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 design~~ing~~ 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 forecast~~ed~~ 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

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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References

Acharya, K.P., Paudel, P.K., Jnawali, S.R., Neupane, P.R., Koehl, M., 2017. Can forest fragmentation and configuration work as indicators of human-wildlife conflict? Evidences from human death and injury by wildlife attacks in Nepal. Ecol. Indic. 80, 74–83.

278 Adams, W.M., Aveling, R., Brockington, D., Dickson, B., Elliott, J., Hutton, J., Roe, D., Vira, B.,
279 Wolmer, W., 2004. Biodiversity conservation and the eradication of poverty. Science. 306,
280 1146–1149.
281 Amirkhiz, G.R., Frey, J.K., Cain Iii, J.W., Breck, S.W., Bergman, D.L., 2018. Predicting spatial
282 factors associated with cattle depredations by the Mexican wolf (Canis lupus baileyi) with
283 recommendations for depredation risk modeling. Biol. Conserv. 224, 327–335.
284 AsERSM, 2017. Report: Asian elephant range states meeting. Jakarta, Indonesia. Retrieved from
285 https://elephantconservation.org/iefImages/2018/03/AsERSM-2017_Final-Report.pdf.
286 Basille, M., Herfindal, I., Santin-Janin, H., Linnell, J.D.C., Odden, J., Andersen, R., Arild Høgda,
287 K., Gaillard, J.-M., 2009. What shapes Eurasian lynx distribution in human dominated
288 landscapes: selecting prey or avoiding people? Ecography. 32, 683–691.
289 Bennett, G., Mulongoy, K.J., 2006. Review of experience with ecological networks, corridors and
290 buffer zones, in: Secretariat of the Convention on Biological Diversity, Montreal, Technical
291 Series 23:5–6.
292 Berry, N.J., Phillips, O.L., Lewis, S.L., Hill, J.K., Edwards, D.P., Tawatao, N.B., Ahmad, N.,
293 Magintan, D., Khen, C. V, Maryati, M., Ong, R.C., Hamer, K.C., 2010. The high value of
294 logged tropical forests: lessons from northern Borneo. Biodivers. Conserv. 19, 985–997.
295 Brodie, J.F., Giordano, A.J., Zipkin, E.F., Bernard, H., Mohd-azlan, J., Ambu, L., 2014.
296 Correlation and persistence of hunting and logging impacts on tropical rainforest mammals.
297 Conserv. Biol. 29, 110–121.
298 Calabrese, A., Calabrese, J.M., Songer, M., Wegmann, M., Hedges, S., Rose, R., Leimgruber, P.,
299 2017. Conservation status of Asian elephants: the influence of habitat and governance.
300 Biodivers. Conserv. 26, 2067–2081.
301 Campos-Arceiz, A., Larrinaga, A.R., Weerasinghe, U.R., Takatsuki, S., Pastorini, J., Leimgruber,
302 P., Fernando, P., Santamaria, L., 2008. Behavior rather than diet mediates seasonal difference
303 in seed dispersal by Asian elephants. Ecology 89, 2684–2691.
304 Cao, M., Peng, L., Liu, S., 2015. Analysis of the network of protected areas in China based on a
305 geographic perspective: Current status, issues and integration. Sustain. 7, 15617–15631.
306 Ceballos, G., Ehrlich, P.R., 2002. Mammal population losses and the extinction crisis. Science.
307 296, 904–907.
308 Chen, J., Deng, X., Zhang, L., Bai, Z., 2006. Diet composition and foraging ecology of Asian
309 elephants in Shangyong, Xishuangbanna, China. Acta Ecol. Sin. 26, 309–316.
310 Chen, M., Hong, G., Li, Z., Dong, Y., Yang, Y., 2013. Studies of conflict between elephant and
311 human being in China. Yunnan Science and Technology Press, Kunming, Yunnan, China.
312 Chen, M., Li, Z., Guo, X., Yang, Z., Dong, Y., 2010. Asian elephant conservation corridors in
313 China. Yunnan Science and Technology Press, Kunming, Yunnan, China.
314 Chen, S., Yi, Z., Campos-Arceiz, A., Chen, M., Webb, E.L., 2013. Developing a spatially-explicit,
315 sustainable and risk-based insurance scheme to mitigate human–wildlife conflict. Biol.
316 Conserv. 168, 31–39.

