Habitat suitability and connectivity inform the co-management policy of protected area networks for Asian elephants in China (#33037)

First revision

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Habitat suitability and connectivity inform the co-management policy of protected area networks for Asian elephants in China

Cheng Huang [1,2] , **Xueyou Li** [1] , **Laxman Khanal** [3] , **Xuelong Jiang** [Corresp. 1]

[1] Kunming Institute of Zoology, Chinese Academy of Sciences, Kunming, China
[2] Kunming College of Life Sciences, University of Chinese Academy of Sciences, Kunming, China
[3] Central Department of Zoology, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal

Corresponding Author: Xuelong Jiang
Email address: jiangxl@mail.kiz.ac.cn

Enlarging protected area networks (PANs) is critical to ensure the long-term population viability of Asian elephants (*Elephas maximus*), which are globally impacted by habitat loss and fragmentation. Strict policies aimed at enlarging PANs have largely failed due to difficulties in meeting the habitat requirements of Asian elephants and persuading the participation of stakeholders. A co-management policy that promotes sustainable resource use and multilateral participation may have greater feasibility than strict policies in enlarging PANs in a “developing” world. Here, we elucidated this issue from the standpoints of elephant habitat suitability and socio-economic background of the habitat. We (1) identified suitable Asian elephant habitat using maximum entropy modeling (MaxEnt) and (2) examined whether habitat suitability was indirectly associated with local economic development. We found that (1) Asian elephants preferred forest matrix habitats with multiple land uses (50% natural forest cover) rather than intact forests and roamed in proximity to human settlements (mean distance 2 km) and (2) habitat suitability and local economic development were negatively associated (p=0.04). Thus, our results indicate that co-management demonstrates better feasibility than the strict approach for the expansion of PANs. Additionally, our MaxEnt results provide information for elephant corridor design in China.

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Cheng Huang[1,2], Xueyou Li[1], Laxman Khanal[3] and Xuelong Jiang[1]

[1] Kunming Institute of Zoology, Chinese Academy of Sciences, Kunming, Yunnan, China
[2] Kunming College of Life Sciences, University of Chinese Academy of Sciences, Kunming, Yunnan, China
[3] Central Department of Zoology, Institute of Science and Technology, Tribhuvan University, Kathmandu, Nepal

Corresponding Author:
Xuelong Jiang
32 Jiaochang Donglu, Kunming, 650223, China
E-mail address: Jiangxl@mail.kiz.ac.cn

Abstract

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Enlarging protected area networks (PANs) is critical to ensure the long-term population viability of Asian elephants (*Elephas maximus*), which are globally impacted by habitat loss and fragmentation. Strict policies aimed at enlarging PANs have largely failed due to difficulties in meeting the habitat requirements of Asian elephants and persuading the participation of stakeholders. A co-management policy that promotes sustainable resource use and multilateral participation may have greater feasibility than strict policies in enlarging PANs in a "developing" world. Here, we elucidated this issue from the standpoints of elephant habitat suitability and socio-economic background of the habitat. We (1) identified suitable Asian elephant habitat using maximum entropy modeling (MaxEnt) and (2) examined whether habitat suitability was indirectly associated with local economic development. We found that (1) Asian elephants preferred forest matrix habitats with multiple land uses (50% natural forest cover) rather than intact forests and roamed in proximity to human settlements (mean distance 2 km) and (2) habitat suitability and local economic development were negatively associated (p=0.04). Thus, our results indicate that co-management demonstrates better feasibility than the strict approach for the expansion of PANs. Additionally, our MaxEnt results provide information for elephant corridor design in China.

is more feasible

Introduction

Protected area networks (PANs), which are comprised of core protected areas (PAs) and corridors, are the cornerstones for safeguarding and maintaining contiguous habitat for wildlife dispersal, migration, and gene flow (Wilson & MacArthur, 1967, Bennett & Mulongoy, 2006, Geldmann et al., 2013). PANs are targeted to cover 17% of global land by 2020 (Joppa & Pfaff,

