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Sensitivity evaluation and land-use control of urban ecological corridors: A case study of Shenzhen, China

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ABSTRACT

Constructing an urban ecological corridor system is a major component and critical factor of forming an effective network within an urban ecosystem. Shenzhen, as a highly urbanized area in China, is facing the dual pressures of urban development and ecological conservation. The ecological corridors in Shenzhen are being constantly eroded by urban expansion, resulting in an urgent need to carry out sensitivity evaluations and ecological land management studies. By identifying the spatial range of planned ecological corridors in Shenzhen, we develop a GIS-based ecological sensitivity evaluation model from the perspectives of soil environment, habitat conditions, geological hazards, and human disturbance. Management strategies are proposed with regard to macroscopic protection guidance and microscopic land-use control. The results show that there is little difference in the sensitivity grade of ecological corridors in Shenzhen. With regard to spatial distribution, the sensitivity level is high in the north and low in the south, with moderately sensitive corridors being the dominant type. Meanwhile, we design the land-use control program by taking into account the present management and new land demand and provide the path for implementing the withdrawal, reservation, occupation, and avoidance polices. The results of the sensitivity evaluation objectively reflect the eco-environmental condition of ecological corridors in Shenzhen. The classified and graded protection guidance and space regulatory framework proposed in this study are of significance for guiding the ecological conservation, land use, and sustainable development in urban contexts with similar issues.

1. Introduction

Ecological sensitivity caused by human activities has become a root cause of many environmental problems. Ecologically sensitive areas generally refer to the ecological factors and entities that play a decisive role in the overall eco-environment of a region (Lu et al., 2013; Jennings and Reganold, 1991). These entities and elements have poor capabilities for internal or external interference and self-recovery (Yan et al., 2009). Ecologically sensitive areas are associated with the most intense eco-environmental changes and are most prone to ecological problems. Ecological corridors, as critical areas in the urban ecosystem (Forman, 1995), mainly comprise vegetation, water, and other elements, with a spatial distribution in a line or strip pattern. Ecological corridors provide a passage for biological dispersal and migration and a buffer zone between city groups and possess the dual attributes of nature and society with a high degree of sensitivity. Therefore, ecological corridors should be classified as the priority of eco-environmental protection and construction.

From a functional point of view, the core of ecological corridors includes the connection of organisms with landscape and the isolation of city groups (Bennett, 1999; Ramiadantsoa et al., 2015; Ottomano Palmisano et al., 2016). Additionally, ecological corridors provide ecological services such as water conservation, contaminant purification, and reduction of the heat island effect (Bryant, 2006; Haaren and Reich, 2006). Ecological corridors are beneficial for animals and plants, allowing them to migrate between the habitat patches and thus enhance the connectivity of isolated populations (Hilty et al., 2012). Wilson and Willis (1975) proposed linking isolated habitat patches using corridors to mitigate the negative impact of habitat fragmentation. From a conceptual point of view, the Conservation Management Institute (USA) started from the perspective of biological conservation and defined ecological corridors as "narrow strip-like vegetation for wildlife, which usu-

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ally can promote the movement of biological factors between two places." The concept of linking natural reserves (or protected areas) to reduce regional fragmentation is normally accepted (Hansen and Defries, 2007; Hoctor et al., 2000). Therefore, nearly 30 synonyms have been used to describe ecological corridors (Hellmund and Smith, 2013; Hess and Fischer, 2001). In addition to the common term ecological corridors (or eco-corridors), which is used preferentially in South America, conservation corridor is more frequently used by researchers in North America. With regard to construction management, ecological corridors are divided into planned and non-planned corridors. The planned corridor is a biological conservation corridor constructed artificially and subjectively to strengthen habitat connectivity (Whitelaw and Eagles, 2007), and it aims to achieve the conservation, maintenance, and restoration of single species, species combinations, or the entire biological community. Studies and investigations have focused on ecological corridors that occur naturally and benefit biological conservation (Evans, 2007; Naiman et al., 1993; Newmark, 1993), while few researches are available on ecological corridors formed by artificial planning and construction. For instance, Wu et al. (2013) has used RS, GIS and landscape indicator analysis methods to identify the important strategic points for ecological corridor planning in the proposed low-carbon city in Shenzhen, which could provide references in terms of goals and methodology.

