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Research Paper

Community-driven skyrise greenery in a dense tropical city provides biodiversity and ecosystem service benefits

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ABSTRACT

Community-driven vertical greenery provides a previously under-appreciated resource that could be an important component of tropical urban ecology. While the corridors of buildings have been designed to facilitate the circulation of residents between spaces, this study shows that such corridors incidentally served as an informal space for community-driven vertical greenery. Across 1.86 ha of surveyed corridors, a total of 265 plant species and cultivars were present, with an average richness of 124 species per hectare. This is beneficial to urban ecology through its high species diversity, occurrence of endangered and vulnerable native species. Based on a classification of specific plant attributes referenced from literature, provision of food and medicinal resources (77.5%), and aesthetic benefits (72.3%) were the key ecosystem services provided by the species present. Community-driven vertical greenery could function as refugia for native species of conservation interest through providing an additional buffer against further losses in the wild. It also provides immediate opportunities for interactions between humans and nature. This study finds that corridors with larger areas and simpler geometries typically hold a higher abundance of plant pots. Future efforts to increase the abundance and diversity of vertical greenery, and its concomitant increase in the provision of ecosystem services, could be driven by local communities, rather than be formally planned by landscape architects, engineers and urban planners.

1. Introduction

The human population today is highly urbanised, with 54% of the world's population living in cities (United Nations, 2014). Continuing urbanisation and global population growth will lead to increasing densities of people living in cities (United Nations, 2014), and a corresponding need to build taller buildings and denser cities. Such urban densification has removed green spaces within cities (Haaland & van den Bosch, 2015), reducing residents' exposure to biodiversity (Miller, 2005), and the provision of ecosystem services (Dobbs, Nitschke, & Kendal, 2014). The importance of urban greenery for biodiversity conservation, ecosystem service provision and human health (Williams, 2017) has been recognised, as planning policies are developed to encourage the re-greening of cities through traditional nature conservation such as the protection and/or restoration of remnant habitat fragments (Brawn & Stotz, 2001), conservation and development of multi-functional urban greenery and water (Ahern, 1995), and the design of ecological elements onto buildings such as the integration of "vertical greenery" within high-rise architecture (Snep & Odpam, 2010).

This development of sustainable urban systems that seek to harmonise nature with the built environment to the benefit of human society has been driven by landscape architects, engineers and ecologists over the past 30 years (Bergen, Bolton, & Fridley, 2001; Ignatieva, Stewart, & Meurk, 2011; Todd & Todd, 1994). In particular, vertical greenery is now an expanding area of urban design as increasing numbers of buildings assimilate green components into their architecture. For example, Singapore has 213 buildings with skyrise greenery, and aims to achieve 200 ha of skyrise greenery by 2030 (NParks, 2016a, 2016b).

Vertical greenery is commonly formed by integrating green roofs, rooftop gardens, or green walls onto built structures (Francis & Lorimer, 2011). Green spaces on buildings are typically planned by landscape architects and urban planners; vegetation is placed on particular areas of buildings, and the species choice and design configurations are decided upon through the professional expertise of a limited number of designers (Kibert, 2016). Heavily planned and manicured green spaces can still provide benefits for human well-being (Matsuoka & Kaplan, 2008) and biodiversity (Goddard, Dougill, & Benton, 2010), but face some limitations. Broadly, ecological knowledge is not harmonised with

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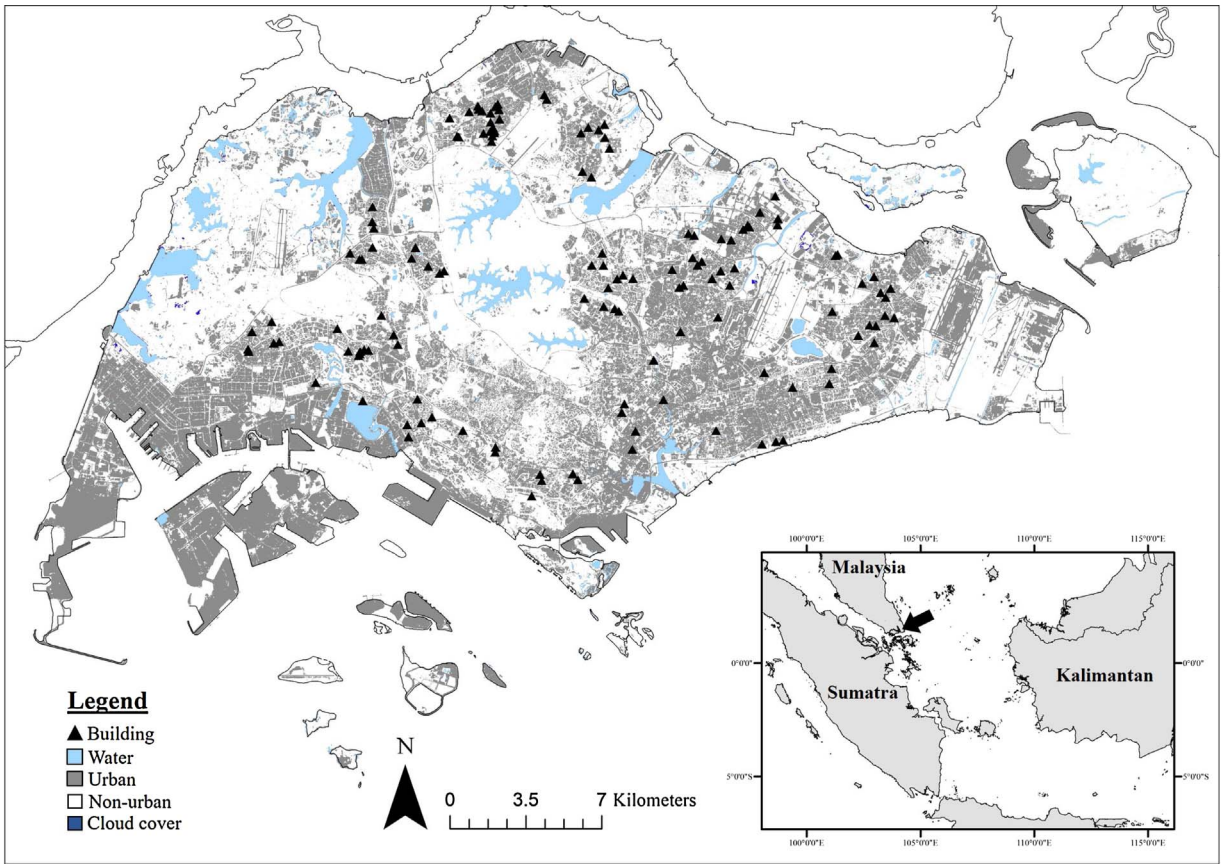

