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Habitat evaluation for Asian elephants (*Elephas maximus*) in Lincang: Conservation planning for an extremely small population of elephants in China

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ABSTRACT

Fewer than 250 Asian elephants remain in China, occupying fragmented habitats of Yunnan Province. One such fragmented population of 18–23 individuals occupies the Nangunhe Nature Reserve Area in Lincang City, Yunnan Province, China. The greatest threat to the survival of this population is the loss and fragmentation of habitat. In this study, we applied an ecological niche factor analysis (ENFA) model to evaluate the habitat suitability of Lincang City for Asian elephants based on geographical factors, vegetation type, and human disturbance. Optimal, relatively suitable, and marginal habitat accounted for 0.16% (38.45 km^2), 0.61% (150.00 km^2), and 3.34% (817.26 km^2) of the total study area, whereas non-suitable habitat accounted for 95.89% (23,463.29 km^2) of this area. The marginality of Asian elephant habitat in Lincang was 1.954, indicating nonrandom selection of various eco-geographical variables in the environment. The primary factor affecting Asian elephant habitat quality was vegetation type, followed by geographical factors and human disturbance. A habitat quality map for the total distribution of Asian elephants remaining in China (i.e., Yunnan Province: Xishuangbanna, Lincang, and Pu'er) based on our current and previous study showed that just 1400.57 km^2 and 2689.62 km^2 relatively suitable and optimal habitat is available, owing to significant deforestation. In addition to reintroduction programs, conservation strategies should focus on improving the quality of marginal habitats for elephants, in parallel to placing ecological corridors through non-suitable habitat to connect all suitable habitats for this and other extremely small elephant populations in China to reduce genetic isolation and secure long-term survival for the species.

1. Introduction

The Asian elephant (*Elephas maximus*) is listed as endangered (EN) species by IUCN, and it is one of the first class state protected species in China. Historically, Asian elephants were widely distributed from the northernmost part of China to the Yellow River Basin three thousand years ago. However, Asian elephant distribution in China has retreated southward at a rate of 0.5° latitude per century, owing to major deforestation activity and potentially climate change (Sun et al., 1998). At present, only 221–245 wild Asian elephants remain in China, all of which are distributed across 3 areas of Yunnan Province: the Xishuangbanna National Nature Reserve in Xishuangbanna, the Nangunhe National Nature Reserve in Lincang City, and Pu'er City (Zhang et al., 2015). Just 18–23 Asian elephants remain in the Nangunhe National Nature Reserve (Zhang et al., 2003), with this population being isolated from all other populations for 50 years. In Nangunhe, the Asian elephant population prefers to inhabit flat valleys or the base of hills below 1000 m with shrub and bamboo-broadleaf mixed forest cover (Feng et al., 2010). However, owing to significant deforestation in the last 40 years, Asian elephants inhabiting Nangunhe area have become a geographically isolated population (Feng et al., 2010). Thus, it is essential to understand the habitat quality of this region to implement conservation strategies that ensure the long-term survival and reproductive output of the Nangunhe population.

Habitat evaluations clarify habitat distribution ranges and characteristics that are important for target species or populations. Such an evaluation involves analyzing target species habitat requirements/preferences, which are then compared against the available habitat of the study area (Xiao et al., 2004). Predictive habitat modeling is currently used for habitat evaluation and associated conservation application (Guisan and Zimmermann, 2000). The ecological niche factor analysis (ENFA) model has been widely used worldwide for many species, including corals (Davies et al., 2008; Tittensor et al., 2009), octopuses (Consuelo et al., 2011), vultures (Hirzel and Arlettaz, 2003), and elephants (Rood et al., 2010). ENFA only requires "species presence" data to simulate and predict species habitat suitability (Hirzel et al., 2002). Because this algorithm does not rely on absence data, which is

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often unavailable because of problems associated with false absences (Hirzel et al., 2002), it is highly applicable to model a cryptic and highly mobile species (Rood et al., 2010).

In China, we previously applied ENFA to evaluate the habitat requirements of Asian elephants in Xishuangbanna (Lin et al., 2015) and Pu′er (Dai, 2012), based on various habitat selection studies (Feng and Zhang, 2005; Feng et al., 2010; Lin et al., 2008; Zhang et al., 2003) and elephant distribution. We accurately predicted potential suitable habitat for elephants in Jiangcheng County (Pu′er City), which is verified by the fact that 18 elephants has immigrated naturally in this area after 2011(Zhang et al., 2015). Furthermore, ecological corridors between Xishuangbanna and Pu′er have been scientifically designed based on these preceding studies.

Here, we present, to our knowledge, the first investigation of habitat suitability for Asian elephants in Lincang using an ENFA model combined with geographic information technology. This study aimed to: (1) determine the extent and distribution of suitable habitat for Asian elephants in Lincang, (2) examine the consistence of the main factors influencing habitat quality for Asian elephants, and (3) design an ecological corridor using science-based data that would help expand the scope of activity of Asian elephants inhabiting Lincang across the national border of China with Myanmar to mitigate small population isolation and further decline.

