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Drivers for colonization and sustainable management of tree-dominated stonewall ecosystems

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ABSTRACT

Cities provide diverse natural, ruderal and artificial habitats for plants to enrich urban biodiversity. Stone retaining walls (SRW) in urban Hong Kong offer unique analog artificial-cliff habitats for spontaneous colonization mainly by native strangler-fig trees of genus *Ficus*, to create a special stonewall ecosystem. Field survey of 289 SRW in the old urban core found 793 stonewall trees from 28 species, 21 of which were rare to solitary. Tree seedlings, hacked trees and coverage of shrubs, herbs and non-vascular plants were also assessed. Old SRW with irregular stone size and shape and open unmortared joints were conducive to seed lodging by frugivorous birds and seedling establishment. Spread of aerial roots on wall face followed by penetration of joints to reach the soil retained behind the wall (aft-soil) denoted the critical tipping point in tree establishment. Regression analysis identified explanatory variables for presence and quantities of wall vegetation. Open joints, ledges and cracks provided enabling micro-niches to raise tree frequencies or diversities. Volcanic masonry blocks with more nutrient release upon weathering were more amenable to tree colonization than granite. Aggressive government wall maintenance regularly removed tree seedlings. Similarly unsympathetic maintenance by private land-owners also led to tree hacking. Low-elevation location with intensive urban development demanded more vigorous wall-vegetation clearance. Similarity in species composition of tree seedlings, hacked trees and established trees signified persistence of initial tree flora in the course of stonewall ecosystem succession. Abiotic components also experienced little changes. Wall and tree should be co-managed as an integrated unit to foster unimpeded tree growth and regeneration. Harmful maintenance operations could be revamped to preserve or restore pertinent conditions for trees. Key research findings were translated into specific measures for sustainable ecosystem management of the valuable natural and cultural heritage.

1. Introduction

Cities are often regarded perhaps erroneously as harmful to life, suppressing both the quantity and diversity of urban flora and fauna. In reality, developed urban areas often contain a surprising range of habitats (Carr and Lane, 1993; Gilbert, 1989). They include natural enclaves inherited from pre-urbanization ecosystems with different levels of human modifications. The quest for urban green spaces in most cities has created many artificial, semi-natural or ruderal sites where human-preferred horticultural species are cultivated (Ignatieva et al., 2000; McKinney, 2002). Buildings and paved areas offer additional niches for opportunistic plants to develop. Wind and animal dispersal agents, including humans, would assist spontaneous colonization or invasion of different habitats by both native and exotic plants.

The biotope diversity in developed areas provides ample opportunities for plant life. Propagules could come from the existing intra- or peri-urban vegetation pool, supplemented by those introduced intentionally or accidentally from nearby or distant areas. A wide variety of plants can overcome the stresses and challenges of novel habitats (Kunick, 1990; Sachse et al., 1990; Sukopp et al., 1990; Breuste et al., 1998; Lososová et al., 2011). In some cases, species richness and geographical origin could exceed those in a city's countryside envelope or surrounding natural areas. Whereas the green coverage of cities may be limited, it is compensated by wide assortments of habitats and associated species and communities. They denote the long-term interplay and resultant of both natural and human processes. This hybrid living resource deserves more conservation efforts.

Urban ecology investigations cover different urban habitats, from common to uncommon and unique. They assess the components and linkages, factors and processes, origins and provenances, and threats and conservation. These empirical studies in conjunction with conceptual contributions have deepened understanding

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of the underlying intricacies. Besides expanding the knowledge base, the findings have reinforced the causes in urban-nature conservation and enhancement of urban biodiversity (Alvey, 2006; Kowarik, 2011). They remind humans of nature's companions in apparently hostile urban areas. If a city can permit other life forms to thrive, it offers a surrogate indicator of livability and hence sustainability for people.

Walls denote a special artificial and synanthropic habitat that are commonly found in cities. They differ in material make-up and receptivity to plant growth. They are made of stones or bricks, with joints left unfilled (dry wall; Rodrigues, 1988) or filled (mortared), wall surfaces left bare or covered by plaster, and free-standing or retaining earth (Gannon, 1995; Hendry and Khalaf, 2001). They share stresses to plant life, including verticality, elevated position, limited mineral and organic substrate, limited storage capacity and supply of nutrients and moisture, exposure to the elements, continual disturbance by human activities, and conflicts with other urban structures. They are deficient in basic necessities for roots to acquire sustenance and anchorage, yet they have been widely colonized by adventive and spontaneous flora.

Wall ecology originated in European cities in the temperate climatic zone. Deakin's (1855) comprehensive classical study of the Colosseum in Rome and Jordan's (1859) and West's (1911) assessments triggered investigations in other countries (e.g., Rishbeth, 1948; Woodell and Rossiter, 1959; Kent, 1964; Payne, 1978; Bolton, 1985; Hruška, 1987; Lisci and Pacini, 1993a,b; Duchoslav, 2002; Francis and Hoggart, 2009; Viles, 2010). The findings were condensed in three books (Segal, 1969; Darlington, 1981; Gilbert, 1992) and a review paper (Woodell, 1979). Relatively rich species assemblages with ruderal or pioneer traits have extensively and voluntarily colonized the mural niches. Their ecology signifies notable affinity with rocky outcrop or cliff communities as habitat analogs (Hannes and Hannes, 1984; Jefferson and Usher, 1989; Cooper, 1997; Láníková and Lososová, 2009). Their variabilities are signified by different combinations of natives and exotics, archaeophytes and neophytes, vascular and non-vascular, arboreal and non-arboreal, and wind and animal dispersal. Plants on walls are largely confined to non-vascular and herbaceous forms with limited occurrence of arboreal components. Other studies in temperate latitudes in New Zealand (de Neef et al., 2008) and Korea (Kolbek and Valachovic, 1996) found a similar floristic profile.