Fig. 1. A map of Singapore indicating the urban, non-urban and water bodies as modified from Yee et al. (2011). The location of 135 residential buildings surveyed are represented by the black triangles. The black arrow in the inset indicates Singapore's location relative to Peninsular Malaysia, Sumatra and Kalimantan.

architecture design and principles at the beginning of the planning process, but included at the end after significant building design decisions have been made (Ignatieva, 2010). The choice of species planted is likely to be based on pragmatic criteria relating to cost, durability or aesthetics, rather than according to their contributions to biodiversity and/or ecosystem service provision. Also, vertical greenery is frequently heavily manicured by paid contractors, typically reducing the biodiversity potential (Khew, Yokohari, & Tanaka, 2014). A further limitation of highly planned vertical greenery is that residents are likely to have little input in the decision-making process, so the species that are planted may not provide the ecosystem services that they desire (Reed, 2008). Finally, the process of designing and maintaining planned vertical greenery can be expensive (Sproul, Wan, Mandel, & Rosenfeld, 2014), thus reducing the incentive for such buildings to be built. For vertical greenery to become a common component of dense urban fabrics, the cost of creating and maintaining such buildings will need to be reduced or subsidised to accrue the wider social benefits.

Instead of relying on heavily planned and manicured vertical greenery, a complementary approach to greening cities would be to use community-driven, or informal, vertical vegetation. At ground level, privately-managed urban gardens are an important component of urban biodiversity in less dense urban landscapes in Europe (Loram, Warren, & Gaston, 2007; Smith, Thompson, Hodgson, Warren, & Gaston, 2006). However, analogous vertical systems such as privately-managed and maintained vertical gardens are rarely considered as design options within the field of vertical greenery, and have not been considered within the typologies of informal urban green space (Rupprecht & Byrne, 2014). Allowing urban residents to manage their own vegetation may have several advantages over planning vertical greenery from the top down; it would reduce the design and maintenance costs of vertical greening for building managers, allow people to plant species that provide ecosystem services that are most relevant to them, and could facilitate the planting of a greater diversity of taxa. In this study, we discuss the potential for community-driven vertical greening by documenting an existing example; the informal planting among Singapore's public housing estates.

Singapore is a highly urbanised country located in tropical Southeast Asia. The country has a high population density of 7697 inhabitants/km^2 (Department of Statistics, 2016). 80% of Singapore's residents are accommodated by Singapore's public housing authority – the Housing & Development Board (HDB), operating across 23 neighbourhoods (HDB, 2016a). The majority of HDB residences are high-rise buildings with no planned green spaces above ground level. However, urban greening has been encouraged in Singapore since the 1960s, earning a reputation as "City in a Garden" (Neo, Gwee, & Mak, 2012; Yuen, 1996). Urban greening in Singapore has included ground-level formal green spaces in the form of nature reserves, parks, private home gardens, and has more recently been extended to include planned vertical greenery such as green walls and rooftop gardens.

Little is known about the extent of community-driven vertical greening in Singapore's HDB buildings, the diversity of species planted, or the ecosystem services that are provided. To encourage such informal vertical gardening in the future, it is important to understand how the quantity and quality of urban greenery depends on the building design. This study captures a first detailed picture of greenery along high-rise residential corridors in a tropical city. Data on the abundance of plant pots, and the number of plant species was collected from 135 residential building corridors to 1) assess the diversity and origin of planted greenery, 2) assign a suite of ecosystem services derived from the plant species present based on their plant traits, and 3) investigate if the structure of the built environment influenced the abundance of community-driven vertical greenery. These data are subsequently

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