Habitat suitability and connectivity inform a co-managed policy of protected areas networks for Asian elephants in China

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Enlarging protected areas (PAs) network is critical to ensure the long-term viability of Asian elephants from habitat fragmentation and loss. While challenges are raised in the strictly government-managed policy of PAs networks due to the difficulties in persuading participation of stakeholders and meeting habitat requirements of the elephants. This study hypothesized that a co-managed policy is more plausible than the strict policy to enlarge PAs network for Asian elephants in a "developing" world. We identified the suitable habitat for Asian elephants using the maximum entropy modeling approach (MaxEnt) and examined the socio-economic context of the habitat. The hypothesis was supported by our results: (1) Asian elephants prefer forest matrix with multiple land use (50% forest cover) rather than interior of large forest and roam in proximity of human habitations (mean distance 1.85 km); (2) suitability and the level of economic development of the habitats are negatively correlated (p = 0.04). Additionally, we provided an empirical study on corridor designing for the study area in China.

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Abstract

Enlarging protected areas (PAs) network is critical to ensure the long-term viability of Asian elephants from habitat fragmentation and loss. While challenges are raised in the strictly government-managed policy of PAs networks due to the difficulties in persuading participation of stakeholders and meeting habitat requirements of the elephants. This study hypothesized that a co-managed policy is more plausible than the strict policy to enlarge PAs network for Asian elephants in a "developing" world. We identified the suitable habitat for Asian elephants using the maximum entropy modeling approach (MaxEnt) and examined the socio-economic context of the habitat. The hypothesis was supported by our results: (1) Asian elephants prefer forest matrix with multiple land use (50% forest cover) rather than interior of large forest and roam in proximity of human habitations (mean distance 1.85 km); (2) suitability and the level of economic development of the habitats are negatively correlated ($p = 0.04$). Additionally, we provided an empirical study on corridor designing for the study area in China.

Introduction

Protected areas networks comprised of core protected areas (PAs) and corridors are cornerstones to safeguard wildlife by maintaining coherent habitats for their dispersal, migration, and gene flow (Bennett and Mulongoy, 2006; Geldmann et al., 2013; Wilson and MacArthur, 1967). PAs networks were targeted to cover 17% of global land by 2020 (Joppa and Pfaff, 2009), and the proportion was forecasted to reach 29% at maximum by 2030 (McDonald and Boucher, 2011). Although new PAs tend increasingly to be co-managed with multiple land use (McDonald and Boucher, 2011), a major proportion of existed PAs is under the strictly government-managed policy similar to IUCN categories I–IV (Protected Planet, https://www.protectedplanet.net/), which draws three concerns from conservation communities. First, habitat suitability for a focal species or taxa might be decreased in strict PAs due to lack of landscape heterogeneity (Evans et al., 2018; Mudappa et al., 2007; Wharton, 1968). Second, strict PAs are often established in areas with intact primary forest and low human pressure (Acharya et al., 2017; Evans et al., 2018; Joppa and Pfaff, 2009), while fragmented primary and secondary forests in human-dominated landscapes are imminently eroded, which led to the increasing isolation of PAs (DeFries et al., 2005; Laurance et al., 2012). Third, strict PAs and local economic development are commonly regarded as opposed issues by local stakeholders, encouraging their participation is challenging, especially in developing countries (Bennett and Mulongoy, 2006; McDonald and Boucher, 2011). A co-managed policy reconciling between economic development and wildlife conservation is promising to enlarge PAs networks for a focal species or taxa in human-dominated landscapes (Evans et al., 2018; Goswami et al., 2014; Zhang et al., 2006).

