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Research Paper

Prioritizing habitat conservation outside protected areas in rapidly urbanizing landscapes: A patch network approach

Bin Xun[a,b], Deyong Yu[b,*], Xue Wang[b]

[a] Department of Environmental Science, College of Urban and Environmental Sciences, Northwest University, Xi'an 710127, China
[b] Human-Environment System Sustainability (CHESS), State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing 100875, China

HIGHLIGHTS

- Habitats around protected areas should be given special care in terms of improving landscape connectivity.
- A spatially explicit representation of habitat mosaics makes conservation planning intuitive and accessible.
- Scenario analysis is important for determining future urban conservation strategies.
- Habitat networks should be species specific and dynamically consummated during the urbanization process.

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ABSTRACT

Biodiversity conservation is challenging in urbanizing landscapes where recurring habitat degradation occurs and space is limited for subsequent restoration. Conservation efforts based on natural reserves may not be able to maintain certain ecological processes that extend beyond the reserves. There is an urgent need to conserve or restore critical habitats outside of protected areas to maintain the functional connectivity of habitat networks. In this study, we developed a connectivity modelling approach associated with varying conservation scenarios to establish habitat conservation priorities in a rapidly urbanizing area of Shenzhen, China. We incorporated unprotected habitat patches into the reserve network via four scenarios and prioritized the contributions of these patches to habitat connectivity. We also investigated the responses of species with different dispersal abilities to habitat changes under each conservation scenario. The results showed that the spatial pattern of unprotected habitats played an important role in enhancing the connectivity of the entire network within the study area. The habitat patches around protected areas could create greater connectivity gains and should be prioritized for conservation. The key patches that substantially enhance connectivity were identified as special conservation concerns. The connectivity benefits from different scenarios were closely linked with species dispersal abilities. This study promotes the understanding of the importance of habitats outside of protected areas in urbanizing landscapes and provides the species-specific and spatially explicit conservation schemes for making informed decisions in urban planning and management.

1. Introduction

Land use/cover change accompanying urbanization is an important driver of multi-scale environmental issues (Grimm et al., 2008). Habitat loss, fragmentation and isolation, as consequences of urban growth, have not only led to native species extinction and biodiversity declines (Hansen et al., 2005; Kowarik, 2011; McKinney, 2002, 2008) but also altered the processes and functions of ecosystems (Alberti, 2005; Grimm et al., 2008; Groffman et al., 2014) and ultimately affected ecosystem services (Eigenbrod et al., 2011; Pataki et al., 2011; Tratalos, Fuller, Warren, Davies, & Gaston, 2007) and human wellbeing (Kuo & Sullivan, 2001; Shanahan, Fuller, Bush, Lin, & Gaston, 2015; Turner, Nakamura, & Dinetti, 2004). There is a consensus that the impacts of urbanization have extended beyond city limits to regional or global scales, although urban expansion occurs locally (Lambin et al., 2001). Urbanization is irreversible across the world (UN, 2015), and its ecological consequences are expected to continue in the coming decades (Güneralp & Seto, 2013; Güneralp

* Corresponding author.
E-mail addresses: xunbin@nwu.edu.cn (B. Xun), dyyucas@163.com (D. Yu), 201521480018@mail.bnu.edu.cn (X. Wang).

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et al., 2013). Therefore, there is an urgent need for sustainable strategies that involve biodiversity and environmental protection in urban areas and those that are under threat of urbanization (Niemelä, 1999). Often, urban management and planning face a dilemma regarding whether limited land resources in cities should serve as areas of urban exploitation versus ecological conservation. An acceptable solution to this issue may be achieved by identifying conservation opportunities that maintain critical ecological functions while minimizing constraints on land development (DeFries, Hansen, Turner, Reid, & Liu, 2007). Determining these “strategic areas” requires quantitative knowledge that integrates ecological theories with urban planning.

Worldwide, protected areas are considered a cornerstone of ecological conservation for safeguarding against habitat degradation and biodiversity declines (Gaston, Jackson, Cantú-Salazar, & Cruz-Piñón, 2008; Joppa, Loarie, & Pimm, 2008; Margules & Pressey, 2000). Over the past several decades, national and regional conservation efforts have mainly focused on biodiversity hotspots where rare, threatened or endangered species have survived (Brooks et al., 2006; Myers, Mittermeier, Mittermeier, da Fonseca, & Kent, 2000). However, conservation strategies based on protected areas may not exert a sufficient effect on the surroundings of protected areas. Recent studies have suggested that natural habitats in the vicinity of protected areas are likely to play vital roles in maintaining species persistence and critical biophysical processes across the entire landscape and providing external “ecological memory” (i.e., population source areas) for habitat recolonization (Bengtsson et al., 2003; Hansen & DeFries, 2007). Hence, protected areas themselves are likely to experience population extinction and functional isolation when the surrounding unprotected habitats are affected by anthropogenic disturbances or are converted to human-modified landscapes (e.g., Laurance et al., 2012; Newmark, 2008; Woodroffe & Ginsberg, 1998). To resist or mitigate the risk of habitat isolation, conservation efforts have highlighted a holistic strategy for ecological integrity (Grumbine, 1994). The increasing consensus is that functionally connected networks should be maintained or restored based on a landscape connectivity perspective (Beger et al., 2010; Opdam, Steingröver, & van Rooij, 2006; Santini, Saura, & Rondinini, 2016).