317 Chen, Y., Marino, J., Chen, Y., Tao, Q., Sullivan, C.D., Shi, K., Macdonald, D.W., 2016.
318 Predicting hotspots of human-elephant conflict to inform mitigation strategies in
319 Xishuangbanna, Southwest China. PLoS One 11, e0162035.
320 Choudhury, A.L., Choudhury, D.K., Desai, A., Duckworth, J.W., Easa, P.S., Johnsingh, A.J.T.,
321 Fernando, P., Hedges, S., Gunawardena, M., Kurt, F., 2008. Elephas maximus. IUCN Red
322 List of Threatened Species.
323 Clements, G.R., Lynam, A.J., Gaveau, D., Yap, W.L., Lhota, S., Goosem, M., Laurance, S.,
324 Laurance, W.F., 2014. Where and how are roads endangering mammals in Southeast Asia's
325 forests? PLoS One 9, 1–25.
326 DeFries, R., Hansen, A., Newton, A.C., Hansen, M.C., 2005. Increasing isolation of protected
327 areas in tropical forests over the past twenty years. Ecol. Appl. 15, 19–26.
328 Desai, A.A., Riddle, H.S., 2015. Human-elephant conflict in Asia. United State Fish and Wildlife
329 Service. Retrieved from https://www.fws.gov/international/pdf/Human-Elephant-Conflict-
330 in-Asia-June2015.pdf.
331 Edwards, D.P., Hodgson, J.A., Hamer, K.C., Mitchell, S.L., Ahmad, A.H., Cornell, S.J., Wilcove,
332 D.S., 2010. Wildlife ‐ friendly oil palm plantations fail to protect biodiversity effectively.
333 Conserv. Lett. 3, 236 ‐ 242.
334 Elith, J., Phillips, S.J., Hastie, T., Dudík, M., Chee, Y.E., Yates, C.J., 2011. A statistical
335 explanation of MaxEnt for ecologists. Divers. Distrib. 17, 43–57.
336 Escalante, T., Rodríguez-Tapia, G., Linaje, M., Illoldi-Rangel, P., González-López, R., 2013.
337 Identification of areas of endemism from species distribution models: threshold selection and
338 Nearctic mammals. TIP 16, 5–17.
339 Evans, L.J., Asner, G.P., Goossens, B., 2018. Protected area management priorities crucial for the
340 future of Bornean elephants. Biol. Conserv. 221, 365–373.
341 Fedrowitz, K., Koricheva, J., Baker, S.C., Lindenmayer, D.B., Palik, B., Rosenvald, R., Beese,
342 W., Franklin, J.F., Kouki, J., Macdonald, E., 2014. Can retention forestry help conserve
343 biodiversity? A meta-analysis. J. Appl. Ecol. 51, 1669–1679.
344 Fernando, P., Wikramanayake, E.D., Janaka, H.K., Jayasinghe, L.K.A., Gunawardena, M.,
345 Kotagama, S.W., Weerakoon, D., Pastorini, J., 2008. Ranging behavior of the Asian elephant
346 in Sri Lanka. Mamm. Biol. 73, 2–13.
347 Ferrier, S., Guisan, A., Elith, J., Graham, C.H., Anderson, R.P., Dudı, M., Hijmans, R.J.,
348 Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion,
349 G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S.J.,
350 Richardson, K., Scachetti-pereira, R., Schapire, R.E., Williams, S., Wisz, M.S.,
351 Zimmermann, N.E., 2006. Novel methods improve prediction of species ' distributions from
352 occurrence data. Ecography 29, 129-151.
353 Gaveau, D.L.A., Kshatriya, M., Sheil, D., Sloan, S., Molidena, E., Wijaya, A., Wich, S., Ancrenaz,
354 M., Hansen, M., Broich, M., Guariguata, M.R., Pacheco, P., Potapov, P., Turubanova, S.,
355 Meijaard, E., 2013. Reconciling forest conservation and logging in Indonesian Borneo. PLoS
356 One 8, e69887.

Geldmann, J., Barnes, M., Coad, L., Craigie, I.D., Hockings, M., Burgess, N.D., 2013. Effectiveness of terrestrial protected areas in reducing habitat loss and population declines. Biol. Conserv. 161, 230–238.

