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# Urban green space network development for biodiversity conservation: Identification based on graph theory and gravity modeling

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ABSTRACT

Urban areas can contain rich flora that contribute significantly to biodiversity, but loss and isolation of habitats due to urban sprawl threaten biodiversity and warrant limits on development. The connectivity provided by urban green spaces offers habitats and corridors that help conserve biodiversity. Researchers and planners have begun using landscape ecology principles to develop green space networks and increase connectivity to preserve and restore biodiversity. In this paper, potential corridors were identified in Jinan City, China, using the least-cost path method, and green space networks were developed and improved based on graph theory and the gravity model. Spatial analysis revealed that the proposed plan decreased fragmentation and increased connectivity. Plaza and roadside green spaces were the main types of green space that increased, but they only weakly improved networks and biodiversity. Identifying potential corridors using least-cost path analysis made the results better approximate the real landscape by including impedance along links. The potential networks revealed problems in the current greening plan. The green space network developed based on graph theory and the gravity model simplified and systematized the complex landscape, helping to identify the significance of each green space and guiding urban planning for biodiversity conservation.



## 1. Introduction

Since the 1992 United Nations Convention on Biodiversity (UNCED, 1992), biodiversity has become a fundamental conservation value. Because urban areas may contain a rich flora that contributes significantly to biodiversity, urban biodiversity conservation should receive more attention (Miller, 1988; Duhme and Pauleit, 1998). Urban green spaces can be defined as outdoor places with significant amounts of vegetation, and exist mainly as semi-natural areas (Jim and Chen, 2003). Urban green spaces offer important harbors for remnant biodiversity. However rapid urbanization has eliminated ever more green space, particularly dispersal corridors (Harris and Scheck, 1991). The proportion of the world's population living in cities is expected to surpass 65% by 2025 (Schell and Ulijaszek, 1999), and dramatic population increases have been accompanied by intensified urban development. China's urban population in 2001 equaled 37.7% of the nation's total population; this proportion is projected to reach 75% by 2050 (Chinese Mayor's Association, 2002). As a result, the remaining urban green space is increasingly encroached upon and fragmented as cities become denser to accommodate population growth (Jongman, 2008a). Habitat fragmentation, loss, and isolation seriously threaten biodiversity and are a primary cause of the present extinction crisis (Collinge, 1996; Adriaensen et al., 2003). For example, more than 180 plant species became locally extinct in the past 100 years in Munich, Germany, alone (Duhme and Pauleit, 1998). This specially made nature conservation change from site protection towards conservation of green space networks including the wider landscape (Opdam, 1991). Green space networks can provide a solution to the problems of intensified land use and fragmentation, enabling natural populations of species and threatened habitats to survive (Jongman, 2008a).

Connectivity is the opposite of fragmentation. To reduce the isolation of habitat fragments, ecologists and conservation biologists recommend maintaining habitat connectivity by preserving corridors that permit movement of species between remaining habitats and by developing urban green space networks (e.g., Jordán et al., 2003; Parker et al., 2008; Esbah et al., 2009). Development of these networks is increasingly considered a suitable approach to improve the ecological value of urban green space (Cook and van Lier, 1994; Hepcan et al., 2009). Landscape-level habitat connectivity plays an important role in population viability by maintaining gene flow and facilitating migration, dispersal, and recolonization (Hargrove et al., 2004; Saura and Pascual-Hortal, 2007). Thus, establishing or