South and Southeast Asia are global hotspots of biodiversity (Myers et al., 2000) and also threats to wildlife conservation (Ceballos and Ehrlich, 2002; Hansen et al., 2013). Deforestation and encroachment of agriculture and infrastructure are among the most devastating threat to wildlife (Clements et al., 2014; Edwards et al., 2010; Hansen et al., 2013). Mega- and large-sized animals are particularly affected because of their large home range (Ceballos & Ehrlich, 2002; Robert et al., 2006) and conflict-proneness with villagers (Acharya et al., 2017; AsERSM, 2017). Asian elephant (*Elephas maximus*) is an endangered, flagship, and umbrella species in South and Southeast Asia. Despite their importance in ecosystem, culture, as well as fundraise for broader wildlife conservation (Campos-Arceiz et al., 2008; Ritchie & Johnson, 2009; Verissimo et al., 2011), only 29.1% of their distribution range was legally protected in thirteen countries (Hedges et al., 2008), most of them persist in human-dominated landscapes (Calabrese et al., 2017; Jathanna et al., 2015). Enlarging PAs network is a priority for their long-term viability (AsERSM, 2017). However, economic development is an undisputable top priority in South and Southeast Asia, the strictly government-managed policy of PAs networks may fail to enlarge habitats for wildlife in human-dominated landscapes (Bennett and Mulongoy, 2006; Evans et al., 2018; Zhang et al., 2006).

Asian elephants are habitat-generalists and occur in primary and secondary forests, grassland, scrubland, and also farmland (Choudhury et al., 2008). The factors affecting their habitat preference are complex, including population size, characteristic of forest and protected areas, and anthropogenic disturbance (Desai and Riddle, 2015; Evans et al., 2018; Liu et al., 2016). For instance, in China, Cangyuan population (20-23 individuals) mostly stay in well-protected nature reserve (Liu et al., 2016); Mengla population (88-98) often roam in the peripheries of nature reserve (Chen et al., 2013); while Menghai-Lancang population (15) and most of Xishuangbanna-Pu'er population (98-109) reside in human-dominated landscapes (Fig. 1) (Zhang et al., 2015). This difference can also be found in other countries, such as India, Indonesia, and Laos (AsERSM, 2017). Despite the difference, there are mounting evidence that Asian elephants are "edge specialists" at fine scales, and disturbed forests are highly suitable for them (Evans et al., 2018; Sitompul et al., 2013; Wadey et al., 2018). On the other hand, Asian

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elephant is a conflict-prone species and caused extensive damages to villagers, such as crop raids, property damages, even people killings (Chen et al., 2016; Gubbi, 2012). The villages in damage hotspots are typified by relatively small size, surrounding nature reserves, with forest matrix and traditional farm practices (e.g., maize and rice) (Chen et al., 2016; Wilson et al., 2013) thus might be economically less-developed. Therefore, enlarging PAs network for Asian elephants is potentially associated with the socio-economic context, the participation of villagers is a critical part for Asian elephant conservation.

Here, we hypothesized that a co-managed policy is more plausible to enlarge PAs networks for Asian elephants than the strict policy. This hypothesis will be supported by two key pieces of evidence: (1) Asian elephants do not prefer forest interiors; (2) characteristic of Asian elephants' habitat and socio-economic context are correlated. Our study guide conservation policy for Asian elephants and additionally provide information for corridor designing in our study area.

Materials & Methods

Study area

This study was conducted in the range of Xishuangbanna-Pu'er population in Xishuangbanna and Pu'er, Yunnan, southwest China, bordering Vietnam and Laos (Fig. 1). This population comprises five subpopulations, i.e., Liushun, Yunxian, Simaogang, Jiangcheng, and Mengyang (Fig. 1). The altitude ranges from 495 m to 1 851 m above sea level; the region's annual mean temperature is about 21 °C; and its annual precipitation is about l 500 mm. The landscape has been fragmented due to agriculture and infrastructure encroachment over the last 40 years (Liu et al., 2017). Natural forests (mainly subtropical evergreen broad-leaved forest) are embedded with production forests (e.g., *Pinus kesiya* and *Eucalyptus* spp.), cash-crop plantations (e.g., rubber, coffee, and tea), and traditional farmlands (e.g., maize, paddy, and sugarcane) (Chen et al., 2010). Three corridors were suggested to connect (a) Menghai-Lancang and Xishuangbanna-Pu'er population and (b) subpopulations of Xishuangbanna-Pu'er population (Zhang et al., 2015). However, a hydro-power dam raised the water level of Mekong River, which isolated Menghai-Lancang population from Xishuangbanna-Pu'er population at least ten years (Chen et al., 2010). In the study area, an administrative village (32 in total) is an extent comprising several communities (251 points in total). These villagers rely on incomes from agriculture and agroforestry (Chen et al., 2010).

