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Original article

Long-term afforestation efforts increase bird species diversity in Beijing, China

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ABSTRACT

Bird communities are important components of biodiversity and provide terrestrial ecosystems with multiple functions. The impact of long-term afforestation and rapid urbanization on bird species diversity (BSD) is of interest and has attracted increasing attention from biologists, government officials and the public. This study focused on patterns of BSD and changes in forest coverage in an Asian mega-city (Beijing). Forest coverage in Beijing increased moderately from 1.3% (in 1949) to 21.26% (in 2003), and rapidly from 21.26% (in 2003) to 41% (in 2014). Natural types of land cover (i.e., woodland, grassland and water) increased from 55.25% (9070.29 km^2) in 1985–63.41% (10411.16 km^2) in 2013, while anthropogenic types (i.e., cultivated land, construction land and unutilized land) decreased from 44.75% to 36.59% based on remote sensing data. Three sets of BSD records were obtained from the published literature, revealing a species diversity of 344 in 1987, 375 in 1994, and 430 in 2014. Approximately 15% of bird species were endemic and 80% were migratory. From 1987–2014, Beijing gained 81 bird species (37 species disappeared while 118 species appeared), which could be a result of the progressive increase in forest coverage. The changes in BSD may be affected by long-term afforestation efforts and rapid urbanization, along with meteorological factors. This study sheds some light on the effects of afforestation and urbanization on biodiversity.

1. Introduction

The quality of the ecological environment can significantly impact biodiversity in natural and built ecosystems. Biodiversity studies are relatively more common in natural ecosystems than in urban ecosystems (Mckinney, 2002; Beninde et al., 2015). Urban biodiversity is of special importance to humans because it provides large and growing urban populations with an opportunity for connectedness to nature (Carrus et al., 2015; Hua et al., 2016). Studies of several major animal groups (e.g., birds, bees, butterflies, and other threatened species) undertaken in urban areas (Mckinney, 2002; Ives et al., 2017; Threlfall et al., in press). Birds are likely to be influenced by food supply, disease, and artificial predation in urban areas (Chace and Walsh, 2006). Overexploitation of resources, forest disturbance, habitat fragmentation, environmental pollution and a modified biogeographical context are also considered to be important factors influencing understory insectivores and patterns of bird diversity, abundance, and composition (Borges et al., 2016; Zhang et al., 2016).

Whether or not there is sufficient food or a safe nesting place can play a vital role in bird survival, especially in the context of significant changes in habitat (Lack, 1933; Martin, 1987; Galbraith et al., 2015; Muiruri et al., 2016). In mega-cities, the diversity, structure, and composition of bird communities can be influenced by the environment, the availability of resources, and human disturbance (Ortega-Álvarez and MacGregor-Fors, 2009; Ferger et al., 2014). It is expected that rapid urbanization will detrimentally influence the diversity and structure of avifauna worldwide (Ortega-Álvarez and MacGregor-Fors, 2011; Aronson et al., 2014; Runge et al., 2015). Therefore, understanding and exploring how bird communities respond to urbanization is essential to support conservation of urban biodiversity. Perhaps due to the ease of monitoring by skilled observers, bird species diversity (BSD) has been considered as a good indicator of the quality of ecosystem health (Fontana et al., 2011).

Afforestation activities, and appropriate forest management during

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Table 1
Attributes and phenological phases of ten commonly used tree species (> 1 million individuals) planted in Beijing during the Plain Afforestation Project (2012–2014).

Species	Families	Provenance	Leaf attributes	Main flowering periods	Main fruiting periods
Pinus tabuliformis	Pinaceae (Gymnosperm)	Indigenous	Evergreen	Apr.–May	Sept.–Oct.
Ginkgo biloba	Ginkgoaceae (Gymnosperm)	Indigenous	Deciduous	Mar.–Apr.	Sept.–Oct.
Fraxinus chinensis	Oleaceae	Indigenous	Deciduous	Apr.–May	Jul.–Sept.
Sophora japonica	Leguminosae	Indigenous	Deciduous	Jul.–Aug.	Aug.–Oct.
Robinia pseudoacacia	Leguminosae	Introduced	Deciduous	Apr.–Jun.	Aug.–Sept.
Salix matsudana	Salicaceae	Indigenous	Deciduous	Apr.	Apr.–May
Populus tomentosa	Salicaceae	Indigenous	Deciduous	Mar.	Apr.–May
Ulmus pumila	Ulmaceae	Indigenous	Deciduous	Mar.–Apr.	May–Jun.
Koelreuteria paniculata	Sapindaceae	Indigenous	Deciduous	Jun.–Aug.	Sept.–Oct.
Acer truncatum	Aceraceae	Indigenous	Deciduous	Apr.	Aug.

