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Conceptual Design of Asian Elephant Ecological Corridors in China and Related Conservation Recommendations: Postprint

Authors: Li Xueyou, Yu Qiupeng, Hu Zhechang, Jiang Xuelong

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Abstract

To implement the coordinated development concepts of "lucid waters and lush mountains are invaluable assets" and "mountains, rivers, forests, farmlands, lakes, grasslands, and deserts constitute a community of life" , this study adopts the theoretical guidance of "promoting green development and fostering harmonious coexistence between humanity and nature" proposed in the Party' s 20th National Congress report. Aiming to enhance ecosystem integrity and connectivity, facilitate population exchange, improve population viability, and provide a demonstration for flagship species ecological corridor construction, and based on the current distribution patterns of Asian elephant populations and their habitat selection strategies, we propose conceptual designs and conservation recommendations for Asian elephant ecological corridor construction following the technical workflow of: acquiring species distribution data—identifying source patches and resistance surfaces—constructing corridors using the least-cost path model—analyzing corridor centrality, ecological pinch points, and barrier points via circuit model—conducting field surveys—adjusting and optimizing ecological corridor designs—recommending corridor construction schemes—implementing long-term monitoring of wildlife corridor utilization. These concepts and recommendations serve the strategic objectives of "strengthening ecosystem conservation" and "optimizing ecological security barrier systems while constructing ecological corridors and biodiversity conservation networks" , thereby providing technical support for the scientific conservation and effective management of Asian elephant populations, and offering a scientific basis for habitat restoration and the planning of proposed protected areas such as the Asian Elephant National Park.

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Preamble

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Title: Conception on Asian Elephant Ecological Corridor Planning with Implications for Conservation

Authors: Li Xueyou, Yu Qiupeng, Hu Zhechang, Jiang Xuelong*

Affiliation: State Key Laboratory of Genetic Resources and Evolution & Yunnan Key Laboratory of Biodiversity and Ecological Conservation of Gaoligong Mountain, Kunming Institute of Zoology, Chinese Academy of Sciences, Kunming 650201, China

Abstract

To implement the concepts of "Lucid waters and lush mountains are invaluable assets" and "Mountains, rivers, forests, farmlands, lakes, grasslands, and deserts are a community of life," this study adopts "pursuing green development and promoting harmony between humanity and nature" from the report of the 20th National Congress of the Communist Party of China as theoretical guidance. The objectives are to enhance ecosystem integrity and connectivity, facilitate population exchange, improve population viability, and provide a demonstration model for flagship species ecological corridor construction. Based on the current distribution and habitat selection strategies of Asian elephants, we propose a technical workflow for Asian elephant ecological corridor construction: (1) obtain species distribution data; (2) identify source patches and resistance surfaces; (3) construct corridors using a least-cost path model; (4) analyze corridor centrality, ecological pinch points, and barrier points through circuit theory; (5) conduct field surveys; (6) adjust and optimize corridor design; (7) recommend corridor construction schemes; and (8) carry out long-term monitoring of wildlife corridor utilization. These proposals serve the strategic layout of "intensifying ecosystem protection" and "optimizing the ecological security barrier system by constructing ecological corridors and biodiversity protection networks." This work provides technical support for the scientific protection and effective management of Asian elephant populations and offers a scientific basis for habitat restoration and the layout of proposed Asian elephant national parks and other protected areas.

Keywords: Asian elephant, ecological corridor, conservation, human-elephant conflict

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1. Asian Elephant Conservation Status and Human-Elephant Conflict

1.1 Asian Elephant Population and Distribution

The Asian elephant (*Elephas maximus*) is the largest extant terrestrial vertebrate in Asia and a keystone species for maintaining forest ecosystem health. The global wild Asian elephant population is estimated at 45,671–49,028 individuals, distributed across 13 countries including India, Sri Lanka, Myanmar, Thailand, and China [Figure 1: see original paper]. Due to continuous population decline and threats from habitat compression, fragmentation, and poaching, the species is assessed as Endangered by the International Union for Conservation of Nature (IUCN), listed in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and designated as a National First-Class Protected Species in China.