Methods

Data collection

The first author collected the data on the signs of the presence of Asian elephants (i.e., dung pile and footprint) and ground-truth points (or control points) of land cover along with 91 line transects (306.83 km) conducted between December 2016 and March 2017 assisted by local forestry staff. These line transects were defined to traverse all types of land cover (Fig. 1 and 2) (Liu et al., 2016); the presence signs were detected within 20 m width of line transects and recorded with at least 200 m intervals. Land cover was recorded into seven types (Chen et al., 2010): natural forests, pine plantation (i.e., *Pinus kesiya*), cash-crop plantation, shrubland, traditional farmland, infrastructure site (e.g., settlements and roads), and water body (i.e., rivers, reservoirs, and ponds). In total, we collected 245 presence points of Asian elephants.

We treated the per-capita annual income of villages as the proxy for economic development; higher income represents a higher level of economic development. We collected the data from the Digital Village of Yunnan (http://www.ynszxc.gov.cn/) which established by People's Government of Yunnan Province.

Data analyses

The data analyses included six steps. First, independent variables were selected for habitat suitability model (HSM). Second, a land cover map was developed from remote-sensing images. Third, pseudo-absence points for HSM were generated. Fourth, we tuned HSM and used the optimized model to generate a habitat suitability map; then we summarized the characteristic of suitable habitat for Asian elephants. Fifth, we examined whether suitability and level of local economic development of habitat are correlated. Sixth, to provide information on corridor designing for the study area, we used a habitat resistance surface to simulate the pathway of Asian elephants by least-cost and circuit model.

Independent variables

We initially selected 13 variables of three categories to describe the occurrence probability of Asian elephants according to previous studies (Lin et al., 2015; Liu et al., 2016) (Table 1): geographical and topographic (altitude and terrain roughness index), vegetation (distance to, edge density of, and percentage of natural forest, pine plantation, and traditional farmland), and human disturbance (distance to town and community).

Land cover classification

We used Landsat 8 OLI_TIRS images (30 m resolution from Data Cloud of CAS, http://www.csdb.cn/) to develop the land cover map. We added ancillary layers to improve the classification accuracy (Wegmann et al., 2016), including ASTER GDEM grids (Data Cloud of CAS), slope and its texture, and Normalized Difference Vegetation Index and its texture. We performed a supervised classification using random forest algorithm with 25% of the control points left to validate the classification (Leutner and Horning, 2016). The overall classification accuracy was 0.91.

Selection of pseudo-absence points

We randomly generated 10 000 pseudo-absence points in a background extent to reflect the availability of environmental conditions and discriminate the presence points (Elith et al., 2011; Timm et al., 2016). We defined the background extent as where Asian elephants might occur (113 km^2 buffer zone of the presence points) (Fernando et al., 2008; Amirkhiz et al., 2018).

MaxEnt modeling

Of HSM for presence-only data, the maximum entropy model of MaxEnt outperforms the other existing models (Ferrier et al., 2006; Phillips et al., 2006). We followed the modeling approach of Amirkhiz et al. (2018). First, we excluded the variables which highly correlated ($|r| > 0.7$) and contributed less than 5 % to the models and selected the optimized β multiplier in a step-wise approach (0-15 by 0.5 intervals). Second, MaxEnt calculates five models for each independent variable known as features: linear (L), quadratic (Q), product (P), threshold (T), and hinge (H) (Phillips et al., 2017). We selected the feature set of the model with the lowest sample size corrected Akaike Information Criteria among "L", "H", "LQ", "LQT", "LP", "HP", "LQP", and "LQTP", then used the model to produce a habitat suitability map. The prediction was evaluated by random partitioning k-fold cross-validation, threshold independent omission rate, and threshold dependent omission rate. Third, 10% training presence threshold was used for delineating suitable from unsuitable habitat (Escalante et al., 2013; Hughes, 2017), then we summarized the characteristic of suitable habitat for Asian elephants. The modeling was performed in R with MaxentVariableSelection and ENMeval package (Jueterbock, 2015; Muscarella et al., 2014; R Development Core Team, 2013).