2009) and forecast to reach 15%–29% by 2030 (McDonald & Boucher, 2011). About half of PAs are currently managed as socially exclusive landscapes by authorities similar to IUCN categories I–IV (McDonald & Boucher, 2011), namely, under strict policy. This practice generates three concerns from conservationists. First, the habitat suitability in strict PAs might be overestimated for some species or taxa due to lack of landscape heterogeneity (Wharton, 1968, Mudappa et al., 2007, Evans et al., 2018). Second, strict PAs are often established in areas with intact primary forest and low human pressure (Joppa & Pfaff, 2009, Acharya et al., 2017, Evans et al., 2018), while fragmented primary and secondary forests in human-dominated landscapes are continually eroded, leading to increased isolation of PAs and wildlife (DeFries et al., 2005, Laurance et al., 2012). Third, the establishment of strict PAs and local economic development are commonly regarded as competing issues by local stakeholders and so encouraging their participation is difficult, especially in developing countries (Bennett & Mulongoy, 2006, McDonald & Boucher, 2011). A co-management policy potentially provides a more feasible means for expanding PANs for a focal species or taxa in a human-dominated landscape (Zhang et al., 2006, Goswami et al., 2014, Evans et al., 2018). This policy promotes sustainable resource use, wildlife conservation, and participation of villagers and other stakeholders. **Above - Convincing justification for article**

South and Southeast Asia are global hotspots of biodiversity (Myers et al., 2000), but are areas in which wildlife is increasingly threatened by human activities (Ceballos & Ehrlich, 2002, Hansen et al., 2013). Agriculture and infrastructure expansions are among the most devastating threats (Edwards et al., 2010, Hansen et al., 2013, Clements et al., 2014). Large animals are particularly affected because of their considerable home range requirements (Ceballos & Ehrlich, 2002; Robert et al., 2006) and extensive negative interactions with villagers (Acharya et al., 2017, AsERSM, 2017). Asian elephants (*Elephas maximus*) are endangered and are flagship and umbrella species in their native regions. Despite their importance in ecosystem function, culture, and fundraising for wildlife conservation (Campos-Arceiz et al., 2008; Ritchie & Johnson, 2009; Verissimo et al., 2011), only 29% of their distribution range is legally protected in 13 countries (Hedges et al., 2008), and thus most Asian elephants persist in human-dominated landscapes **inhabit** (Jathanna et al., 2015, Calabrese et al., 2017). Enlarging PANs is a priority for the long-term population viability of Asian elephants (AsERSM, 2017). However, economic development is the current top priority in many regions, and thus expanding PANs for Asian elephants under strict policy is likely to fail in human-dominated landscapes (Bennett & Mulongoy 2006, Zhang et al., 2006, Evans et al., 2018) as well as fail to meet habitat requirements.

Asian elephants are extreme habitat generalists and occur in primary and secondary forests, scrubland, grassland, and farmland (Choudhury et al., 2008). They have very specific strategies to utilize resources and avoid mortality risks according to socio-environments. For instance, the Cangyuan population (20–23 individuals) in China mostly stays within a nature reserve (NR) (520 km^2) (Liu et al., 2016); the Mengla population (88–98) is located within a NR (1 239 km^2) and its periphery (Chen et al., 2013); the Menghai-Lancang population (15) and most of the Xishuangbanna-Pu'er population (98–109) frequently use human-dominated landscapes (Fig. 1, Zhang et al., 2015). Despite these differences, there is mounting evidence that Asian elephants need supporting evidence

are "forest-edge specialists" at the fine scale. However, strict PAs substantially reduce forest regeneration by humans and fires (Nelson & Chomitz, 2011), resulting in intact closed forests, which are less suitable for Asian elephants than moderately disturbed forests (Sitompul et al., 2013, Evans et al., 2018, Wadey et al., 2018); for example, cleared land can exceed the optimal forest stature for Asian elephants in just 17 years in tropical regions (Evans et al., 2018).