Goswami, V.R., Sridhara, S., Medhi, K., Williams, A.C., Chellam, R., Nichols, J.D., Oli, M.K., 2014. Community-managed forests and wildlife-friendly agriculture play a subsidiary but not substitutive role to protected areas for the endangered Asian elephant. Biol. Conserv. 177, 74–81.

Gubbi, S., 2012. Patterns and correlates of human-elephant conflict around a south Indian reserve. Biol. Conserv. 148, 88–95.

Hansen, M.C., Potapov, P. V, Moore, R., Hancher, M., Turubanova, Sa., Tyukavina, A., Thau, D., Stehman, S. V, Goetz, S.J., Loveland, T.R., 2013. High-resolution global maps of 21st-century forest cover change. Science. 342, 850–853.

Hedges, S., Fisher, K., Rose, R., 2008. Range-wide mapping workshop for Asian elephants (Elephas maximus). Rep. to US Fish Wildl. Serv. Cambodia.

Hughes, A.C., 2017. Mapping priorities for conservation in Southeast Asia. Biol. Conserv. 209, 395–405.

Jathanna, D., Karanth, K.U., Kumar, N.S., Karanth, K.K., Goswami, V.R., 2015. Patterns and Determinants of Habitat Occupancy by the Asian Elephant in the Western Ghats of Karnataka, India. PLoS One 10, e0133233.

Joppa, L.N., Pfaff, A., 2009. High and far: biases in the location of protected areas. PLoS One 4, e8273.

Jueterbock, A., 2015. R package MaxentVariableSelection: selecting the best set of relevant environmental variables along with the optimal regularization multiplier for Maxent niche modeling.

Kioko, J., Kiffner, C., Ndibalema, V., Hartnett, E., Seefeld, C., 2015. Maasai people and elephants: values and perceptions. NISCAIR-CSIR, India.

Kumar, M.A., Mudappa, D., Raman, T.R.S., 2010. Asian elephant Elephas maximus habitat use and ranging in fragmented rainforest and plantations in the Anamalai Hills, India. Trop. Conserv. Sci. 3, 143–158.

Laurance, W.F., Carolina Useche, D., Rendeiro, J., Kalka, M., Bradshaw, C.J.A. et.al, 2012. Averting biodiversity collapse in tropical forest protected areas. Nature 489, 290.

Leutner, B., Horning, N., 2016. RStoolbox: Tools for Remote Sensing Data Analysis.

Lin, L., Jin, Y., Yang, H., Luo, A., Guo, X., Wang, L., Zhang, L., 2015. Evaluation of habitat for Asian elephants (Elephas maximus)in Xishuangbanna,Yunnan,China. Acta Theriol. Sin. 35, 2–13.

Liu, P., Hui, W., Liu, L., Jing, L., Li, Z., 2016. Habitat evaluation for Asian elephants (Elephas maximus) in Lincang: Conservation planning for an extremely small population of elephants in China. Biol. Conserv. 198, 113–121.

Liu, P., Wen, H., Harich, F.K., He, C., Wang, L., Guo, X., Zhao, J., Luo, A., Yang, H., Sun, X., Yu, Y., Zheng, S., Guo, J., Li, L., Zhang, L., 2017. Conflict between conservation and development: cash forest encroachment in Asian elephant distributions. Sci. Rep. 7, 6404.

McDonald, R.I., Boucher, T.M., 2011. Global development and the future of the protected area strategy. Biol. Conserv. 144, 383–392.

Mcrae, B.H., Dickson, B.G., Keitt, T.H., Shah, V.B., Mcrae, B.H., Dickson, B.G., Keitt, T.H., Shah, V.B., 2008. Using Circuit Theory to Model Connectivity in Ecology , Evolution , and Conservation. ECOLOGY 89, 2712–2724.

McRae, B.H., Shah, V.B., 2009. Circuitscape user's guide. Univ. California, St. Barbar.

Mudappa, D., Noon, B.R., Kumar, A., Chellam, R., 2007. Responses of small carnivores to rainforest fragmentation in the southern Western Ghats, India. Small Carniv. Conserv. 36, 18–26.