1.2 China’ s Asian Elephant Population and Distribution

In China, Asian elephants are distributed in southern Yunnan Province and the Tibet region [Figure 1: see original paper]. Under strong national protection, the population has continued to grow. The 2018 Yunnan wild Asian elephant survey recorded at least 293 individuals, nearly triple the 101 individuals documented in the first systematic survey in 1976 [1]. Recent monitoring shows no abnormal deaths and continuous births, with the current population estimated to exceed 300 individuals [2]. Population viability analyses of Yunnan’ s largest (189 individuals) and smallest (12 individuals) elephant populations indicate no immediate survival bottlenecks [3,4].

1.3 Major Protection Measures Implemented

China has established protected areas such as Xishuangbanna and Nangunhe National Nature Reserves specifically for Asian elephants, created the Xishuangbanna Asian Elephant Rescue and Breeding Center, constructed multiple feeding grounds and artificial salt licks, and built monitoring towers. During construction of highways and the China-Laos Railway, extensive use of viaducts and tunnels has avoided isolating elephant populations and habitats [5-7]. Additionally, on December 30, 2016, China issued the “Notice of the General Office of the State Council on Orderly Ceasing Commercial Processing and Sales of

Ivory and Ivory Products," requiring closure of ivory processing facilities and complete cessation of commercial ivory trade by December 31, 2017.

1.4 Human-Elephant Conflict from Population Growth

As Asian elephant populations increase, habitat changes in original ranges can no longer support the growing numbers, forcing elephants to disperse into human-dominated areas and creating spatiotemporal overlap between human and elephant activities [8]. The 2018 survey revealed that only 22.9% of elephants reside within protected areas, 14.7% live at the edges, while 62.4% are active outside protected areas, making human-elephant contact inevitable and increasingly frequent. Human-elephant conflict has become the greatest challenge in Asian elephant conservation and management in China. Between 2013-2017, elephants in Lancang-Menghai caused 31 human deaths, over 50 injuries, and nearly ¥20 million in economic losses [9]. In 2021, the northward-migrating elephant herd generated 1,501 compensation claims totaling ¥5.1252 million . After entering human production and living areas, elephants significantly altered their behavior, extensively raiding crops and entering villages for food and salt. Among local residents in elephant-active areas, 83% reported crop damage [10]. Frequent elephant activity near villages prevents timely tea picking and rubber harvesting, causing substantial indirect losses and psychological stress [10]. Despite this, no retaliatory killings of elephants have occurred in China. However, elephant incidents remain frequent, threatening local lives and property and hindering economic development.

1.5 Current Measures to Address Human-Elephant Conflict

Research suggests that incident frequency is central to human-elephant conflict consequences, so mitigation should focus on reducing incidents [10]. Current measures include monitoring via drones, infrared cameras, and early warning systems; protective measures like electric fences and elephant-proof trenches; compensation through public liability insurance; and conservation actions such as feeding ground construction and habitat restoration. However, except for monitoring systems, most measures suffer from limited coverage, high costs, poor effectiveness, and unsustainability. International studies show similar results: in Sri Lanka, problem elephants translocated to protected areas often return to original conflict sites [11]; in India, elephants have habituated to deterrents like bonfires and loud noises [12].

1.6 Necessity of Ecological Corridor Construction

Landscape connectivity is crucial for species conservation [13]. Economic development, large-scale plantations, linear transportation infrastructure, and reservoirs have destroyed natural vegetation, creating artificial barriers that fragment Asian elephant habitats into isolated "islands" and severely impede population exchange. For example, the Simao-Xiaomengyang Highway divides the Xishuangbanna-Pu' er population into eastern and western sections; the