Not clear-revise

On the other hand, Asian elephants are conflict-prone and often cause extensive loss to villages by raiding crops, damaging property, and even killing people (Gubbi, 2012, Chen et al., 2016). Villages in damage hotspots (or areas preferred by elephants) are typified by hilly terrain in regions relatively far from major roads and where traditional farming is practiced (e.g., corn and rice crops) within a forest matrix (Wilson et al., 2013, Chen et al., 2016). These areas are generally less developed economically than villages with flat terrain that produce large cash-crop plantations in proximity to major roads. Thus, alternative support for these villages is necessary to encourage the participation of villagers to enlarge PANs for Asian elephants.

villages, with

Here, we propose that co-management policy is more feasible than a strict policy for enlarging PANs for Asian elephants. This proposal is supported by two key pieces of evidence: (1) Asian elephants would not prefer intact forests and roam in proximity of human settlements and (2) habitat suitability and local economic development are negatively associated, in other words, poorer village areas likely provide more suitable habitat for Asian elephants than relatively rich villages. Our study provides useful information to guide conservation policy for enlarging PANs and for corridor design in China.

Materials & Methods

Asian elephants roam near human settlements more often than in intact forests

Study area

This study was conducted within the range of the Xishuangbanna-Pu'er population in Xishuangbanna and Pu'er, Yunnan, southwest China, bordering Vietnam and Laos (Fig. 1). This population consists of five subpopulations, i.e., Liushun, Yunxian, Simaogang, Jiangcheng, and Mengyang (Fig. 1). The region ranges from 495 m to 1 851 m above sea level, with an annual mean temperature of 21 °C and annual precipitation of ~1 500 mm. Natural forests (mainly subtropical evergreen broad-leaved forest) are fragmented by production forests (e.g., *Pinus kesiya* and *Eucalyptus* spp.), cash-crop plantations (e.g., rubber, coffee, and tea), and traditional farmlands (e.g., corn, rice, and sugarcane) (Chen et al., 2010). Three corridors (I, II, and III) connect the (a) Menghai-Lancang and Xishuangbanna-Pu'er population and (b) subpopulations of the Xishuangbanna-Pu'er population (Fig. 1, Zhang et al., 2015). However, a hydro-power dam raised the water level of the Mekong River, isolating the Menghai-Lancang population from the Xishuangbanna-Pu'er population since 2005 (Chen et al., 2010). The study area includes 32 villages, each of which comprises several community settlements (251 in total). The primary livelihoods rely on agriculture and agroforestry (Chen et al., 2010).

industries are

Methods

Data collection

In the confirmed range of the elephants, we collected data on the presence of Asian elephants (i.e., dung pile and footprint) and ground-truth points (or control points) of land-cover along with

What does this mean?

Dung piles and footprints within 20-m of the line transects were recorded, with intervals of at least 200 m

(Fig. 2; Liu et al., 2016)

91 line transects (307 km) from December 2016 and March 2017, with the assistance of forestry rangers. These line-transects were designed to traverse all types of land-cover (Fig. 1 and 2) (Liu et al., 2016). Signs of presence were detected within a 20-m width of the line-transects and recorded with at least 200 m intervals. Land cover was categorized into seven types (Chen et al., 2010): i.e., natural forest, 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).

We treated the per-capita annual income of villages as a proxy for economic development, with higher incomes representing higher levels of economic development. We collected data from the Digital Village of Yunnan (http://www.ynszxc.gov.cn/).

Data analysis

Analysis included five steps. First, independent variables were selected for habitat suitability modeling. Second, a land-cover map was developed from remote-sensing images. Third, the maximum entropy model (MaxEnt) was used to describe the occurrence probability of Asian elephants and generate a habitat suitability map, after which the characteristics of suitable habitat were summarized. Fourth, the possible negative association between habitat suitability and level of economic development was examined. Fifth, a habitat resistance surface was used to simulate the pathways of Asian elephants by least-cost and circuit models.

Independent variables

How was it examined? Which statistic?

We initially selected 13 variables in three categories following Lin et al. (2015) and Liu et al. (2016) (Table 1): i.e., geographic 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 distance to community settlement).

natural forest - calculated for pine plantation,

Land-cover classification

We used Landsat 8 OLI_TIRS images (30-m resolution from the Data Cloud of CAS, http://www.csdb.cn/) to develop a land-cover map. We added ancillary layers to improve 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 supervised classification using the random forest algorithm with 25% of the control points left to validate the classification (Leutner & Horning, 2016).