Note: Data are reported from field surveys and the Flora of China partially (http://foc.eflora.cn/).

urban development, may help mitigate bird loss. Several hypotheses from different hierarchical levels and viewpoints have been proposed to explain patterns of urban biodiversity (including for birds). The "big-size tree hypothesis" suggests that the number and density of large and old trees play several critical ecological roles for birds in a specific region (Stagoll et al., 2012). Large trees can function as keystone structures in urban areas to attract and shelter wildlife species, supplying food and providing nesting places. Unfortunately, it is often difficult to conserve large old trees in the face of changing and human-modified environments (Lindenmayer and Laurance, 2016). The "multi-species understory hypothesis" suggests that biodiversity outcomes can benefit from a high volume of understory vegetation and more native plantings in urban green spaces (Threlfall et al., in press). However, urban green spaces are usually dominated by a limited number of plant species, and urban forests are relatively simple (Konijnendijk et al., 2005). The "habitat selection hypothesis" suggests that animals prefer sites where it is easy to obtain supplementary feeding (Richards and Robson, 1926). Therefore, birds tend to assemble in large forest patches and connected corridors. However, widespread habitat destruction and fragmentation frequently influences urban bird communities (Evans et al., 2009). These hypotheses may fit for a local area (i.e., site-dependent) or partially explain patterns of BSD in urban regions (i.e., scale-dependent). In the light of these findings, urban forest ecosystems can conserve high biodiversity, provided that proportional species composition, stable community structure, connected forest patches/corridors and proper forest management are available.

Afforestation is useful to protect urban biodiversity including birds. As key components of forest biodiversity, birds are also important contributors to the forest community (e.g., as pollinators, dispersers, and pest controllers). However, very few reports have shown BSD benefitting from long-term afforestation projects in a fixed region (Morelli et al., 2017). Beijing is a highly developed metropolis and impacts of long-term afforestation efforts on the BSD dynamics in this region are still to be explored. In this study, we combined land use classification data by remote sensing with data from three bird surveys in Beijing between 1987 and 2014. We explored whether there was any relationship between urban tree cover change and BSD. Furthermore, we investigated which bird species either disappeared or appeared between these three survey events and attempted to explain this through an assessment of bird functional types and traits.

2. Methods and materials

China is undergoing rapid development both economically and socially (with an urbanization rate of around 56% in 2015). In order to improve the ecological environment in the region, in 1979 China has launched the "Three Norths Shelter Forest System Project", which will continue until 2050. This project is officially considered to be extremely necessary and generally successful, though accompanied with misunderstandings and even controversies. In order to enlarge the ecological area in urbanized plains, the Beijing municipal government decided to carry out the "Plain Afforestation Project (PAP)". Initiated in early 2012 and basically completed by late 2014, the project resulted in the planting of over 50 million individuals of more than 160 plant species (ca. 700 km^2), increasing the forest coverage to 41% (ca. 24.5% in urbanized plains).

2.1. Forest coverage and land use types

Values of forest coverage (a comprehensive biotic indicator) recorded since 1949 were extracted from the Beijing Statistical Yearbook (http://www.bjstats.gov.cn/). Woodland areas with a canopy density≧ 0.2 were included in the calculation of forest coverage. Records of land use and land-cover change (LUCC) in 1985, 1995 and 2013 were available in the database, which corresponded approximately to records of BSD from 1987, 1994 and 2014. Representative land-use categories can be used as indicators of urbanization and can reflect a gradient of urban development (Ortega-Álvarez and MacGregor-Fors, 2009). Land use was classified into six types: cultivated land, woodland, grassland, water, construction land, and unutilized land according to a well-accepted classification in northern China (Liu, 1996). Furthermore, cultivated land, construction land and unutilized land were categorized into anthropogenic land-cover, while others were categorized into natural land-cover.

2.2. Spatial pattern of new plantations and tree species information in the PAP

Several biological characteristics of commonly used tree species were identified during the PAP study, including taxonomical, geographical, and phenological items (Table 1). Spatial patterns of new plantations were also illustrated, showing the annual afforestation process during 2012, 2013 and 2014. All of the spatial pattern images were created using ArcGIS (ArcMap 10.0.1; Redlands, CA; http://www.esri.com/) and adjustment calculations were performed in Microsoft Office Excel 2013.

2.3. Records and dynamics of bird species diversity

More than 1250 bird species, belonging to 83 families and 21 orders, are known from China, with approximately 8% being endemic (Lei et al., 2003; Zheng, 2011).The present study focused mainly on published surveys of all bird species (including forest and water birds, sampled using line transect and point-counts; the same methodologies used in Cai (1987), Gao et al. (1994), and Beijing Bird Watching Society, (2014)) in natural reserves and urban green areas. Records of BSD were obtained from continuous field-observations at more than 30 sites from the 1950s −1990s, across the whole Beijing city area (i.e., including diverse habitats in suburban areas and urbanized plains). After examining dozens of studies reporting records of BSD across Beijing,

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