Correlation between habitat suitability and socio-economic context

We extracted habitat suitability value by each community point and treated it as the habitat suitability of the area adjacent the community for Asian elephants. Due to the village-scale data of the annual income, we averaged the habitat suitability values of the area adjacent the communities for that of corresponding villages. We used a linear regression model to examine whether the habitat suitability of the villages for Asian elephants and the level of economic development are correlated. We used a level of 0.05 for statistical significance.

Pathway mapping

Least-cost and circuit model are two widely used approach for corridor designing (Ruiz-González et al., 2014; Wang et al., 2014). We simulated the pathway of Asian elephants by least-cost and circuit model using the software Linkage Mapper and Circuitscape (McRae & Shah, 2009; Wang et al., 2014; Mcrae et al., 2008). Resistance surface was calculated by 1 minus the habitat suitability values. The least-cost model was constructed with three core areas, i.e., Mengyang, Liushun and Simaogang, and Jiangcheng (Fig.1). All presence points of Asian elephants were used to produce a connectivity map for the entire study area by circuit model.

Results

The model with the lowest AICc used a β multiplier = 1; linear, quadratic, threshold, and product features ("LQTP"), and it had 8 uncorrelated variables with a contribution > 5%, including terrain roughness index, distance to town, community, natural forest, and traditional farmland, and percentage of natural forest, pine plantation, and traditional farmland. Percentage of natural forest was the strongest variables in predicting the occurrence of Asian elephants (22.61%), followed by distance to town and community (22.55% and 16.34%, respectively).

The model was generally accurate to discriminate the presence points from the background (mean AUC = 0.86). The AUC difference was low (0.05), suggesting that the model not be over-fitting to the presence points. Threshold-dependent measures indicated that the model had low over-fitting and high discriminatory ability at 10% omission rate (0.20) and lowest presence threshold (< 0.001). The threshold value of suitable habitat was 0.28. In our study area, Asian elephants prefer forest matrix with multiple land use (50% natural forest cover) rather than the interior of large forest, away from towns (mean distance 10.16 km), near community (mean distance 1.85 km), and flat terrain (mean terrain roughness index 4.83) (Fig. 2).

The habitat suitability of the villages for Asian elephants was significantly negatively correlated with the level of economic development of the villages (p = 0.04).

The least-cost model predicted three potential pathway (1, 2, and 3) to connect the three core areas of Asian elephants, of which the length are 23.44 km, 34.58 km, and 14.46 km, respectively (Fig. 3). The circuit model predicted habitat connectivity of the entire area and supported the least-cost pathway 1 (Fig. 2 and 3).

Discussion

Across the distribution range, Asian elephants are greatly affected by habitat fragmentation and loss, enlarging PAs network is a priority for their conservation (AsERSM, 2017). In a "developing" world, reconciling between wildlife conservation and economic developing draws increasing attention (Adams et al., 2004; Zhang et al., 2006). This study found that (1) nature forest cover in a landscape is the strongest factor in determining Asian elephant occurrence; (2) Asian elephants prefer forest matrix with multiple land use rather than the interior of large forest; and (3) suitability and level of economic development of the habitat are negatively correlated. Our results support the hypothesis that a co-managed policy of PAs networks is more plausible than the strictly government-managed policy to enlarge PAs networks for Asian elephants. In addition, we provided an empirical study for corridor designing in the study area.