MaxEnt modeling

Among habitat suitability modeling with presence-only data, the MaxEnt maximum entropy approach outperforms other existing models (Ferrier et al., 2006, Phillips et al., 2006). In MaxEnt, pseudo-absence points are required to reflect the availability of environmental conditions and discriminate presence points (Elith et al., 2011, Timm et al., 2016). We randomly generated 10 000 pseudo-absence points in a background area. We defined the background area as where Asian elephants might occur (113 km^2 buffer zone of the presence points) (Fernando et al., 2008; Amirkhiz et al., 2018).

How did you choose the shape of the buffer zone?

Perhaps (H): Phillips et al., 2017)

optimized the

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

Team, 2013,

Association between habitat suitability and level of economic development

In the study area, the annual income of a village is related to its altitude, terrain, and land-use pattern, and thus may be indirectly associated with habitat suitability of Asian elephants. The habitat suitability of a village for Asian elephants was calculated by averaging the habitat suitability of community settlements, which was extracted by the locations of the community settlements from the habitat suitability map. We used a linear regression model to examine the direction and significance of the association between the habitat suitability of a village and its level of economic development.

which was extracted from the habitat suitability map using the

Pathway mapping

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

The Resistance

Results

Should this be " Liushun, Simaogang and Yunxian" - or is Yunxian dropped from consideration?

In total, we collected 245 Asian elephant presence points. The overall accuracy of the land-cover classification was 0.91.

The model with the lowest AIC had a β multiplier=1; linear, quadratic, threshold, and product features ("LQTP"); and eight uncorrelated variables with a contribution of >5%, including terrain roughness index, distance to town, community settlement, natural forests, and traditional farmlands, and percentage of natural forest, pine plantation, and traditional farmland. The percentage of natural forests (23%), distance to town (23%), and distance to community settlement (16%) were the three strongest variables in predicting the occurrence probability of Asian elephants.

three variables that most strongly predicted

There was a significant negative correlation between the habitat suitability for Asian elephants and the level of economic development (p=0.04)

In general, the model accurately discriminated presence points from pseudo-absence points (mean area under the curve (AUC)=0.86). The low AUC difference (0.05) suggested that the model did not over-fit 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 the suitable habitat was 0.28. In our study area, Asian elephants preferred forest matrix habitat with multiple land uses (50% natural forest cover) rather than intact forest away from towns (mean distance 10 km), near community settlements (mean distance 2 km), or flat terrain (mean terrain roughness index 4.83) (Fig. 2). The habitat suitability of villages for Asian elephants was significantly negatively associated with the level of economic development (p=0.04). On Fig. 3, the shortest path is #3 and the longest path is #2 ~~The least-cost model predicted three potential pathways (1, 2, and 3) connecting the three core ranges of the elephants; the lengths of pathways 1, 2, and 3 were 29 km, 41 km, and 47 km and the resistances were 60, 74, and 71, respectively (Fig. 3~~). The circuit model predicted the habitat connectivity pattern of the entire study area and pointed to potential corridors; for example, pathway 1 connected the isolated subpopulations between Mengyang and Jiangcheng (Fig. 2 and 3).

Discussion

For elephants, habitat selection reflects a trade-off between

Habitat selection reflects a trade-off for elephants between resource use and mortality-risk avoidance (Munshi-South et al., 2008, Basille et al., 2009). The percentage of natural forest was the strongest variable affecting the presence of Asian elephants. This finding is consistent with with a previous study on the Cangyuan population in China (Fig. 1, Liu et al., 2016) and demonstrated the substantial role of natural forests for Asian elephants in regard to providing food, refuge, and thermoregulation (Kumar et al., 2010, Goswami et al., 2014, Evans et al., 2018). In particular, our study revealed that Asian elephants prefer forest matrix habitats with multiple land uses rather than intact forest in human-dominated landscapes, which is supported by previous studies (Sitompul et al., 2013, Evans et al., 2018, Wadey et al., 2018). Forest matrix and their edges forest edges (?) provide better light conditions for *Ficus* spp. and gramineous plants, which are primary natural foods of Asian elephants (Chen et al., 2006, Sitompul et al., 2013, Wadey et al., 2018). Furthermore, traditional farmlands around community settlements are attractive to the elephants, with 68% of feeding sites found in such areas during the rainy season (Zhang et al., 2003). On the other hand, elephants do suffer mortality at the hands of humans, both directly and indirectly, from ditches, electrocution, and retaliatory killing (Chen et al., 2013; Palei et al., 2014; AsERSM, 2017). Therefore, Asian elephants occurred less frequently in the proximity of towns characterized by dense human infrastructure, plantations, and management (Fig. 2). Although we focused on habitat selection patterns of Asian elephants in human-dominated landscapes, similar patterns can be found in PAs and their peripheries. For example, the Shangyong and Mengla subpopulations mostly inhabit the buffer and experimental zones of NRs and their peripheries (Fig.1, Hongpei Yang pers. comm.). In Fig. 2, it is difficult to see any infrastructure sites (red squares)