2. Materials & methods

2.1. Study area

Lincang City (total area 24,469 km^2) is located in the southwestern part of Yunnan Province, China, between 98°40′ and 100°34′E and 23°05′ and 25°02′N. To the south, Lincang borders with the neighboring country Myanmar. Lincang is located in a typical southwest monsoon climate zone, with distinct dry and rainy seasons.

The Nangunhe Nature Reserve covers an extremely small area (just 519.39 km^2). Within the Nangunhe National Nature Reserve, temperature and precipitation greatly vary with increasing altitude. Mean annual temperature is 16.6–24.4 °C, while mean annual precipitation is 1750–2460 mm (Feng et al., 2010). Consequently, there is a distinct transition from tropical to subtropical climate in terms of habitat type, as well as plant and animal species and distribution. The valley is a low altitude (below 600 m) region, belonging to a north tropical humid climate, with hot weather, no frost at any time of year, and little fog or dew. Most tropical forests and tropical monsoon forests in the reserve are distributed in this valley region. The middle part of the mountains is a moderate altitude region, belonging to a southern humid subtropical climate, with warm weather and high precipitation. The extensive vegetation of this region is dominated by monsoon evergreen broad-leaf forests. The upper part of the mountains is a high altitude region (above 1700 m), belonging to a humid mid-subtropical climate, with warm weather and high precipitation. This region is dominated by rich evergreen vegetation (Feng and Zhang, 2005, Feng et al., 2010).

2.2. ENFA model

Based on Hutchinson's ecological niche theory, ENFA evaluates habitat suitability by comparing niche factor characteristics between "species presence" and the study area. In this study, ENFA was run in Biomapper 4.0 (Hirzel et al., 2006; URL: http://www2.unil.ch/biomapper). Principal component analysis was used to extract the main factors from multiple environmental variables. The main factors were then combined into unrelated feature factor matrices. Feature factor metrics and feature vectors were used to generate the habitat suitability map. After combining these datasets, the feature factors retained most information from the original habitat factors, showing ecological significance (Chen, 2009; Hirzel et al., 2002; Wang et al., 2008).

For example, we first obtained the data for a specific Eco-Geographical Variable (EGV), in which m_G is the mean value of the EGV in the whole study area, σ_G is the standard deviation of the EGV, m_S is the mean value of the EGV in the species distribution area, and σ_S is the standard deviation of the EGV within the species distribution area. Then 3 indicators were calculated; namely, including marginality (M), specialization (S), tolerance (T).

M represents the difference in the mean EGV value between the suitable ecological niche of a species and the whole study area (standard distance), denoted as:

$$M = \frac{|m_G - m_S|}{1.96\sigma_G}.$$

An M value >1, or close to 1, indicates that the suitable niche is far from the center of the entire study area, while the species distribution is nonrandom and selective. An M value <1, close to 0, indicates that the suitable niche is close to the study area, while the selection of EGVs is random.

S is the ratio of the standard deviation of the EGV between the suitable niche for a certain species and the entire study area, which describes the selection range of habitat factors by the species, whereby:

$$S = \frac{\sigma_G}{\sigma_S}.$$

The greater the S value, the narrower the ecological niche occupied by the species and the higher level of specialization of the niche in the study area.

T is the reciprocal of S, representing the tolerance of a species to EGV, in which:

$$T = \frac{1}{S}.$$

T ranges from 0 to 1. A T value closer to 0 indicates lower tolerance and narrower distribution of the species. A T value closer to 1 indicates higher tolerance and wider distribution of the species.

2.3. Habitat assessment

Based on the interpreted remote sensing images, 32 transects in Nangunhe were defined, ensuring that all vegetation types could be traversed within the elephant range areas (Feng et al., 2010; Lin et al., 2014). The distribution data of Asian elephants were obtained from the evidence of animal presence (e.g., footprints and feces, as well as evidence of resting and feeding from disturbed vegetation) and direct observation of individuals (distribution points) recorded during field surveys (Feng and Zhang, 2005). We used data collected from the field survey in 2012, which included 262 elephant distribution points. The distribution data were used to generate an "Asian elephant distribution point grid graph" (grid value = 0 or 1) in ArcGIS 9.3 (ESRI Ltd., CA, USA. 2008. www.esri.com). A grid point value of 1 indicates species presence, while all other grids in the study area are assigned a value of 0.

Key factors for evaluating Asian elephant habitat quality were selected based on previous studies (Supplementary Table A1). These factors were (1) geographical (altitude, slope, aspect, position, and rivers), (2) vegetation (natural forest, tree plantations, shrub, and farmland), and (3) disturbance (villages, main roads, and dirt roads). Subsequently, data for each of the EGVs were obtained from a variety of sources and through software processing (see Supplementary Table A2 for specific sources and access methods).

ASTER GDEM grid data (30 × 30 m resolution) were downloaded from the Chinese Academy of Science Database — International Science Data Services Platform (http://srtm.datamirror.csdb.cn/). Slope and aspect data were obtained using the Spatial Analysis module in ArcGIS 9.3. Ridge and valley data were obtained from hydrological analysis (Hydrology module). Position data were calculated by installing the Topographical Position Index (TPI) expansion module in ArcView 3.3