Impacts of urbanization and landscape patterns on the earthworm communities in residential areas in Beijing

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HIGHLIGHTS
• Both the abundance and biomass of earthworms in residential areas in the metropolitan area were relatively low.
• Soil moisture and pH could be considered as the most important edaphic variables that affected earthworm abundance.
• The construction age of residential areas significantly influenced the earthworm communities.
• The earthworm community assemblage was significantly affected by urban landscape patterns at different scales.

ABSTRACT
Earthworms play an important role in soil processes and functions. However, few studies have focused on their community patterns in perturbed systems, especially in an urban environment with a high turnover rate of land cover. In this study, we collected and identified the earthworms in the residential areas in metropolitan Beijing. We further investigated the effects of urban soil properties, urbanization and landscape patterns on the earthworm communities. The results showed that both the abundance and biomass of earthworms in residential areas in metropolitan was relatively low. The abundance of earthworms was negatively correlated with soil organic carbon (SOC) in this study. Soil moisture and pH could be considered as the most important edaphic variables that affected earthworm communities. The construction age of residential areas significantly influenced the earthworm abundance. Moreover, the earthworm community composition responded differently to urban landscape features at different scales. The percentage of impervious and green space surface, the amount of landscape cover types, patch density and landscape fragment significantly affected the earthworm assemblages. Our result discovered that the edaphic properties, urbanization as well as landscape patterns might be the potential factors that influenced the earthworm community patterns.

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1. Introduction
Serving as one of the most important components in soil, soil fauna communities play a significant role in indicating the variation of condition and function of soil (Edwards and Bohlen, 1996; Jones et al., 1994; Paoletti, 1999). Earthworms, the dominant communities in soil fauna, are especially functionally important in most terrestrial soil systems and thus considered as “soil engineers” (Bartlett et al., 2010; Fründ et al., 2010). Their bioturbation performance within soil environment have crucial impacts on physical, chemical and biological state of soil, as well as the activities of other organisms dwelling within soil
environment (Bartlett et al., 2010). Furthermore, earthworms can have important impacts on nutrient cycling, soil structure and carbon turn- over in terrestrial ecosystem (Lee, 1986; Romanes, 2009), thus they are considered as effective bioindicators of soil health (Valchovski, 2010).

The urbanization process worldwide brings about a succession of problems and challenges. For instance, the urban development dynam- ics has significantly changed the original appearance of the land. (Kostof and Tobias, 1991; Soni and Salokhe, 2017). The worldwide urban population is expected to grow to five billion by 2030, while the expanding urban areas will increase to twice the size of the urban land cover in 2010 (Elmqvist et al., 2013; Nations, 2014). The ever-sprawling urban area and the ever-changing landscapes have dramatically altered the species assemblages and influenced the species habitats in urban area, hence the influence of urbanization on ecological communities has be- come one of the most hot topics in ecological studies (Pickett et al., 2008).

The ecological communities dwelling in the urban area have been suffering certain chronic environmental stress through multi-scales. The loss and fragmentation of habitat may result in the endangerment to urban biotic communities which arise from anthropogenic environ- mental stress and the urban planning rather than soil abiotic conditions (Cilliers, 2010; Liu et al., 2016). Due to the restrictions of geographical and taxonomical approaches, urban areas were usually taken as a ho- mogeneous patch for granted in previous research (Brodie et al., 2012; Ellis and Ramankutty, 2008; Ramalho and Hobbs, 2012). Such measures usually are reasonable and effective especially for larger mobile species. Nevertheless for minor organisms, their distribution and habitats are not continuous but discrete. The inconsistency between the distribution of urban species and conventional homogeneous habitat patch may conceal the potential factors influencing urban species habitat vulnera- bility (Cilliers, 2010; Savage et al., 2015). Therefore, it would be more appropriate that the dispersive living habitats in cities are considered as mosaics with various land cover types under different levels of envi- ronmental stresses.