Habitat selection and potential corridors of Asian elephants

Habitat selection reflects a trade-off of Asian elephants between resource extraction and mortality-risks (Basille et al., 2009; Munshi-South et al., 2008). Natural forests are substantial for Asian elephants by offering foods and refuges (Evans et al., 2018; Goswami et al., 2014; Kumar et al., 2010). Of particular, our study revealed that Asian elephants prefer forest matrix rather than forest interior, which supported by previous studies (Evans et al., 2018; Sitompul et al., 2013; Wadey et al., 2018). The forest matrix and its edges provide better light conditions for the primary natural foods of Asian elephants, such as *Ficus* spp. and gramineous plants (Chen et al., 2006; Sitompul et al., 2013; Wadey et al., 2018). Although we did not include rubber plantation as a variable in the model, it is clear that tracts of rubber plantation are not suitable for Asian elephants from the habitat suitability map (the areas along with the Mekong River, Fig. 2). Asian elephants often roam around communities might be contributed by traditional farmland (e.g., maize and paddy), which offers 68% of feeding sites for Asian elephants (Zhang et al., 2003). On the other hand, mortality-risks for Asian elephants are mostly human-related, including falling in ditches, electrocuted by wires, and retaliatory killings (Chen et al., 2013; Palei et al., 2014; AsERSM, 2017). Asian elephants less occurred in the proximity of town, which characterized by dense human infrastructures, plantations, and management (Fig. 2). In conclusion, Asian elephants prefer or adapted to intermediately disturbed landscapes.

The length and resistance of pathway 2 are much larger than the others and rarely utilized by Asian elephants from long-term experiences (Chen et al., 2010; Zhang et al., 2015). The pathway 3 traversed large rubber plantations (Fig. 2), the stakeholders are less likely to fulfill conservation interests. The pathway 1 is generally consistent with the prediction from circuit model and also the proposed corridor I by Zhang et al. (2015). Thus, the pathway 1 should be set with higher priority than the pathway 2 and 3. Besides, we identified a key area (green rectangle of Fig. 3) to connect the subpopulation Mengyang, Liushun, and Simaogang. Our study provides more precise information for corridor designing than the previous study (Zhang et al., 2015).

Implication for conservation policy for Asian elephants

Based on our results, we concluded that a co-managed policy of PAs networks is more plausible than the strictly government-managed policy to enlarge Asian elephants habitat, which is potentially suitable for other regions with similar land cover and socio-economic context, such as north India and south Laos (AsERSM, 2017; Kumar et al., 2010; Wilson et al., 2013). In China, PAs networks include nature reserves, world natural and cultural heritage sites, scenic zones, wetland parks, forest parks, geological parks, and water conservancy scenic locations (Cao et al., 2015). In the networks, nature reserves (NRs) account for the largest proportion and occupy 14.94% of the national territory in 2012 (1500 000 km^2). Most of the NRs are managed as socially exclusive landscapes (Cao et al., 2015; Zhang et al., 2006). However, Asian elephants prefer forest matrix and are flexible to human disturbance. Conservation policy allowing considerable interventions in nature reserves could enlarge habitats for Asian elephants without great loss of biodiversity. Selective-logged forests appear to maintain ~90% of original biodiversity compared to primary forest (Berry et al., 2010; Brodie et al., 2014), and retention forestry, whereby a proportion of original vegetation is left unlogged, showed to further reduce negative impacts on biodiversity (Fedrowitz et al., 2014; Gaveau et al., 2013). Out of NRs, efforts should be paid to protect community-own forests, which represents a major proportion of natural forests and proved to be critical for Asian elephants (Evans et al., 2018; Kumar et al., 2010) as well as other wildlife (Rodrigues et al., 2017; Rodrigues and Chiarello, 2018). Besides, integrating farmland into the PAs networks can fulfill human livelihoods. It is notable that the villages more suitable for Asian elephants are economically less-developed than that of less suitable, supporting sustainable economic development and reducing the damages by Asian elephants are critical for encouraging human-elephant coexistence, such as developing ecotourism, providing lessons for wildlife-friendly product, and compensating the losses of damages.

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Figure 1

Figure 1: Distribution range of Asian elephants in China and the study area.

The populations are represented by the tags of yellow (Xishuangbanna-Pu'er population), blue (Cangyuan population), green (Menghai-Lancang population), and purple (Mengla population).