Munshi-South, J., Tchignoumba, L., Brown, J., Abbondanza, N., Maldonado, J.E., Henderson, A., Alonso, A., 2008. Physiological indicators of stress in African forest elephants (Loxodonta africana cyclotis) in relation to petroleum operations in Gabon, Central Africa. Divers. Distrib. 14, 995–1003.

Muscarella, R., Galante, P.J., Soley-Guardia, M., Boria, R.A., Kass, J.M., Uriarte, M., Anderson, R.P., 2014. ENMeval: An R package for conducting spatially independent evaluations and estimating optimal model complexity for ecological niche models. Methods Ecol. Evol. 5, 1198–1205.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da, F.G., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853.

Palei, N.C., Palei, H.S., Rath, B.P., Kar, C.S., 2014. Mortality of the endangered Asian elephant Elephas maximus by electrocution in Odisha, India. Oryx 48,

Phillips, S.J., Anderson, R.P., Dudík, M., Schapire, R.E., Blair, M.E., 2017. Opening the black box: an open-source release of Maxent. Ecography 40, 887–893

Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. Ecol. Modell. 190, 231–259.

R Development Core Team, 2013. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing.

Ritchie, E.G., Johnson, C.N., 2009. Predator interactions, mesopredator release and biodiversity conservation. Ecol. Lett. 12, 982–998.

Robert, S., WANLOP, C., NARET, S., 2006. Collaborating to conserve large mammals in southeast Asia. Conserv. Biol. 20, 1391–1401.

Rodrigues, T.F., Chiarello, A.G., 2018. Native forests within and outside protected areas are key for nine-banded armadillo (Dasypus novemcinctus) occupancy in agricultural landscapes. Agric. Ecosyst. Environ. 266, 133–141.

Rodrigues, T.F., Kays, R., Parsons, A., Versiani, N.F., Paolino, R.M., Pasqualotto, N., Krepschi, V.G., Chiarello, A.G., 2017. Managed forest as habitat for gray brocket deer (Mazama gouazoubira) in agricultural landscapes of southeastern Brazil. J. Mammal. 98, 1301–1309.

435 Ruiz-González, A., Gurrutxaga, M., Cushman, S.A., Madeira, M.J., Randi, E., Gómez-Moliner,
436 B.J., 2014. Landscape genetics for the empirical assessment of resistance surfaces: The
437 European pine marten (Martes martes) as a target-species of a regional ecological network.
438 PLoS One 9, e110552.
439 Sitompul, A.F., Griffin, C.R., Rayl, N.D., Fuller, T.K., 2013. Spatial and temporal habitat use of
440 an Asian Elephant in Sumatra. Anim. an open access J. from MDPI 3, 670–679.
441 Timm, B.C., McGarigal, K., Cushman, S.A., Ganey, J.L., 2016. Multi-scale Mexican spotted owl
442 (Strix occidentalis lucida) nest/roost habitat selection in Arizona and a comparison with
443 single-scale modeling results. Landsc. Ecol. 31, 1209–1225.
444 Verissimo, D., Macmillan, D.C., Smith, R.J., 2011. Toward a systematic approach for identifying
445 conservation flagships. Conserv. Lett. 4, 1–8.
446 Wadey, J., Beyer, H.L., Saaban, S., Othman, N., Leimgruber, P., Campos-Arceiz, A., 2018. Why
447 did the elephant cross the road? The complex response of wild elephants to a major road in
448 Peninsular Malaysia. Biol. Conserv. 218, 91–98.
449 Wang, F., McShea, W.J., Wang, D., Li, S., Zhao, Q., Wang, H., Lu, Z., 2014. Evaluating
450 Landscape Options for Corridor Restoration between Giant Panda Reserves. PLoS One 9,
451 e105086.
452 Wegmann, M., Leutner, B., Dech, S., 2016. Remote sensing and GIS for ecologists: using open
453 source software. Pelagic Publishing: Exeter, UK.
454 Wharton, C.H., 1968. Man, fire and wild cattle in Southeast Asia, in: Proceedings of the Annual
455 Tall Timbers Fire Ecology Conference. pp. 7–167.
456 Wilson, E.O., MacArthur, R.H., 1967. The theory of island biogeography. Princeton, NJ.
457 Wilson, S., Davies, T.E., Hazarika, N., Zimmermann, A., 2013. Understanding spatial and
458 temporal patterns of human-elephant conflict in Assam, India. Oryx 49, 140-149.
459 Zhang, L., Dong, L., Lin, L., Feng, L., Yan, F., Wang, L., Guo, X., Luo, A., 2015. Asian elephants
460 in China: Estimating population size and evaluating habitat suitability. PLoS One 10,
461 e0124834.
462 Zhang, L., Lichao, M.A., Feng, L., 2006. New challenges facing traditional nature reserves: Asian
463 elephant (Elephas maximus) conservation in China. Integr. Zool. 1, 179–187.
464 Zhang, L., Wang, N., Wang, Y., Ma, L., 2003. A Preliminary Study on the Habitat and Behaviors
465 of Asian Elephant (Elephas maximus) in Simao, Yunnan, China. Acta Theriol. Sin. 23, 185–
466 192.

