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Diversity and ecology of vascular plants established on the extant world-longest ancient city wall of Nanjing, China

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ABSTRACT

Spontaneous vegetation established on the city wall constitutes a characteristic greenspace within the urban matrix. Nanjing city wall of the Ming Dynasty (NJCW), as an extraordinary huge defensive masonry project, was built in 1393, the extant, basically intact ancient city wall is 25.09 km long, 9–26 m high, and is protected now as a key national cultural relic. Species composition and life forms of the vascular plants established on the vertical or inclined wall surfaces of NJCW were investigated, and its diaspore sources and dispersal modes were also analyzed. Totally, 159 species in 125 genera of 70 families were found inhabiting the joints between bricks or between block stones, trees, shrubs and woody lianas accounts for 51.57% of the species assemblage, while herbaceous plant species makes up 48.43% of them. Fifteen alien species were found colonizing NJCW, including 12 invasive species. Six 100-m-long quadrats were sampled in different segments of NJCW, each quadrat contained 39–77 species, and 755–3006 individuals. In total, 10785 individuals of vascular plants were recorded, consisting of 104 species in 89 genera of 56 families. 65.25% of the total individuals, and 53.85% of the total species are adapted to the primary dispersal of diaspores by wind, whereas 34.75% of the individual assemblage, and 46.15% of the species assemblage are adapted to the primary dispersal of seeds by birds. A bird-dispersed, native pioneer tree, *Broussonetia papyrifera*, was the most abundant species among the six quadrats, even developed coppices on the vertical wall surface. Location and aspect of the quadrats may have affected the species diversity of vascular plants established on its wall surfaces. A diversity of vascular plants established on NJCW, as a valuable urban ecological heritage, is worthy of sustainable wall management, while management priorities should be given to those large trees inhabiting the walls made of bricks, and to the invasive alien species to prevent them from further spreading over the adjacent urban habitats.

1. Introduction

The floras of vascular plants on masonry walls are usually considered as a distinctive element of the urban ecosystem, and have contributed many substantial case studies to urban ecology (Rishbeth, 1948; Brandes, 1992; Duchoslav, 2002; Láníková and Lososová, 2009; Jim, 2013, 2014). Although vascular plants growing on masonry walls are inevitably subjected to a variety of environmental stresses, e.g. dryness, insufficient supplies of water and nutrients, limited substrate volume, often alkaline microenvironment caused by the binding materials, mostly of calcareous mortar, however, a diversity of plant species are still successful in colonizing the walls around the world, and have certainly enriched the city biodiversity (Rishbeth, 1948; Bimal et al., 1991; Brandes, 1992; Lisci and Pacini, 1993a,b; Galera and Sudnik-Wojcikowska, 2000; Duchoslav, 2002; Pavlova and Tonkov, 2005; Reis et al., 2006; Jim and Chen, 2010; Jim, 2014). Wall vegetation also provides a range of resources for birds in urban areas without the need for expensive additional land-take (Chiquet et al., 2013). On the other hand, the spontaneous vegetation thrived on the walls is also considered as a threat to its stability and safety (Mishra et al., 1995; Lisci et al., 2003). Accordingly, the ruderal vegetation of walls provide a platform for probing some basic ecological mechanisms, including seed dispersal, plant adaptation and establishment, and for discussing the management strategy of the ruderals on the wall (Rishbeth, 1948; Lisci and Pacini, 1993a,b; Mishra et al., 1995; Jim, 1998, 2013, 2014; Duchoslav, 2002; Lisci et al., 2003). Nevertheless, so far, most studies on wall floras were carried out in Europe, only a few similar studies have been conducted in America (Reis et al., 2006) and Asia (Bimal et al., 1991; Mishra et al., 1995; Jim and Chen, 2010,

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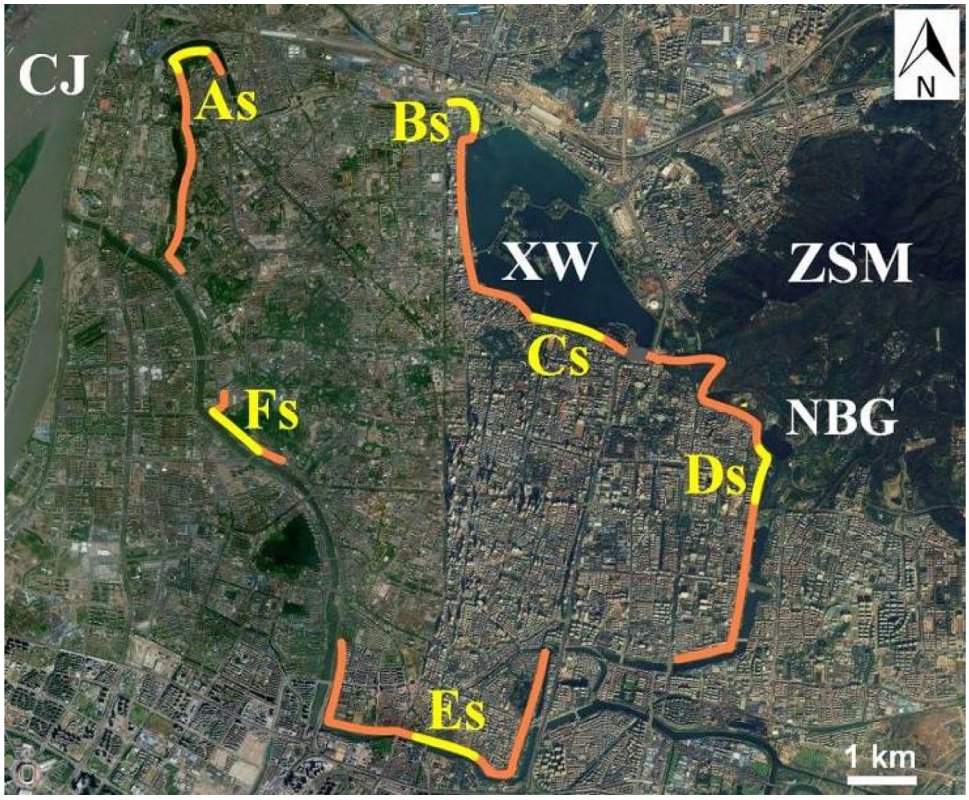

