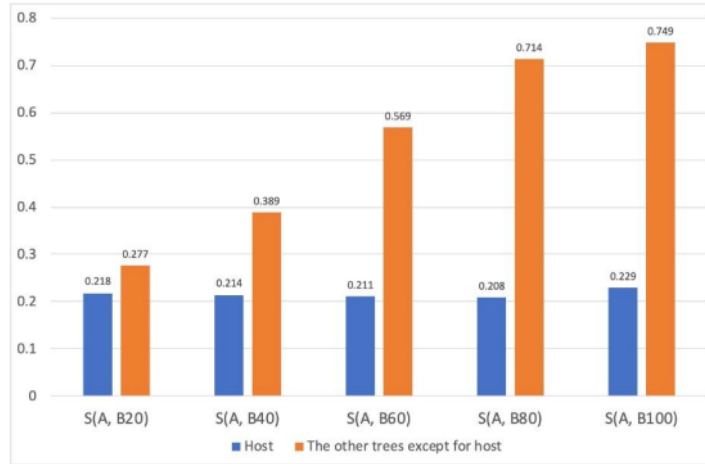
Figure 7. The management performances among the scenarios. The y-axis is the value of $S(A,B)$ described in Equation 2. In the x-axis, "A, Bn" means the scenario Bn vs. the original connectivity model.

663
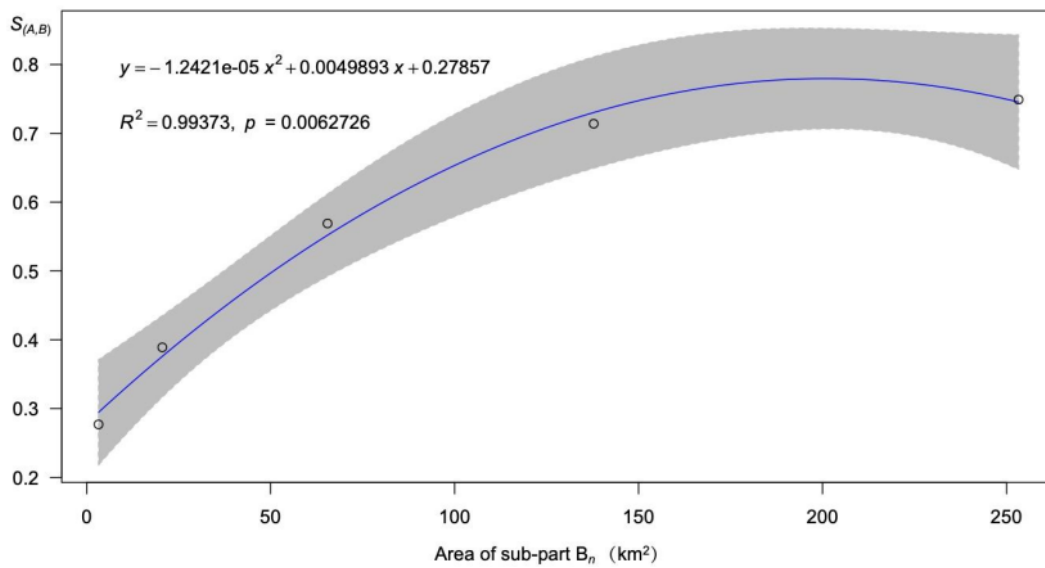
Figure 8. Result of the regression model. The y-axis is the value of $S(A,B)$ described in Equation 2. The x-axis means the area of sub-part Bn (km^2). The grey shaded areas are 95% confidence intervals.

22

Semiothisa cinerearia

517 occurrence points

Periodic pest outbreak

MaxEnt

Habitat suitability

Suitability
High   Low

Circuit theory

Landscape connectivity

Current densities
/SDM-circuit values
High   Low

Legend
Pinch points
Populations

Pest management

Potential management region

Scenarios comparison

e.g.
Scenario B20
Region for pesticide increased 3.22km² (11.9%)
Management achievement increased by 27.7%
Compared with region for pesticide only at the
location of the host

(a) Scenario B20

666

667   **Figure 9**. Flow chart for the combinational modeling between habitat suitability and landscape
668   connectivity to identify the potential regions for pest management.

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