Does this mean Fig. 1 in this paper or Fig. 1 in the 2016 paper?

Based on quantitative analysis and land-use practices, conservation efforts could be concentrated on the predicted pathways. With the greatest length and largest movement resistance, pathway 2

Pathway 2 did not have the greatest length - Pathway 3 was longer

Pathway 3 did NOT have the shortest length - Pathway 1 did

was rarely utilized by Asian elephants based on long-term monitoring (Chen et al., 2010, Zhang et al., 2015); despite having the shortest length, the resistance of pathway 3 was only slightly smaller than that of pathway 2 and traversed tracts of rubber plantations (Fig. 2), where stakeholders are unlikely to restore contiguous natural habitat for Asian elephants; pathway 1 was most consistent with the connectivity pattern predicted from the circuit model and has the shortest length and lowest resistance. Thus, the pathway 1 should be allocated higher conservation priority than either pathway 2 or 3. Furthermore, we identified a key area (green rectangle of Fig. 3) for connecting the subpopulations of Mengyang, Liushun, and Simaogang. Our study provides more precise information for corridor design than Zhang et al. (2015) (see Fig. 3), highlighting that transferring ecological niche models in PAs to human-dominated landscapes might produce biased results for animals with high behavioral flexibility. Specifically, sampling strategies biased to PAs with primary natural forests could produce biased connective habitat to natural forests in human-dominated landscapes.

Should "pathway 3" be "Pathway 3", etc.?

Why is this a key area?

Why?

Habitat selection of Asian elephants is a complex issue and affected by many factors. Our study is limited by our reliance on presence-only data to determine habitat suitability of Asian elephants, from which the resistance layer for simulating pathways was generated. Detailed movement data of the focus species could improve habitat suitability models and corridor design.

Why?

In China, PANs include NRs, world natural and cultural heritage sites, scenic zones, wetland parks, forest parks, geological parks, and water conservancy scenic locations (Cao et al., 2015), with NRs accounting for the largest proportion, occupying ~15% of national territory. Most NRs are managed as socially exclusive landscapes (Zhang et al., 2006, Cao et al., 2015), including the Xishuangbanna Nature Reserve (green area in Fig. 1). However, Asian elephants prefer forest matrix with multiple land-use and are flexible to human disturbance. Conservation policies allowing considerable interventions in NRs could enlarge Asian elephant habitat without great loss of biodiversity. For example, selectively-logged forests appear to maintain ~90% of the 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, further reduces the negative impacts on biodiversity (Gaveau et al., 2013, Fedrowitz et al., 2014). Among NRs, attention should be paid to protect community-own forests, which represent a major proportion of natural forests and are critical for the elephants (Kumar et al., 2010, Evans et al., 2018) and other wildlife (Rodrigues et al., 2017, Rodrigues & Chiarello, 2018). In addition, integrating traditional farmlands into PANs can fulfill human needs. Generally, villages more suitable for Asian elephants are economically less-developed than less suitable villages. Thus, supporting sustainable economic development and reducing Asian elephant damage are needed to encourage human-elephant coexistence, and may include developing ecotourism, encouraging wildlife-friendly products, and compensating damage loss.