Landscape connectivity has been defined as the degree to which the landscape facilitates or impedes the movement of organisms among resource patches (Taylor, Fahrig, Henein, & Merriam, 1993), and it relies on landscape patterns and the ability of species to cross landscape mosaics. Highly connected networks can ensure species movements related to predation, seasonal migration, home range shifts and gene exchange and allow habitat recolonization after the local extinction of a metapopulation (Hanski, 1991). Thus, network connectivity and associated population dynamics should be taken into account by landscape ecologists, planners and designers for successful conservation (Bengtsson et al., 2003; Fajardo, Lessmann, Bonaccorso, Devenish, & Muñoz, 2014; Van Teeffelen, Vos, & Opdam, 2012). Within the problem domain of planning, one of the operable approaches is to quantitatively identify critical network components that have significant impacts on species dispersal processes.

Network modelling has gained increasing attention in the fields of landscape ecology and conservation biology. Graph theory is considered a promising approach and has been successfully applied in several real-world planning cases (e.g., Bergsten, Bodin, & Ecke, 2013; Loro, Ortega, Arce, & Geneletti, 2015; Rudnick et al., 2012; Yu, Xun, Shi, Shao, & Liu, 2012; Zetterberg, Mörtberg, & Balfors, 2010). Graph-based models provide a spatially conceptualized representation by characterizing habitat patches as nodes and possibilities of species dispersal between patches as links between nodes (Urban & Keitt, 2001; Urban, Minor, Treml, & Schick, 2009). Multiple graph-based indices have been developed to evaluate the degree

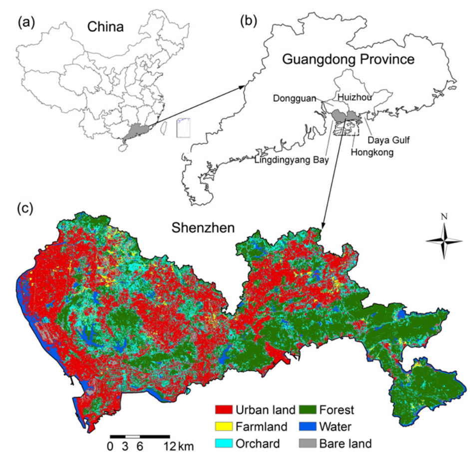

Fig. 1. Location (a–b) and land use map (c) of the study area.

of connectivity of habitat networks via well-developed algorithms (Kindlmann & Burel, 2008; Rayfield, Fortin, & Fall, 2011). Recent studies have suggested that graph-based methods have the ability to assess the importance of habitat patches by removing an individual patch and ranking the resulting effect on network connectivity (e.g., Bodin & Saura, 2010; Saura & Pascual-Hortal, 2007; Urban & Keitt, 2001). However, the removal of a single patch may play a limited role in identifying risks in the remaining landscape since the vulnerability of the landscape to further patch removals cannot be predicted (Bodin & Saura, 2010; Rubio, Bodin, Brotons, & Saura, 2015). Hence, integrating the graph-based model with predetermined patch removal (or additional) sequences may be a useful approach to determine which critical patches should be preserved to avoid large connectivity losses.

In this study, we evaluated the impacts of varying conservation scenarios (which are formulated based on different patch additional sequences, see Section 2.5) on habitat connectivity and the associated responses of species with different dispersal abilities and then identified key patches that significantly increase habitat connectivity to establish conservation priorities. Our purpose was to quantitatively answer three questions: (1) which conservation scenarios produce the optimal connectivity benefits in the habitat network; (2) which habitat patches are responsible for disproportionate increases in habitat connectivity; and (3) what are the responses of species with different dispersal abilities to the conservation scenarios?

2. Materials and methods

2.1. Study area

Our study focused on a rapidly urbanizing area of Shenzhen City in the southern Chinese province of Guangdong (Fig. 1a and b). Shenzhen has an area of approximately 2020 km^2 and lies between 22°26′N and 22°51′N latitude and 113°45′E and 114°37′E longitude. It has a subtropical marine climate with a mean annual temperature of 22.4 °C and mean annual precipitation of 1933.3 mm. Overall, 85% of the precipitation is concentrated during the rainy season from April to September.

Shenzhen exhibits a high diversity of plants and animals. The main vegetation types are tropical monsoon forest and subtropical monsoon evergreen broad-leaved forest, which are dominated by families such as *Lauraceae*, *Theaceae*, *Euphorbiaceae*, *Papilionaceae*, *Fagaceae*, *Moraceae*, *Rubiaceae* and *Asteraceae*. Approximately 20 nationally rare and endangered plants in these forests are listed on the China Species Red List (e.g., *Alsophila spinulosa*, *Cycas fairylakea*, *Camellia granthamiana*, *Archiboehmeria atrata* and *Nauclea*