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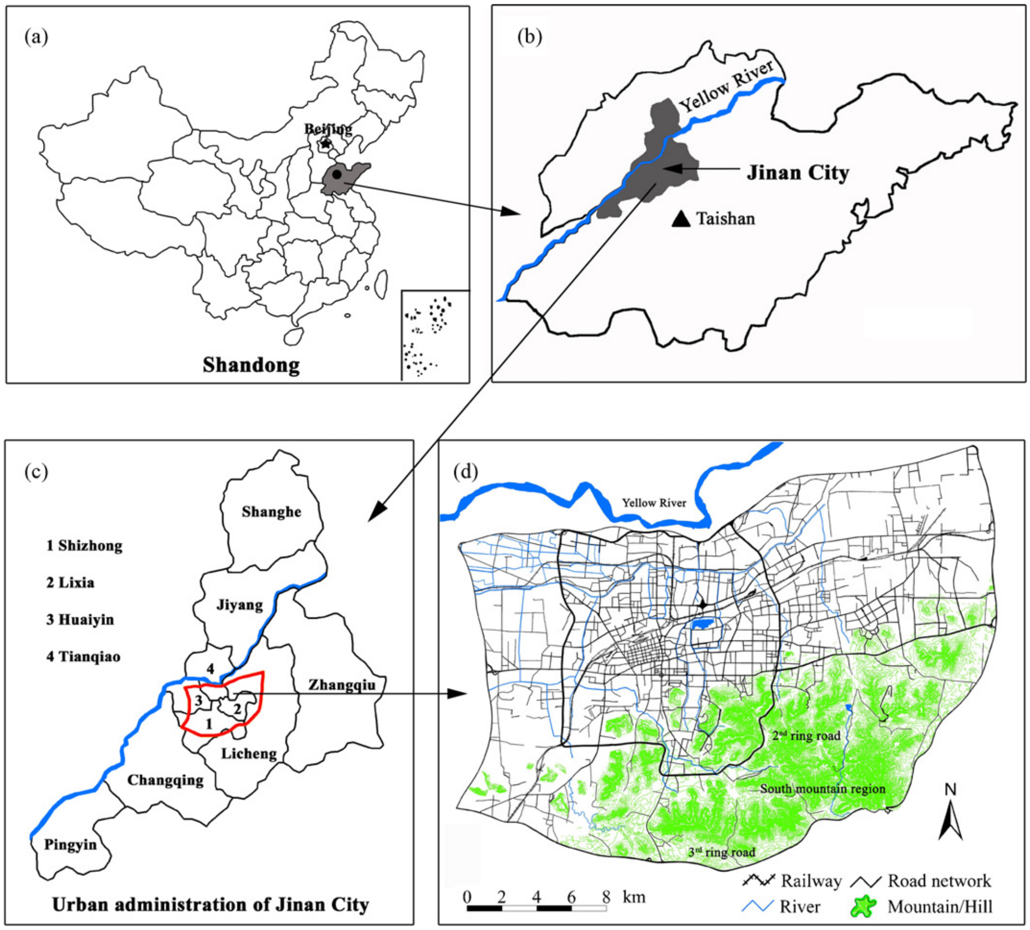


**Fig. 1.** Location of the study area.

maintaining connectivity among patches is essential to facilitate biodiversity conservation.

The landscape-scale spatial configuration and distribution of habitats determine species distribution and migration (Swingland and Greenwood, 1983; Debinski et al., 2001). The spatial pattern and functional analysis of the "patch–corridor–matrix" are basic components of landscape ecology. Landscape ecologists use connectivity (corridors) to describe a landscape's structural and functional continuity in space and time (e.g., Forman and Godron, 1986). In sustainable urban development, urban greening is a key element, but biodiversity must be an integral component of this greening. Consequently, preserving habitat and dispersal routes and developing a comprehensive green space network that can maintain landscape-scale connectivity have become crucial factors in urban biodiversity conservation (Bennett, 2003; Parker et al., 2008).

The development of urban green space networks includes protection of existing green spaces, creation of new spatial forms, and restoration and maintenance of connectivity among diverse green spaces. To maintain or restore connectivity, planners must identify the best habitat and potential corridors by considering distances and the barriers between habitats (impedance) posed by the landscape and land use (Opdam, 1991). However, no current analytical tools comprehensively identify potential dispersal corridors in real-world landscapes while considering impedance to movement along corridors in terms of island biogeography theory (Noss, 1987; Hargrove et al., 2004). Planners generally consider only distances between habitat patches, not the spatially heterogeneous impedance of the landscape matrix (Hargrove et al., 2004). In the present paper, we propose the identification of potential corridors using least-cost path tools provided by geographical information systems software. We also used the gravity model and graph theory to develop green space networks from potential corridors so planners can identify the relative high-quality habitats and choose the best opportunities to maintain and restore connectivity.

The goals of our study were: (a) to conserve critical urban green space; (2) to model potential corridors and develop green space network based on the least-cost path method; (3) to develop planning scenarios for green space networks and accordingly identify the relative significance of each habitat or corridor based on the gravity model and graph theory; (4) to assess whether or not planned green spaces would improve the green space network, and subsequently identify opportunities for allocation and planning of new green space to optimize the network.

## 2. Study area

Jinan City (36°42′N, 117°02′E) lies in the middle of Shandong Province of China (Fig. 1a), in the eastern coastal region, north of Taishan and straddling the Yellow River (Fig. 1b). Jinan City is the capital of Shandong Province, and has existed for more than 2600 years. It has experienced dramatic population and spatial growth in the last 50 years: the population increased from 3.19 million in 1952 to 5.90 million in 2005 (Jinan Statistics Bureau, 2005) and the built-up area increased from 24.6 km$^2$ in 1949 to more than 190 km$^2$ in 2003 (Jinan Statistics Bureau, 2003). Jinan consists of six districts, three counties, and one county-level city (Fig. 1c). The Jinan Planning Bureau's 2004–2020 Master Plan proposed to expand the city eastward, with the urban area expanding to the third ring road (Fig. 1d). The area examined in this study includes