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).

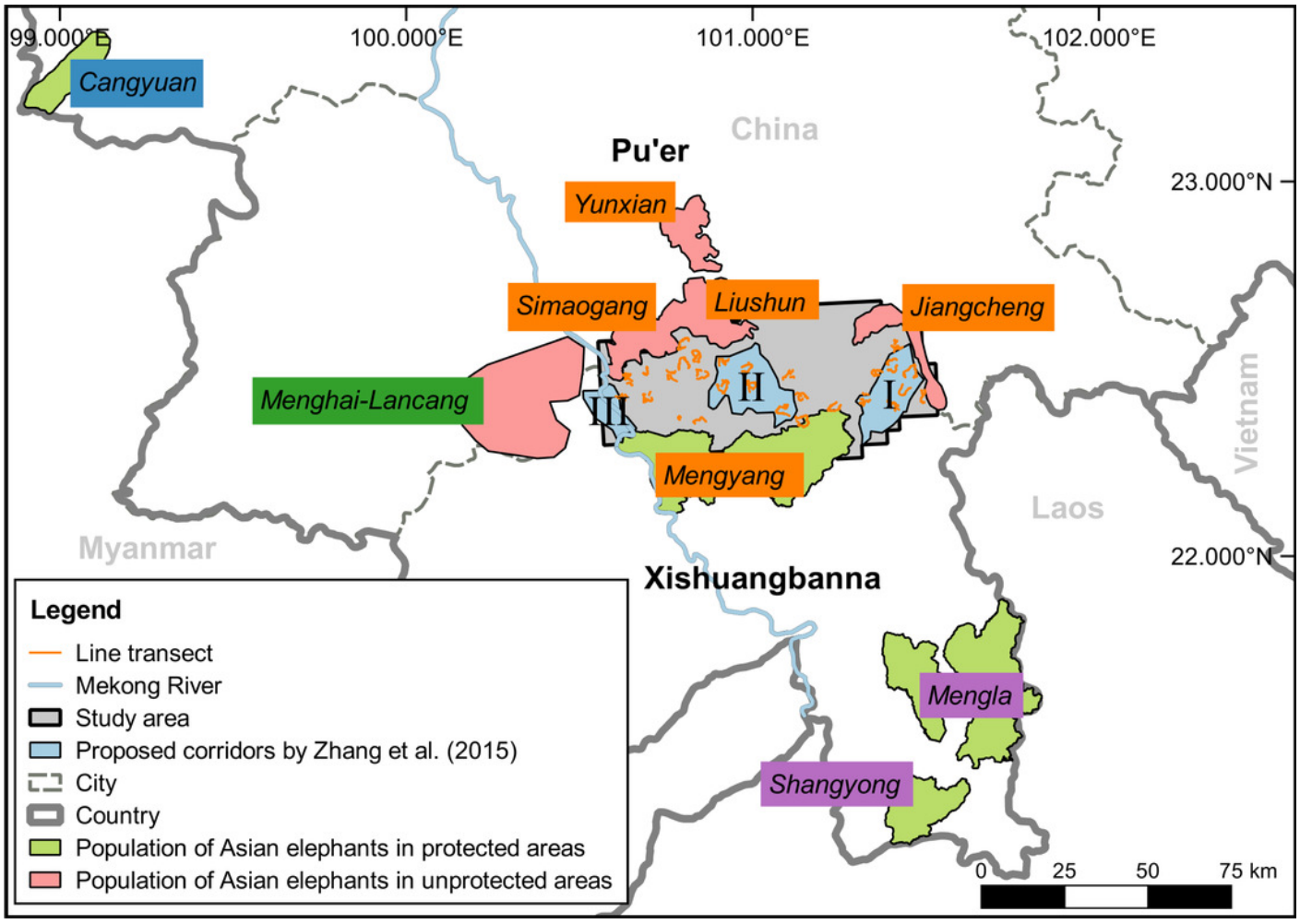

Figure 2

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