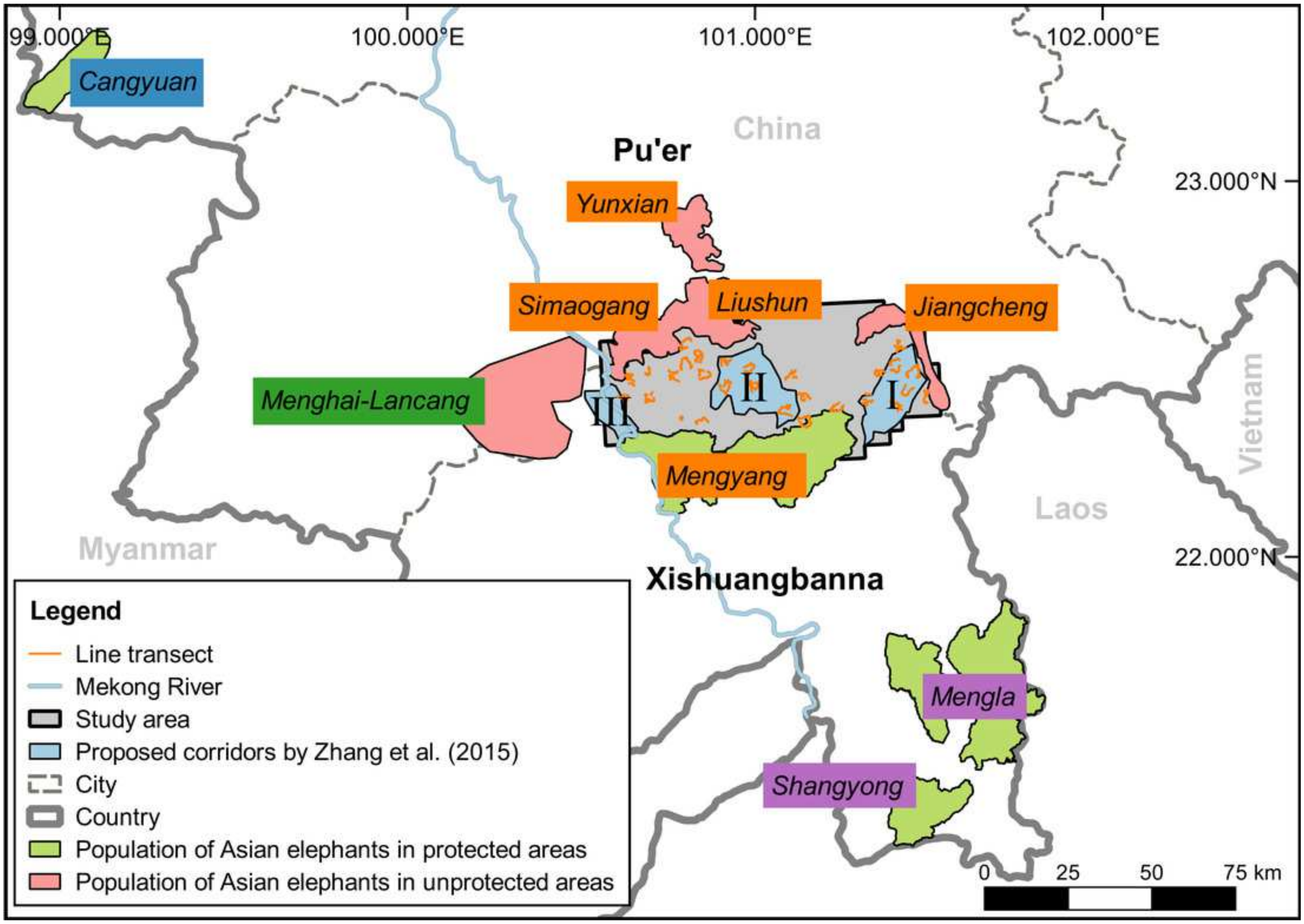

Figure 2

Figure 2: Habitat suitability map for Asian elephants in the study area.