Since the 1960s, ecological sensitivity has been extensively studied, especially in the United Kingdom, the USA, and other countries experiencing rapid urbanization at that time. Studies were mainly conducted in edge zones and environmentally sensitive areas (Jennings and Reganold, 1989; Turner and Brooke, 1988; Gühnemann et al., 2014; Steiner et al., 2000; Potter, 1988). The studies on urban sensitive areas in China can be summarized in eight aspects: ecological evaluation, ecological zoning, system theory, indicator system, land use, ecological security, ecological industry, and ecological landscape (Lu et al., 2014). The first two are hot issues, accounting for more than 50% of relevant studies. Compared with ordinary ecologically sensitive areas, urban ecological corridors show peculiarities: one is the relatively small spatial scale of the study area, and the other is more significant disturbance by human activities in this area. Studies that integrate natural and human factors to investigate the sensitivity of ecological corridors are still unsystematic (Da et al., 2004; Yang et al., 2002). Meanwhile, systematic studies on the sensitivity of ecological corridors are rarely carried out. Researchers have more frequently investigated suitable width, fragmentation, and biological species, among various structural characteristics of corridors (Bryant, 2006; Bueno et al., 1995; Lees and Peres, 2008; Newmark, 1993). Currently, there is little research on the construction and management of biological conservation corridors. The studies involved are mainly focused on the legal management and development policy of corridors by the government (Evans, 2007; Jongman and Kamphorst, 2002; Priemus and Zonneveld, 2003). In a number of respects, the evaluation assumes that the policy will be successful prior to the analysis (Hodge and McNally, 1998). The study of ecological control has not received sufficient attention, making it difficult to support effective management of ecological corridors.

Management of land-use policies which balance economic development with environmental protection has become an increasingly important issue (Ndubisi et al., 1995). Since it was listed as China's first special economic zone in 1979, Shenzhen has undergone rapid social and economic development, accompanied by the continuous rapid expansion of urban construction land and constant decreases in the total urban natural ecological space year by year. In 1996, the first edition of the Urban Master Plan of Shenzhen began to lay out ecological corridors and establish group isolation corridors to prevent the disorderly expansion of construction land. In 2005, most of the corridors were included in the basic ecological control line for steel-wire management. In recent years, however, ecological corridors have gradually become sites that are seriously threatened by development and construction or actually broken apart. The eco-environment is deteriorated in ecological corridors, making it difficult to ensure effective connections between green spaces in various regions. Therefore, there is an urgent need to investigate the sensitivity of ecological corridors, clarify the content of protection, and control land use changing for construction purposes, to ultimately guarantee the ecological services and bearing functions of ecological corridors.

2. Study area

Shenzhen is located in the southern part of Guangdong Province, China. It is on the east coast of the Pearl River Delta adjacent to Hong Kong (Fig. 1). Under the jurisdiction of Shenzhen, there are six administrative regions- Futian, Luohu, Nanshan, Yantian, Bao'an, and Longgang- and four new districts- Guangming, Longhua, Pingshan, and Dapeng. Shenzhen is the first Special Economic Zone established since China's reform and opening up, and has created a remarkable "Shenzhen speed". The total land area of Shenzhen is 1996 km^2. The status quo of land use is mainly ecological land including farmlands, park lands, woodlands, grasslands, park green lands, and water areas. By the means of unified collection within the zone in 1992 and land conversion by urbanization out of the zone in 2004, Shenzhen became the first city without rural institution in China and achieved an urbanization rate of up to 100%. In 2014, the annual gross production reached 1.6 trillion Yuan, and the per capita GDP exceeded $20,000 in Shenzhen, which has long ranked first among China's major cities.

With the increasingly prominent contradiction between urban construction and ecological land, Shenzhen classified half of the city's land as part of the ecological control line in 2005. The aim was to prevent the disorderly expansion of urban construction that endangers the security of urban ecosystem and promote the sustainable development of urban construction in Shenzhen (Fig. 1). In November of the same year, the Regulations of the Basic Ecological Control Line in Shenzhen were implemented and became an important starting point for strengthening eco-environmental protection in this city.

3. Data and methods

3.1. Data sources and processing

The data used in the study are presented as follows: soil, population, and pollution data were derived from the second soil survey of China (1986), the sixth population census of China (2010), and the soil pollution survey of Shenzhen (2014), respectively; the habitat condition was extracted from the ecological resources and afforestation resources survey of Shenzhen (2014); geologically disaster data on susceptibility and protection level were extracted from the Geological Disaster Prevention and Control Planning of Shenzhen (2007–2015); rainfall and evaporation data were obtained from 25 meteorological monitoring data collection sites in Shenzhen over the past four years; the vegetation cover index (Crippen, 1990) was calculated using the 2014 Landsat 8 image (LC81210442014249BJC00/LC81220442014288BJC00).

Data above were converted into grid format with a spatial resolution of 10 m using the ArcGIS 10.2 platform. For discrete point data of soil contamination and rainfall, continuous data of the entire city were obtained using spatial interpolation.