Jinghong Hydropower Station on the Lancang River flooded migration routes, isolating the Lancang-Menghai population; and the Mengla-Shangyong population is restricted to border areas near Laos due to barriers from towns, reservoirs, and scenic areas [14]. Climate change, including rising temperatures and reduced precipitation, alters natural vegetation and land use, reducing food and water availability and affecting habitat suitability [23,24]. For species like Asian elephants living in human-dominated fragmented habitats, long-term survival depends on the ability to move freely across large landscapes [15]. Ecological corridors between habitat patches increase landscape connectivity, provide larger habitat ranges, improve habitat structure and function, effectively alleviate population isolation, and ensure population exchange [16], thereby reducing crop raiding and mitigating human-elephant conflict. Corridors also enhance species resilience to climate change by enabling movement to new climate refugia and increasing resource access [18]. Natural and artificial corridors can benefit other wildlife migration as well [19]. The 19th and 20th National Congress reports emphasized implementing major ecosystem protection and restoration projects, optimizing ecological security barriers, and constructing ecological corridors and biodiversity networks as key measures for building a Beautiful China.

2. Asian Elephant Ecological Corridor Construction Concept

2.1 Design Principles

Maintaining functional connectivity between patches is essential for species, habitat, and ecosystem conservation [20,21]. Ecological corridors aim to connect fragmented Asian elephant habitats, enhance landscape connectivity, help elephants adapt to climate change, and improve population viability [14,22]. During corridor design, it is necessary to identify elephant activity ranges and consider how long-distance movements for food and shelter are influenced by climate change, natural environment, and human activities [25-27]. The least-cost path (LCP) method based on minimum cumulative resistance models and connectivity models based on circuit theory (hereafter "circuit models") are the two most common approaches [28,29]. Minimum cumulative resistance models convert distance and landscape feature effects on species movement into spatial resistance to identify LCPs [5,6], while circuit models simulate species movement as electrical current flow across conductive surfaces to assess habitat connectivity [30,31]. Combining both methods provides complementary advantages for effectively identifying corridors and landscape elements affecting connectivity [28].

2.2 Corridor Design Scheme

Over the past two decades, scholars have proposed numerous corridor plans for Chinese Asian elephants [14,32-34], but some cover large areas with long distances, high modification difficulty, and high costs [Figure 2: see original paper].

As elephant ranges shift northward [31,33], some planned corridors have become either active elephant areas or unsuitable due to environmental changes. Therefore, urgent re-planning based on current elephant activity ranges is needed.

Addressing habitat degradation, population isolation, and frequent human-elephant conflict from climate change and land use change, this study builds on previous corridor planning [14,32-34] and integrates elephant population and habitat distribution, human activities, and land use status. The technical workflow is: (1) obtain species distribution; (2) identify source patches and resistance surfaces; (3) construct corridors via least-cost path modeling; (4) analyze corridor centrality, pinch points, and barriers through circuit models; (5) conduct field surveys; (6) adjust and optimize design; (7) recommend construction schemes; and (8) monitor wildlife corridor use long-term.

Using several active area patches of the Pu' er-Xishuangbanna elephant population during 2020–2022 as corridor endpoints, we used the difference between habitat suitability index and its theoretical maximum as movement cost to reflect realistic resistance. Integrating circuit theory identified eight major ecological corridors [Figure 3: see original paper]. Field surveys marked high-resistance features like settlements, roads, farmland, and fishponds, enabling model parameter adjustment and corridor optimization.

Optimized circuit model results show the Pu' er source patch serves as a landscape core and east-west connector with extremely high centrality, making it critical for overall landscape connectivity. Corridors eastward and westward from Pu' er to Dadugang, Mengwang, and Kangping are high-centrality corridors essential for landscape and habitat network integrity. The Mengwang-Jiangcheng (A) and Pu' er-Nanping (B) corridors have relatively high resistance values (37.71 and 26.64), making full passage difficult, but their per-unit-distance resistance is low, requiring only brief resting areas [28,34]. The Nanping-Liushun (C), Pu' er-Jingne (D), Pu' er-Banzhulin (E), and Pu' er-Mengwang (F) corridors have low resistance values (5.39–8.85), minimal passage obstacles, and are located in key connectivity areas (high current density zones) [Figure 4: see original paper], facilitating elephant movement [28,30,31].

