Science of the Total Environment 650 (2019) 335–342

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Impervious surface area is a key predictor for urban plant diversity in a city undergone rapid urbanization

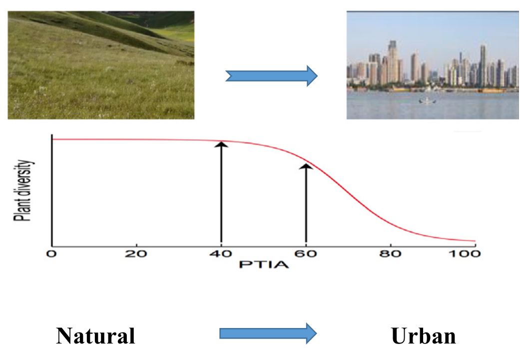
Zhaogui Yan, Mingjun Teng, Wei He, Anqian Liu, Yiran Li, Pengcheng Wang *

College of Horticulture and Forestry Sciences/Hubei Engineering Technology Research Center for Forestry Information, Huazhong Agricultural University, Wuhan 430070, China

HIGHLIGHTS

- Urban plant diversity decreased as the percentage of total impervious surface areas (PTIA) increased.
- High PTIA was associated with reduced endemic species and increased proportion of exotic species.
- When PTIA reached 40% and above, plant diversity decreased sharply.
- PTIA can be used as a key criterion for urban planning to ameliorate urban plant diversity.
- Our findings extend current understanding of urban plant diversity for cities in developing countries.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 2 August 2018
Received in revised form 2 September 2018
Accepted 3 September 2018
Available online 05 September 2018

Editor: Jay Gan

Keywords:
Endemic species
Exotic species
Impervious surface area
Plant diversity
Urbanization

ABSTRACT

Urban biodiversity has increasingly been recognized by the scientific community and environmental policymakers as a part of conservation efforts worldwide. However, most studies on urban biodiversity focus on cities in developed countries. An information gap exists for urban biodiversity of cities in developing countries. Here we focused on variability in plant diversity, a major component of biodiversity, in a Chinese city that has undergone rapid urbanization in recent time. The influence of urbanization was determined by comparing plant diversity and proportion of exotic/endemic plant species with the intensity of urbanization across the study area. We used percentage of total impervious surface area (PTIA) as an indicator of urbanization intensity, ranging from 5% to 95% across the study area. In the study area, a total of 321 plant species was recorded, totaling 83 trees, 113 shrubs and 125 herbs. Plant diversity, measured by number of plant taxa and other indices, was driven by PTIA; an increase in PTIA reduced plant diversity. In addition, the ratio of exotic to endemic plant species increased as PTIA increased. Among the exotic species, most of the tree and shrub species were purposely introduced. Above 40% PTIA, plant diversity decreased sharply and the proportion of exotic species rose. As a valuable predictor of urban biodiversity, PTIA can thus be used as a key criterion for urban planning to ameliorate urban biodiversity. Further, our findings extend current understanding of urban biodiversity for cities in developing countries.

1. Introduction

The gradient paradigm approach has been used to study species diversity in natural and urban ecosystems (Whittaker, 1967; Stevens, 1989; Lomolino, 2001; Dobbs et al., 2017; Ossola and Hopton, 2018).

* Corresponding author.
E-mail addresses: gyan@mail.hzau.edu.cn (Z. Yan), weihe@mail.hzau.edu.cn (W. He), liyiran@webmail.hzau.edu.cn (Y. Li), wangpc@mail.hzau.edu.cn (P. Wang).

https://doi.org/10.1016/j.scitotenv.2018.09.025
0048-9697/© 2018 Published by Elsevier B.V.

McDonnell and Pickett (1990) argue this approach assumes that "environmental variation is ordered in space, and that spatial environmental patterns govern the corresponding structure and function of ecological systems, be they populations, communities or ecosystems. The degree of the environmental change in space determines, in part, the steepness of the gradient in system structure and function." Urbanization has brought fundamental changes to natural ecosystems; natural or rural areas are converted for urban usage, coupled with the corresponding human population shift. It has resulted in landscapes created entirely by humans. These ecosystems differ from natural ecosystems in that resource spatial variability – the driving force for plant spatial patterns in natural ecosystems – is largely homogenized. In these ecosystems, as reticulation and fertilization are commonly used, grounds are leveled, soils are removed or replaced, the effects of many of the factors contributing to resource spatial variability are nullified. In addition, species (both plants and animals) have been intentionally (planned) or unintentionally introduced to urban areas.

The structure of urban areas and their fringes consists of a variety of components, ranging from totally built environments (urban core) to relatively natural or semi-natural areas. In and around urban areas, species diversity has been found to be affected by factors other than those recognized by commonly-applied ecological theories. For instance, Hope et al. (2008) analyzed plant diversity at the generic level in metropolitan areas of Arizona-Phoenix, USA, and found that in addition to the spatial variability of resources, socioeconomic factors, such as family income and housing age, contribute to variability of plant diversity. They concluded that there may be a functional relationship between human resource abundance (wealth) and plant diversity in urban ecosystems. Similarly, Kinzig et al. (2005) showed that urban patterns of biodiversity (birds and plants) are influenced by cultural and economic status of the urban residents, independent of the effects of population density, distance from urban center or time since disturbance. However, species composition of earthworms change markedly with the age of residential areas coupled with an increase in population density for most of the species (Xie et al., 2018). In an attempt to study the impact of urbanization on biodiversity globally, Aronson et al. (2014) compiled the largest global dataset of two diverse taxa from cities around the world; birds (54 cities) and plants (110 cities). Their results showed that species density of cities (species/km^2) had declined by 92% for native birds and 75% for native plants relative to estimates of non-urban areas. Anthropogenic related factors, such as land cover and city age, were considered to be the major contributors to this loss. Despite declines in the density of species, their analyses also showed cities still have local native species, highlighting the importance of cities when considering regional and global biodiversity conservation.