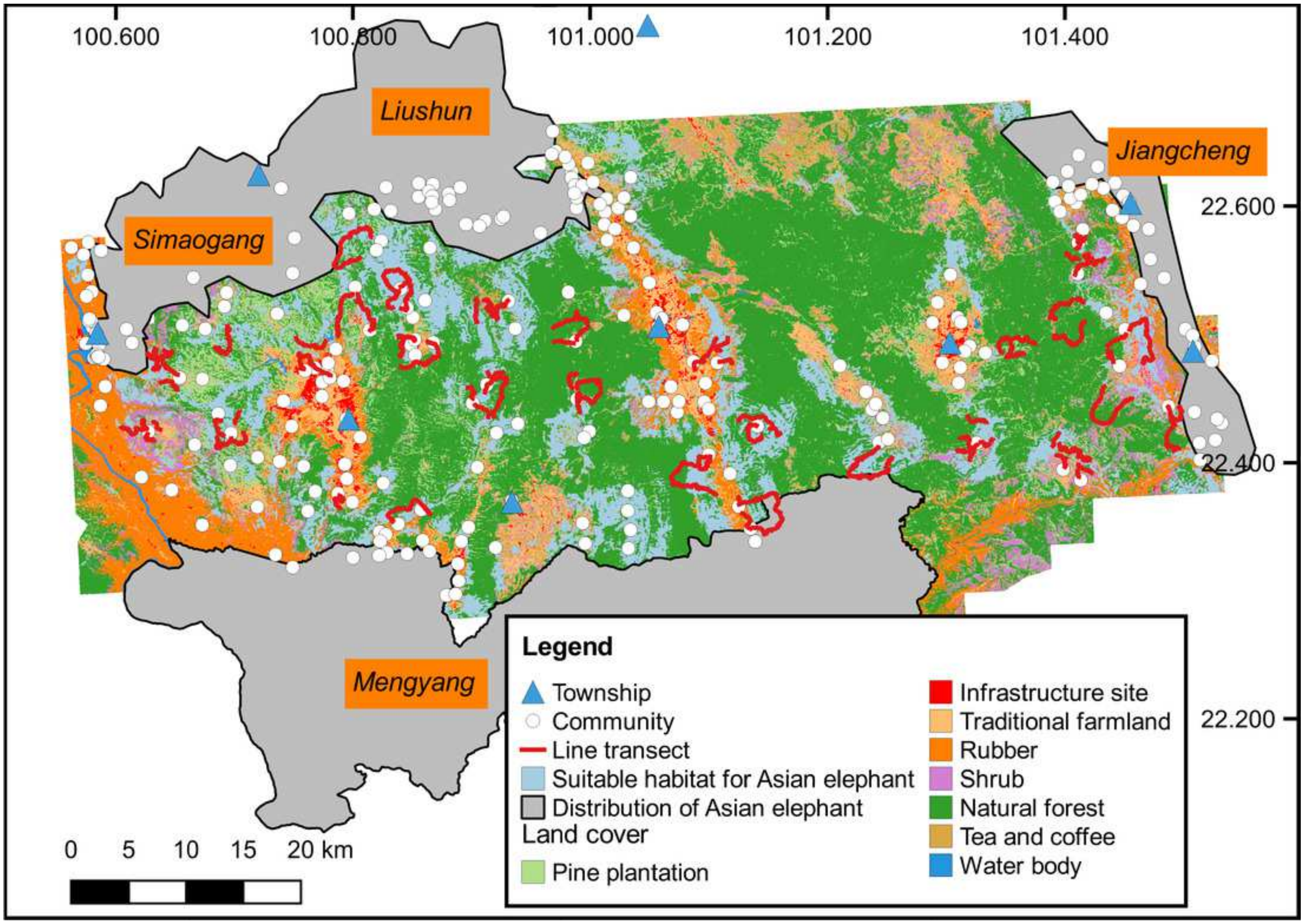

Figure 3

Figure 3: The least-cost path and habitat connectivity for Asian elephants calculated by the circuit model in the study area.