This scheme' s technical workflow incorporates variables including natural and anthropogenic factors directly affecting elephants, plus climate-influenced land use, vegetation change, and water availability, providing comprehensive migration resistance assessment. Corridor optimization considered effectiveness, feasibility, and local impacts, adjusting designs through field surveys to avoid farmland, settlements, and roads while connecting isolated groups and mitigating human-elephant conflict. The empirical corridor planning approach will support Asian elephant national park construction.

3. Recommendations for Advancing Asian Elephant Conservation

The 17th Fifth Plenary Session of 2010 emphasized building a resource-saving and environmentally friendly society, improving ecological civilization, addressing climate change, developing circular economies, strengthening resource conservation, environmental protection, and ecological conservation systems. The Communist Party of China proposed ecological civilization construction, coordinating systematic management of mountains, rivers, forests, farmlands, lakes, grasslands, and deserts to maintain ecological balance and achieve green development. To better protect the "engineers" of forest ecosystems—Asian elephants—we propose four conservation measures:

(1) Establish a national park-based Asian elephant conservation engineering system. Guided by the "life community" concept, strengthen restoration of degraded ecosystems, advance regional biodiversity conservation in natural and artificial ecosystems, and maintain comprehensive ecological services. This system would achieve full coverage of Asian elephant conservation in China, enhance natural population and genetic exchange, promote population recovery, mitigate human-elephant conflict, and provide scientific support for national park planning and sustainable regional development.

(2) Build an Asian elephant ecological corridor network to connect isolated populations. Using national parks and protected areas as key nodes, scientifically construct a "habitat-corridor" network system. Optimize corridor spatial structure, improve environmental quality, and enhance landscape connectivity to link isolated populations. Corridor design must consider elephant dispersal capacity and habitat needs for food, water, and shelter, avoiding large farmlands, dense villages, and linear infrastructure. Implement holistic habitat planning with zoning management, continuously improving protection systems. Based on elephant dispersal trends, adjust planting structures in elephant ranges and supplement food resources and artificial salt licks in core activity areas, combined with fences and elephant-proof trenches, to guide elephants back to nature reserves and promote human-elephant coexistence.

(3) Create new models for broad social participation in Asian elephant conservation. Establish and improve long-term protection mechanisms led by government with multi-stakeholder participation, refine biodiversity and wildlife protection laws, and enhance supervision capacity of national parks and protected areas to promote harmony between humanity and nature. Governments and society should conduct education and outreach on Asian elephant and endangered species conservation through online platforms to raise public awareness. Leverage research institutions for technical support and talent development. As ecosystem and biodiversity protection is a global task requiring international cooperation, transboundary collaboration among Asian elephant range countries can facilitate technical exchange, joint strategy development, transnational corridor construction, and coordinated anti-poaching efforts.

(4) Strengthen basic research on Asian elephants to guide scientific conservation. Focus on scientific frontiers and key technical challenges in Asian elephant conservation, conducting in-depth research on behavior, ecology, physiology, habitat, population structure, and genetics to provide theoretical and technical support for effective management and scientific solutions to human-elephant conflict. Apply findings on elephant feeding habits and suitable habitat characteristics to habitat modification and feeding ground construction, enhancing native habitat attractiveness. Analyze elephant movement patterns and dispersal drivers between patches to guide population movements back to protected areas. Employ GPS collars, infrared camera arrays, drone patrols, and community-based monitoring, train monitoring personnel, improve monitoring efficiency, and issue timely warnings to ensure human and elephant safety and reduce conflict losses.

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Author Biographies

Li Xueyou is an Associate Professor at the Kunming Institute of Zoology, Chinese Academy of Sciences. His research focuses on biodiversity and conservation of flagship and endangered wildlife species. E-mail: lixueyou@mail.kiz.ac.cn

Jiang Xuelong is a Professor at the Kunming Institute of Zoology, Chinese Academy of Sciences. His research focuses on mammal taxonomy and systematics, and ecology and conservation of endangered animals. E-mail: jiangxl@mail.kiz.ac.cn

*Corresponding author

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