Few wall vegetation studies have been attempted in the humid-tropical region. They include cases in India (Sharma and Shringi, 1990; Bimal et al., 1991; Ghosh and Das, 2002), Hong Kong (Jim, 1998a; Jim and Chen, 2010), Brisbane in Australia (McPherson, 1999), and Brazil (Des Reis et al., 2006), and are marked by common to dominant occurrence of trees. They include notably the genus *Ficus* or Banyans (Janzen, 1979; Starr et al., 2003; Lansky and Paavilainen, 2011), which can overcome the acute habitat challenges to achieve the keystone species status. Some tree species could reach sizeable dimensions exceeding 20 m in height and crown spread to exert notable influence on wall microclimate and urban wildlife. The fundamental drivers for plant life on masonry walls are similar in temperate and tropical regions, but their exploitation and utilization by plants differ significantly. The divergence deserves in-depth investigations. The ability of *Ficus* trees to scale walls is also demonstrated in colonization of buildings in the tropics (Wee, 1992; Jim and Chen, 2011).

Hong Kong is one of the most compact cities in the world, with pervasive land conversion and exclusion of nature. It has, however, interesting sites for ruderal vegetation in the form of old stone retaining walls (SRW) built mainly according to traditional Chinese design (Lo, 1971; Committee on Infrastructure of Liaoning Province, 1973). To create developable urban land, the hilly terrain has been carved into giant steps supported by SRW. About 500 of such vertical habitats have been colonized spontaneously by about 1500 trees and other companion vegetation to enrich landscape and ecology. The city probably has the highest concentration of SRW and stonewall trees in the world. The oldest walls and companion trees have co-existed for over 100 years. They embrace handsome large trees in the form of a linear and hanging urban forest that penetrates the city's hilly neighborhoods.

This study investigated the main determinants of flourishing tree growth on the unique SRW habitat. The main stonewall features conducive to plant growth were assessed in detail in the field. The stonewall trees were evaluated with reference to species composition and biomass structure. The intimate association between trees and walls conducive to developing and sustaining this urban ecosystem was analyzed. The findings were translated into practical hints to inform conservation of this precious nature-in-city wall-cum-vegetation heritage, and precautions to be adopted in preventing their degradation and maintaining or restoring it.

2. Study area and methods

The study area includes the oldest districts, developed since the 1840s, in the urban core of Hong Kong around the Victoria Harbour, covering 9.8 km^2. The city is located at the coast of south China on the east side of the Pearl River Estuary. In districts developed after the Second World War, the retaining walls made of reinforced concrete are rarely colonized by vegetation. They tend to follow the contour and road alignment. Most walls are situated at road edge or between building and adjoining slope.

Only SRW (holding back soil materials behind the wall structure) are included in this study; free-standing ones are excluded. SRW shorter than 2 m were excluded. A stonewall tree is defined as one with most of its roots spreading on the stone wall face or penetrating through the stonewall structure, and with the trunk base partly or wholly situated within the confines of a stone wall (Jim, 1998a). The qualifying parts of a stone retaining wall run from the toe to the crest, including the coping. A tree overhanging above a wall but not physically attached to it, and a tree with trunk base and most roots located outside the wall boundaries, does not qualify.

After reconnaissance field assessments, four detailed record forms were developed respectively for walls, trees, tree seedlings and hacked trees. The last two provide indicators of the survival and reproduction dynamics of stonewall trees. The prototype forms were pilot tested and refined to collect systematic data. The main geometric and other traits of the stone walls were also assessed (key attributes listed in Table 1). Measurable traits were recorded as continuous variables, and as far as possible the non-numerical data were organized in ordinal format. Trees shorter than 2 m were considered as seedlings and given less elaborate evaluation. For trees hacked at or near the original trunk base, the trunk diameter at the cut face was measured. The positions of the seedlings and hacked trees on the walls were recorded. Soil pits were excavated behind a stone wall to evaluate the spread, density and size of roots in the soil retained behind the wall.

A LaserAce Hypsometer (Measurement Devices Limited, York, UK) was used to measure tree height, crown spread, crown clearance, trunk diameter, tree lean, root spread, wall height, wall width, and wall inclination (Fig. 1). A pair of Plant Stress Detection Glasses (Forestry Supplies Inc., Jackson, MS) was enlisted to check the health status of tree seedlings. The botanical nomenclature follows Hong Kong Herbarium and South China Botanical Garden (2007, 2008, 2009, 2011), and Hong Kong Herbarium (2012). Databases were built with Microsoft Excel 2000, and SPSS version 20 was employed in data analysis which includes linear regression and binary logistic regression.