That area is NOT green in Fig. 1

Selectively logged

community-owned

Generally, the less-developed villages are more suitable to Asian elephants than are the more-developed villages

Conclusions

affected globally

Asian elephants are globally affected by habitat fragmentation and loss. Thus, enlarging PANs is a top priority for their conservation (AsERSM, 2017). Using presence data from an on-ground survey in human-dominated landscapes combined with habitat suitability models, we found that:

(1) Asian elephants preferred forest matrix areas with multiple land-uses rather than intact forests in proximity to human settlements; and (2) habitat suitability and level of economic development were negatively associated. From the standpoints of elephant habitat suitability and local socio-economic background, these results demonstrated that co-management policy possess better feasibility for enlarging PANs to protect habitat for Asian elephants in a "developing" world. Such a policy would also be suitable for other areas with similar land-cover patterns and socio-economic contexts, such as northeastern India and northern Laos (Kumar et al., 2010, Wilson et al., 2013, AsERSM, 2017).

suggest that a co-management policy would be more feasible than the current policies

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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).

The Xishuangbanna-Pu'er populations are indicated by orange, not yellow

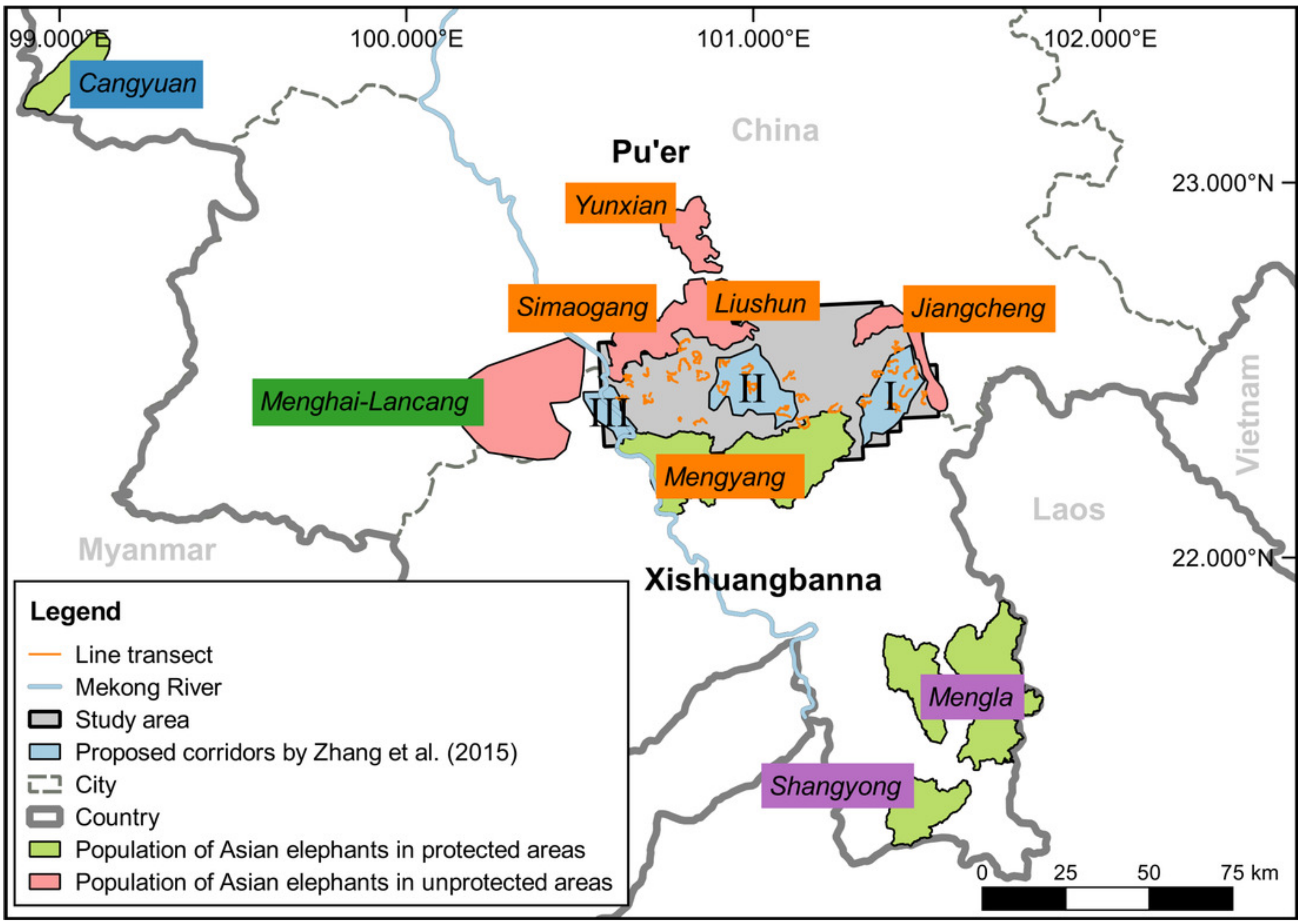

Figure 2

Habitat suitability map for Asian elephants in the study area.