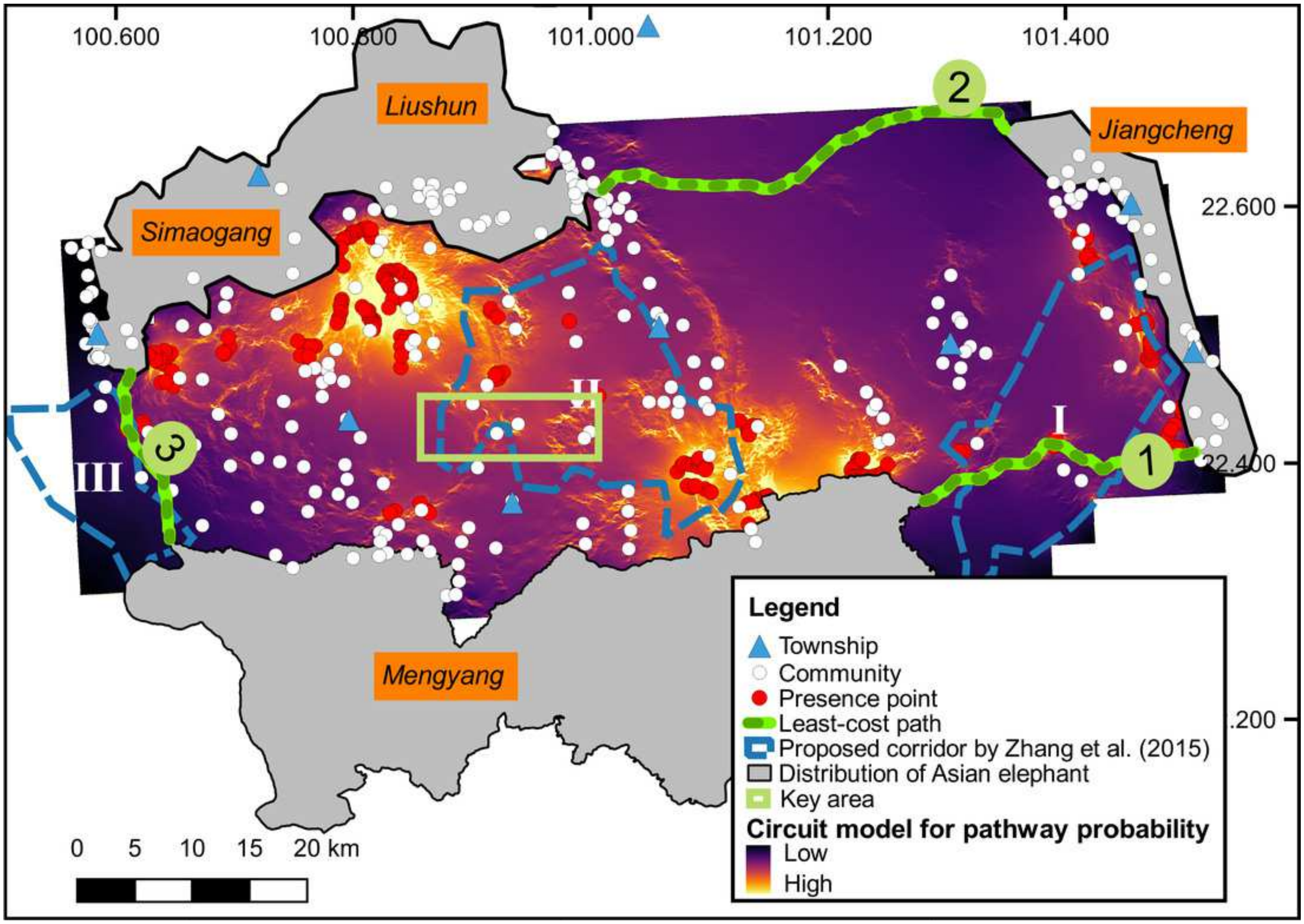

Table 1 (on next page)

Table 1: Variables selected in habitat selection model for Asian elephants

Category	Variable	Data and calculation
Geographic and topographic	Altitude	ASTER GDEM
	Terrain roughness index	Calculated from ASTER GDEM in R
Vegetation	Distance to: natural forest pine plantation traditional farmland	Calculated by “distance” function in R
	Percentage of: natural forest pine plantation traditional farmland	Calculated in Fragstats by 1.5 km radius from land cover map
	Edge density of: natural forest pine plantation traditional farmland	Calculated in Fragstats by 1.5 km radius from land cover map
Human disturbance	Distance to: town community	Calculated by “distance” function in R

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