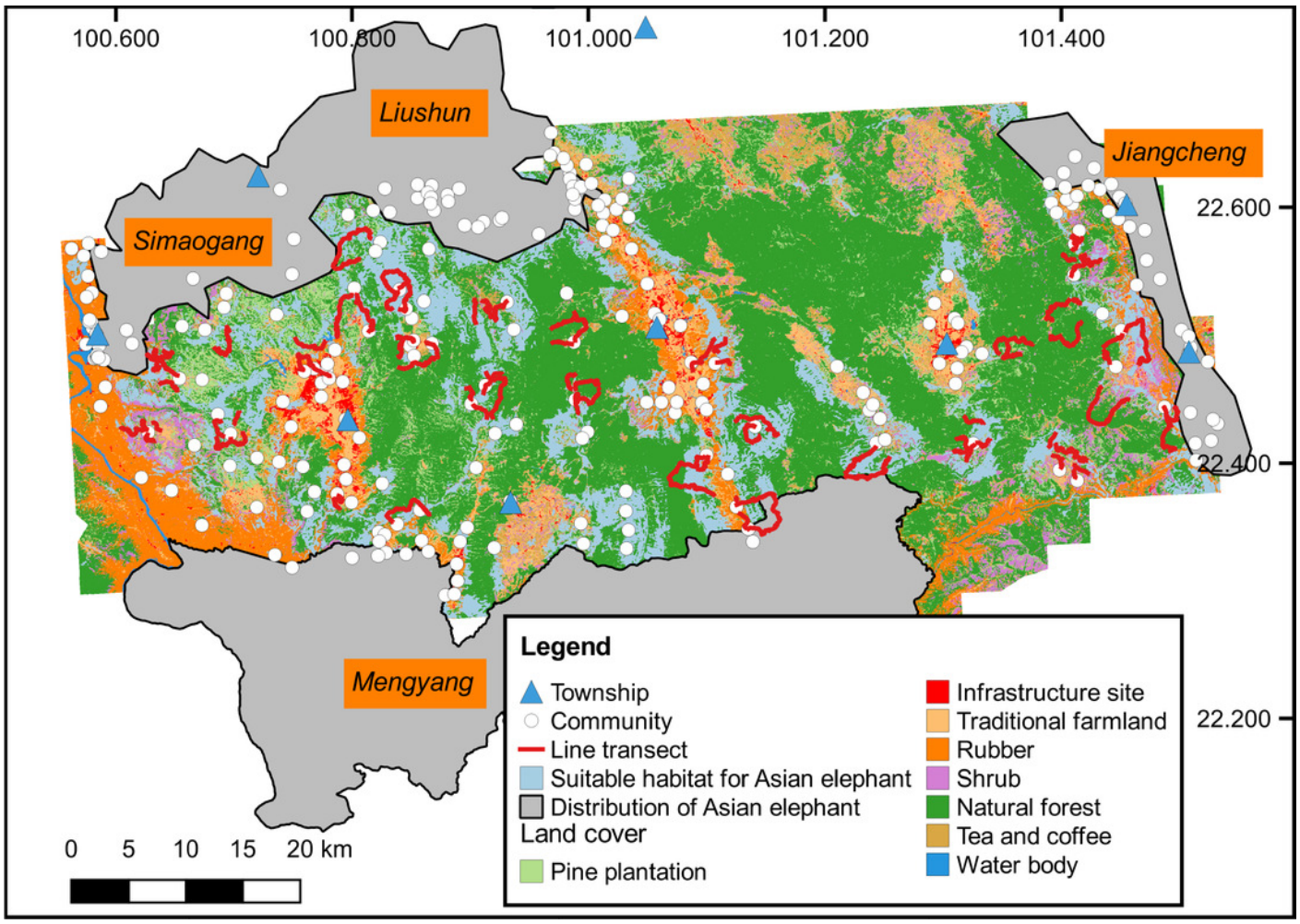

Figure 3

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

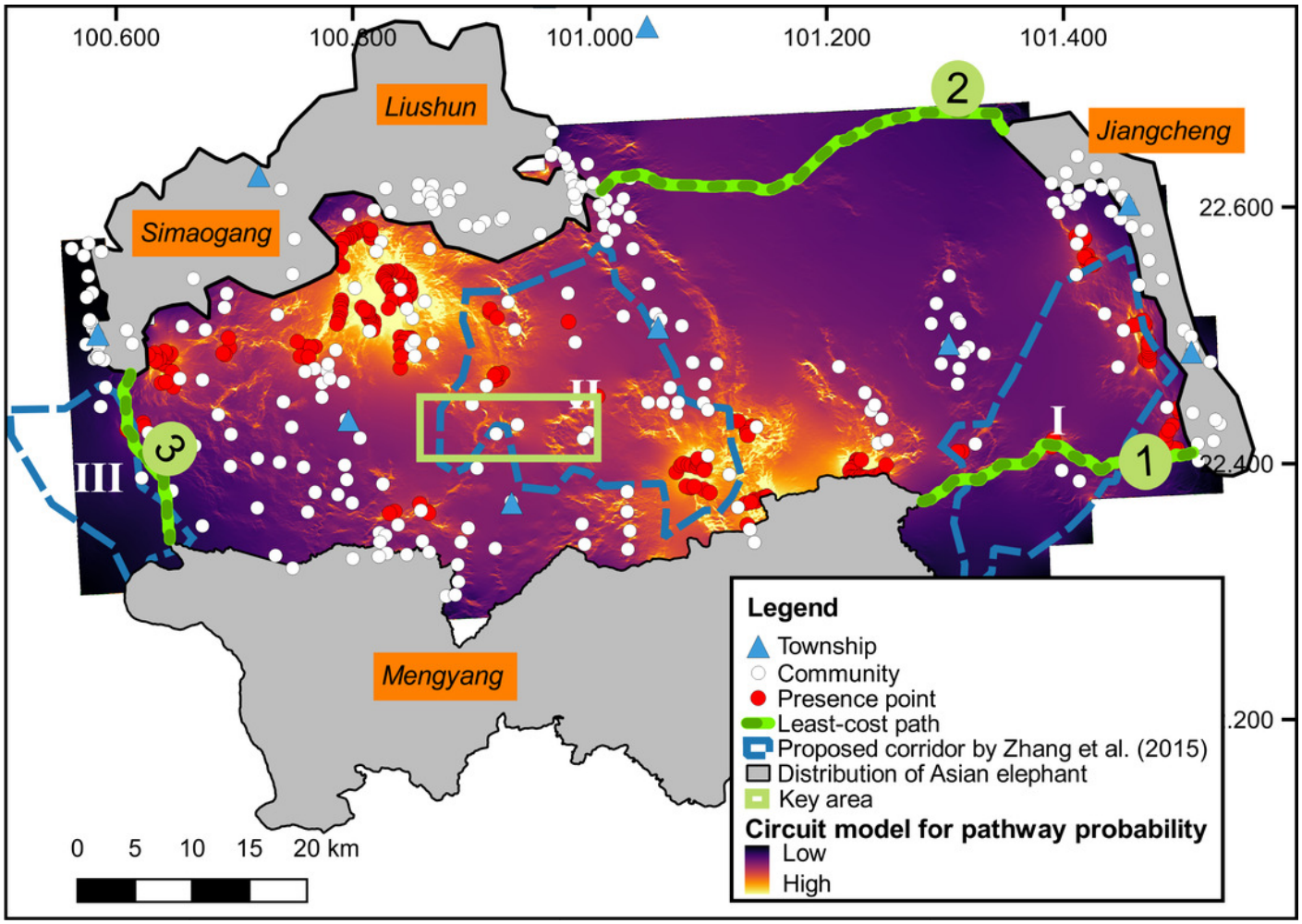

Table 1(on next page)

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

1

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

2

3