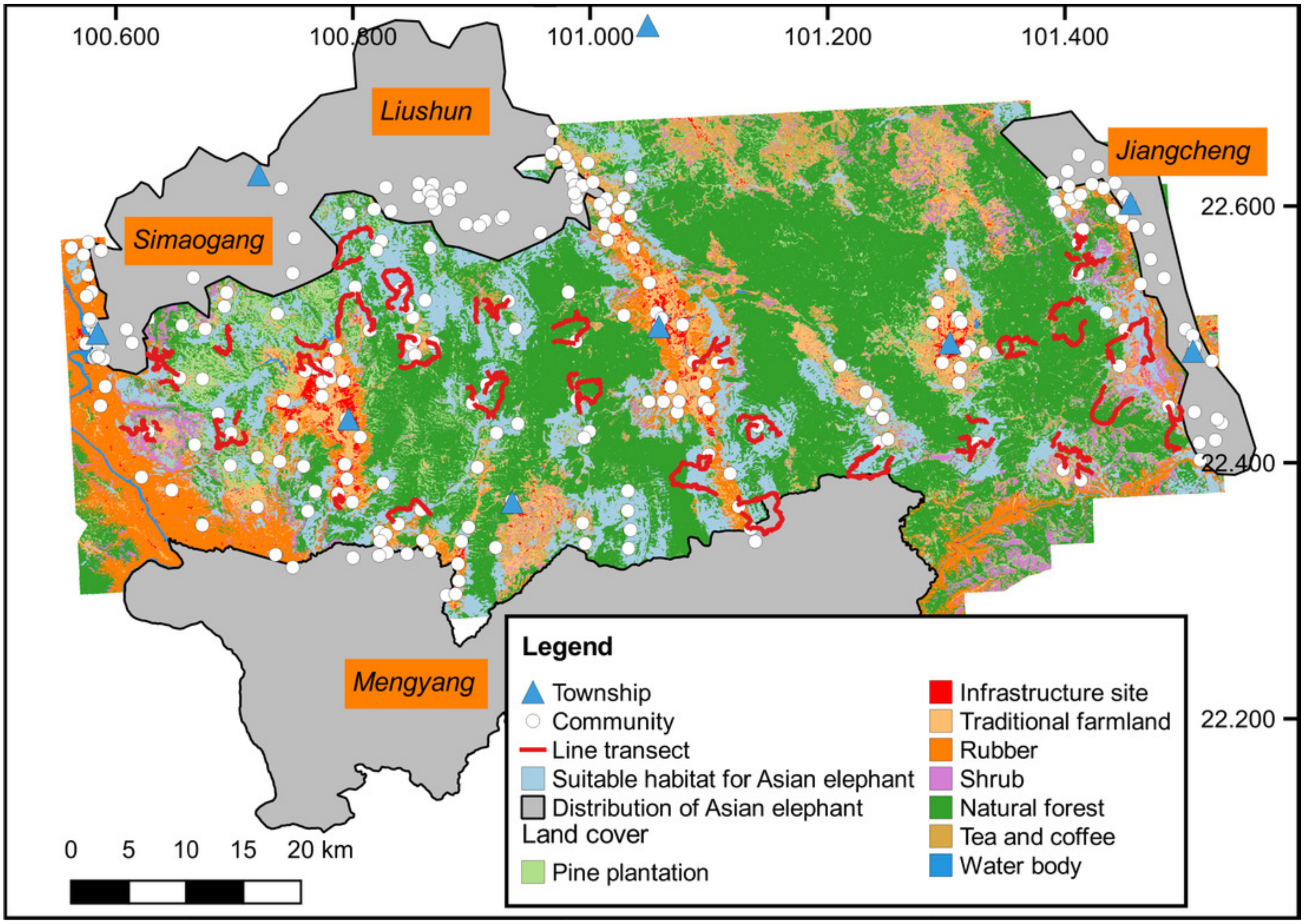

Figure 3

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

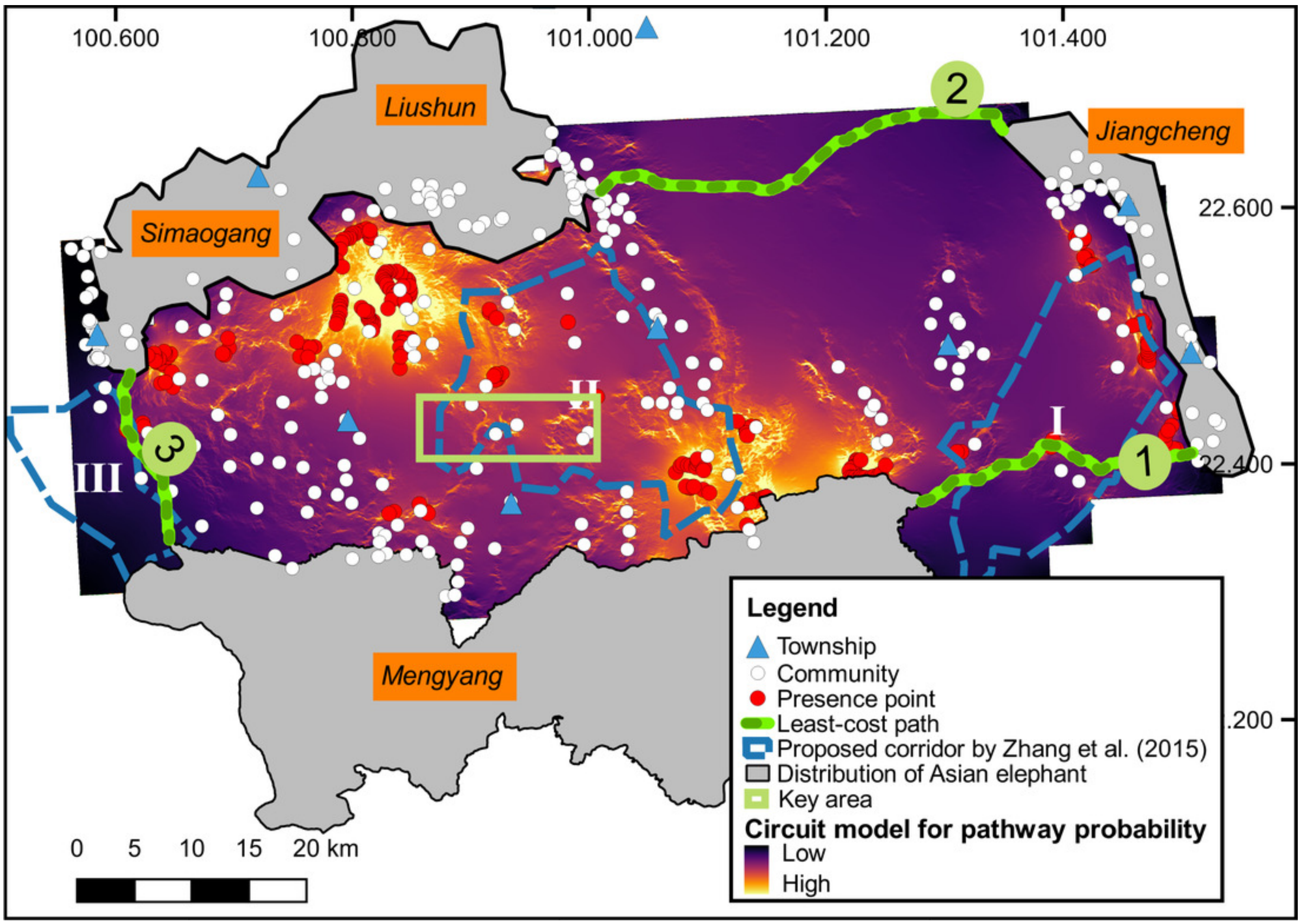

Table 1 (on next page)

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 settlement	Calculated by “distance” function in R