Previous work has documented on the survival characteristics of bi- otic species under a sequence of urban settings. Different species even human beings in urbanized areas were found to significantly respond to different levels of the environmental stress (Teets and Denlinger, 2014). For instance, landscapes transformation could influence both plant species heterogeneity and activities of insectivorous bat species through multiple spatiotemporal scales (Dixon, 2012; Lindborg and Eriksson, 2004). Also, Savage et al. (2015) reported that both the ant composition and richness tended to be significantly different under differ- ent levels of urban environmental stress in Manhattan's urban habi- tat. Yet, theory and empirical investigations on relative hypothesis for urban soil invertebrates, especially for the well-known species like earthworms, are still scarce. In cities, habitat fragmentation could be as- cribed to the anthropogenic alteration to the matrix of built environ- ment (Templeton et al., 2011). Especially for less mobile ground-dwelling annelids, such as earthworms, which are poorly dispersing among isolated patches, their local populations are vulnerable to extinc- tion, but also have a probability of recolonization (Driscoll, 2007; Gilbert, 1989). Thus, metapopulation dynamics approach provides a promising framework for examining ecological patterns and processes in the urban “archipelagoes” (Niemelä, 1999). However, such theory has not been examined within urbanizing landscapes yet (Padilla and Rodewald, 2015). Therefore, it is indispensable to deliberate how earth- worm community patterns respond to the impact of anthropogenic ac- tivities across finer scale in urban mosaics and the fragile landscape patches within cities. Additionally, it’s meaningful to test whether long-term persistence of earthworms in fragmented urbanizing land- scape is facilitated by metapopulation dynamics.

The aim of this paper is to understand how earthworm community patterns are influenced by the environment and landscape stresses through urban habitat mosaics. We are interested in (1) describing the current status of earthworm community in urban environment; (2) examining how soil properties may influence the existence of earth- worm communities in urban areas; (3) investigating how urbanization process as well as landscape patterns may have impacts on the status of earthworms at different scales.

2. Materials and methods

2.1. Study area

The study sites were located in Beijing, the largest metropolis in northern China. As the oldest, population-densest and most urbanized region in Beijing, the urban built-up areas taken the Forbidden City as the city center, are enclosed by five concentric ring roads. This region has a history of over 10 centuries. The local land cover has different types of uses which are distributed dispersely. According to the official government statistics up till 2014, the population of Beijing has grown to 21.5 million and the total residential land cover area takes 2848 km² accounting to 17.7% area of Beijing.

Based on the development characteristics of the built-up areas in Beijing, the study area was divided into different sections by major ring roads. According to the construction age, the geological location and the access of the residential areas, 0–2 residential areas were se- lected from each section. Finally, 39 residential areas were distributed in the built up area of Beijing in Fig. 1.

2.2. Earthworm sampling

Earthworm sampling was carried out in the study area in the late July/early August 2016. All the residential sampling sites selected were free of any application of pesticides to make sure the accuracy of the sampling result. At each site, earthworms were extracted from 6 to 12 pits (each 25 cm × 25 cm with a depth of 20 cm) by the hand sorting method (Callaham and Hendrix, 1997; Satchell and Phillipson, 1971). The blocks of soil were excavated in the same square volume when sampling to avoid overlooking individuals stuck in the soil or roots. The extraction method performed allowed us to figure the density and the assemblages of earthworms more accurately. The numbers of ex- tracted earthworms and excavated holes in each sampling site were carefully recorded. The worms from each site were then stored sepa- rately in centrifuge tubes in portable ice box before being transported to laboratory for further analysis. The identification of live specimens was accomplished according to the morphological characteristics (Chen, 1959; Xu, 2011). Juveniles were separated apart from the adults according to their development of clitellum. In order to ensure the pre- cision of the counting process, only the earthworm with head part was counted and the worms with incomplete morphological features would be tagged as unidentified and excluded from further analysis.

2.3. Soil sampling and chemical analysis

Five surface soil cores of 0–20 cm depth that are adjacent to the soil pits sorted for earthworms at each site were collected. Soil cores were thoroughly mixed to the composite soil sample per sampling site. Surface soil of 0–10 cm for bulk density determination was collected using stainless cutting rings with a volume of 100 cm³. Bulk density and soil moisture content were calculated gravimetrically by oven- drying the soil in the cutting rings and 20 g fresh soil samples respec- tively at 105 °C for 24 h. For the rest of the chemical analyses, fresh soil samples were air-dried and crushed to ground through sieves of 2 mm and 0.149 mm openings. Soil pH was measured in distilled water on a 1:2.5 (soil: water) ratio. SOC were determined using HCl treated method (Rawlins et al., 2008). Total carbon, nitrogen and SOC contents were determined by elemental analyzer (Elementar Vario III, Germany). Microbial biomass carbon (MBC) was estimated by the fumigation- extraction method (Vance et al., 1987).
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