Fig. 1. Location map of the extant Nanjing city wall of the Ming Dynasty. The orange lines show the extant, basically intact ancient city wall, the yellow lines indicate the segments sampled with quadrats. As–Fs. Sites of the quadrats. As-Shizi Hill, north-facing wall surface, Bs-Shence Gate, north-facing wall surface, Cs-Jiefang Gate, north-facing wall surface; Ds-Zhongshan Gate, east- to north-facing wall surface; Es-Zhonghua Gate, south-facing wall surface; Fs-Qingliang Gate, south-facing wall surface. CJ-The Changjiang River, XW-Xuanwu Lake, ZSM-Zhongshan Mountain, a forest park, NBG-Nanjing Botanical Garden Mem. Sun Yat-Sen, located at the southern foot of Zhongshan Mountain. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2011; Jim, 2013, 2014). Despite the fact that China holds many old masonry buildings, and some distinctive city walls with long history, few investigations on the wall flora were reported from the mainland of China (Lei et al., 1996, 1997).

Nanjing city wall of the Ming Dynasty(NJCW)was built between 1366 and 1393, as an extraordinary huge defensive masonry project, its original length was 35.27 km. However, after more than 600 years, mainly because of demolition in wars, city development and natural weathering, the extant, basically intact remnant segments of NJCW are totally 25.09 km long, and still remain the longest and largest, ancient masonry city wall in the world (Yang, 2006). In 1988, NJCW was approved as a key protected national cultural relic by the State Council of the P.R. China.

The present study aims to survey, for the first time, the species composition and species abundance of the spontaneous vascular plants colonizing the vertical or inclined wall surfaces of NJCW, to investigate the source and dispersal mechanisms of their disseminules, and to evaluate the management strategy of the ruderal vegetation on the city wall.

2. Study area and methods

2.1. Site and brief description of the city wall

Nanjing is the capital of Jiangsu Province, East China, with a development history of more than two thousands years, located in the Lower Reach of the Changjiang River, or the Yangtze River, belonging to the northern edge of the northern subtropical climatic zone. Mean annual temperature is 15.4 °C, with an average temperature of 2.3 °C and 27.7 °C in January and July, respectively. Average annual rainfall is 1013 mm. NJCW is located between 30°14′–32°36′ N, 118°22′–119°14′ E, encloses the old city core of Nanjing. The extant NJCW is totally 25.09 km long (Fig. 1), 9–26 m high, average height being 14 m, 8.0–27.0 m wide at the base, 2.6–19.8 m wide at the top (Yang, 2006).

As a whole, NJCW was made of bricks and block stones, which were generally joined together by lime mortars, but occasionally additives of glutinous rice flours were probably applied to the mortars for constructing a few important fortresses (Ji, 1984; Yang, 2006). Considering the topography surrounding the old city, the design and construction of NJCW had integrated some key elements of the terrain, including the Shizi Hill, Qingliang Hill, Qinhuai River and Xuanwu Lake. NJCW was once regarded as one among the three major greenways in Nanjing (Jim and Chen, 2003).

2.2. Survey methods

From August 2004, a comprehensive survey was initiated to record the spontaneous vascular plants inhabiting the wall surface of NJCW. Habitats of the vascular plants were confined to the area from the wall top downwards to the wall base, whereas plants growing in the pavement along the wall crest, and those appearing in the joints between the wall base and the ground were ignored. Thus, the vascular plants surveyed on the city wall (VPW) were all rooted at joints or crevices between the bricks or block stones on the vertical or inclined wall surface.

Species identity of VPW was recorded by direct observation, or with a 8×42 binoculars, and most VPW were photographed, so as to not only confirm a few confusing species later in laboratory, but also record locations and habitats of the plants. Botanical nomenclature basically adopts Flora of China (http://foc.eflora.cn). The primary dispersal agents of seeds, fruits or spores of VPW were