In recent decades, urban biodiversity has increasingly been recognized by the scientific community and environmental policymakers as a part of conservation efforts worldwide (Platt et al., 1994; Gustafsson et al., 2005; Alvey, 2006; Elmqvist et al., 2013). However, most research on urban biodiversity and the conceptual models have focused on cities in developed countries. Much less is known about the impacts of urbanization on species composition and diversity of cities in developing countries (Pauchard et al., 2006) and almost none for Chinese cities despite China having the largest urban population in the world (770 million in 2015) (China Statistical Yearbook 2015, http://www.stats.gov.cn/english). Meta-analysis of global urban biodiversity patterns by Aronson et al. (2014) synthesized data from >140 cities around the world. A close examination of the data sources of their study revealed, however, that almost all of the cities are from the developed countries. Only a single data point (Hong Kong) was a Chinese city. This sampling imbalance reflects the lack of data from Chinese cities. An information gap exists for urban biodiversity of cities from developing countries, and more so for Chinese cities.

In this study, we focused on variability in plant diversity at the species level and how it related to the intensity of urbanization across the metropolitan area of Wuhan in central China. Plant diversity is regarded as the primary determinant of overall ecosystem biodiversity that influences the composition and abundance of associated biota (Hooper and Vitousek, 1997; Grime, 1998). We used the percentage of total impervious surface area (PTIA) as an indicator for urbanization intensity. PTIA refers to areas covered by impenetrable materials, such as concrete, stone, brick, asphalt, metal and roofing, expressed as a percentage of total land in an area assessed. It has a profound impact on water quality and water hydrology (Brabec et al., 2002; Shuster et al., 2005; Luo et al., 2018), urban heat island effects (Xiao et al., 2007; Yuan and Bauer, 2007), precipitation (Jennings and Jarnagin, 2002) and biodiversity (Arnold and Gibbons, 1996; Wang et al., 2018). As such, PTIA is regarded as a good predictor of environmental degradation and the effects of urbanization (Schueler, 1994; Morse et al., 2003). In addition, PTIA can be easily measured in the field. The spatial and temporal patterns of PTIA over large areas, and for prolonged periods of time, can be monitored and estimated with remote sensing coupled with geostatistical technology (Hu and Weng, 2009; Zhang et al., 2012).

Other abiotic factors, such as elevation, soil nutrients and water, are purposely ignored. Socioeconomic factors, such as age of the residence and individual wealth, that have been found to contribute to urban species diversity of cities in western countries (*e.g.*, Hope et al., 2008; Aronson et al., 2014) were also not considered for two reasons. Compared with cities of the developed countries, Chinese cities are unique in two aspects. First, there was a revolution of urbanization starting in the 1980s with the most rapid expansion of urban areas ever witnessed in human civilization. The urbanization level in China increased from 18% in 1978 to 26% in 2000, and to 56% in 2015 (China Statistical Yearbook 2015, http://www.stats.gov.cn/english). The rate of urbanization in China is two to three times that of western countries (Zhang and Song, 2003). This rapid urban expansion has resulted in urban areas of relatively young and uniform in age (<40 years).

Second, the Chinese urban housing development is based on an estate-style model; a developer acquires land on which several to dozens of high-rise apartment buildings are built (Fig. 1a). Individual apartments are then sold to the public. The whole estate is usually fenced off from the surrounding areas and managed as a whole. Within the estate, green space (lawns, street trees and gardens) planning and maintenance are the responsibility of the developer and/or the estate management company (known as *wùyè* in China). Residents, irrespective of their socioeconomic status, contribute little to the process. In comparison, cities in many developed countries are often characterized by cottage-style residences (Fig. 1b) (Golland and Blake, 2004). Individual lots (blocks of building land ranging in size of a few hundred to thousands of m^2) developed by real-estate company or government are sold to the public. Cottage-style houses are then built by those who purchased the land. Individuals are responsible for the selection and maintenance of vegetative gardens in and around the house. Hence, their preference and selection of species contribute directly to plant diversity, which is not the typical case in China. We hypothesized that diversity of urban plant community is negatively impacted by PTIA. Our aims in this study was to investigate changes of urban plant diversity and to explore its relationship with the intensity of urbanization, both of which are crucial for management and conservation of urban biodiversity.

2. Materials and methods

2.1. Study area

Wuhan (113°41′–115°05′ E, 29°58′–31°22′ N), the capital of Hubei Province, is one of the largest cities on the upper and middle reaches of the Yangtze River in central China (Fig. 2). The city is located east of the Jianghan Plain at the confluence of the Yangtze and Han Rivers, and has a subtropical humid monsoon climate with hot and rainy summers, and cold winters. The mean annual precipitation is 1259 mm, mean annual temperature is 16.8 °C, and mean annual relative humidity is 77%. By the end of 2016, the city had about 10.6 million inhabitants