Urbanization effects on spatial-temporal differentiation of tree communities in high-density residential areas

C. Y. Jim[1] · Hao Zhang[1]

Abstract The changing mode of urban development through time can bring a varied land-scape mosaic accompanied by spatial-temporal differentiation of urban vegetation. Hong Kong as an ultra-compact city generates intense interactions between trees and urban fabric to highlight urbanization effects on tree communities. The study areas cover public housing estates which accommodate about half of the 7.26 million population. Thirteen site factors related to estate, landform and habitat traits were measured or computed as surrogate urbanization effects. Species composition and diversity of tree communities in 102 estates were assessed by field surveys, including four estate groups: older or newer ones situated respectively in urban core or new towns. They contain 48,823 trees belonging to 232 species with heavy exotic representation. Total tree density and native tree density in newer estates were significantly higher than older ones. Differences in species richness and diversity and native species richness between older and newer estates were not significant, expressing to a certain extent the floristic-homogenization phenomenon. Multi-response Permutation Procedures (MRPP) results showed significant difference in species composition between older and newer estates, which could be explained by variations in development age, density, town plan and pre-urbanization land cover. Nonmetric Multidimensional Scaling (NMDS) results found tree distribution patterns in four estate groups strongly associated with estate area, open space area, estate population, estate age, Shannon index (H′) at planting strip and tree pit, and tree site quality index. Urban-forest management could be improved by adopting more native species and providing high-quality and spacious planting sites to accommodate more and larger trees. The research methods and findings could be used by policy makers and planners in similar large and developing cities to evaluate, design, maintain and enhance urban biodiversity.

Keywords Biotic homogenization · Floristic diversity · Native species adoption · Public housing estate · Urban biodiversity · Urbanization effect

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Introduction

Urbanization is recognized as a driver of biotic homogenization and environmental degradation (Peterson et al. 1998; Chapin III et al. 2000; Allen et al. 2006; Werner and Zahner 2010). Sustainable protection and management of urban biodiversity could contribute to conservation of global biodiversity (Werner and Zahner 2010). To realize this goal, it helps to understand urbanization effects on species abundance, diversity and composition of urban communities, structure and function of urban ecosystems, and quality of life (Duffy 2009; Kowarik 2011). In the past decade, urban biodiversity has been assiduously studied by researchers, environmental planners and policy makers (Gustafsson et al. 2005; Jooss et al. 2009). In this context, urban trees have been increasingly recognized as important biological-ecological components of city-level biodiversity (Dwyer et al. 1992; Kuo and Sullivan 2001; Nowak 2002; Fang and Ling 2005; Konijnendijk et al. 2006; Pickett et al. 2011; Gaffin et al. 2012; Jones et al. 2012; Jim 2013). They offer a wide range of direct and indirect ecosystem services in urbanized areas, including environmental improvement, aesthetic enhancement, ecological enrichment, and economic, social and health benefits for residents (Konijnendijk 2008; Gaffin et al. 2012; Jones et al. 2012; Jim and Zhang 2013).

With high-rise, high-density and multiple-intensive land-use, Hong Kong presents an ultra-compact city (Zaman et al. 2000; Zhang and Wang 2006). It demonstrates extreme human modification and obliteration of nature. The city core was urbanized since the 1840s (Tregear and Berry 1959), filled with high-rise buildings and dense road networks with meager interstitial open spaces. The new town program, launched in the 1960s, has relieved population and development pressures on the old urban core. New towns have relatively lower population and building density, and more greenery and remnant forest patches. Due to differences in development age, density, town plan, and pre-urbanization land cover, urban core and new towns have different landscape, habitat and floristic ingredients.

In response to fast population growth with a substantial migrant component, a public housing program was initiated by the Hong Kong government in the 1950s (Smart 2006). Large-scale public housing estates (hereinafter referred to as "estates") were initially built in the urban core, and since the 1970s spread to new towns. Each estate is composed of a cluster of high-rise blocks to accommodate low-income families at high density. At present, they accommodate 45.8 % of the 7.26 million population (Census and Statistics Department 2014). The government has become the world's largest urban-housing landlord based on housing units, residents, land area and real-estate value (Hong Kong Housing Authority 2014). In the estates, the quantity and quality of open spaces and constituent greenery can contribute to the physical and mental health of 3.31 million residents, aesthetic quality of the estates, and habitats for companion urban wildlife. Compared with natural communities, these green enclaves have diverse mixtures of cultivated and volunteer species, often with a high proportion of exotics (Thompson et al. 2003). After six decades of continual and massive development, the estates present opportunities to investigate urbanization effects on spatial-temporal differentiation of tree communities in high-density residential areas.

In Hong Kong, few studies have covered the urbanization effects on habitat characteristics and tree community structure. High land-use intensity and intensive interactions amongst urban fabric, people and trees provide chances to explore such intrinsic urban-forestry factors. To evaluate their spatial-temporal effects, the composition and diversity of tree communities in estates with different age and location were evaluated.

Three hypotheses were developed based on reconnaissance surveys of trees in estates: (1) species richness and diversity are higher in newer than older estates; (2) more native species are planted in newer than older estates; (3) species composition differs between newer and older estates. To determine the relationship between site factors and tree species distribution, three additional hypotheses were tested: (4) species distribution at the estate scale is affected by estate area, open space area, estate age and residents population; (5) species distribution at the landform scale is affected by estate absolute elevation and relative relief; (6) species distribution at the habitat scale is affected by tree site quality index. Trees in the estates denote management decisions and actions made at different periods by different people in response to different site conditions. Findings of the study could inform policy makers and forest planners in the design, maintenance and enrichment of urban biodiversity.

Study area and methods

Study area

Hong Kong is located on the eastern side of the Pearl River Estuary in south China. It has a mainland part (Kowloon and the New Territories), Hong Kong Island, and over 100 small islands. Urban development is constrained by a limited land area of merely 1108 km^2 and rugged topography, confining built-up areas to merely 24.7 % of the territory (Census and Statistics Department 2014; Planning Department 2014). The humid-subtropical climate has a mean annual temperature of 23.3 °C and annual rainfall 2398 mm (1981–2011) (Hong Kong Observatory 2015). The seasonally contrasting Asian Monsoon system yields hot-wet summer (May to August) and cool-dry winter (November to February) (Lam 2011). Summer afternoon temperature often exceeds 31 °C, whereas night temperature generally remains around 26 °C. Over 80 % of the rains fall in the summer period. In winter, the temperature occasionally falls below 10 °C and it receives less than 10 % of annual rainfall.

Hong Kong has 206 public housing estates, which are found in every district except old Wan Chai. In this study, 102 estates were randomly selected as study sites, accounting for about half of the estate stock. The selection attempted to sample about half of the estates in each district in a stratified sampling scheme. They were distributed in all 3 regions (i.e., Hong Kong Island, Kowloon and New Territories) and 16 districts (Table 1). Districts in Hong Kong Island and Kowloon represent the urban core, and the New Territories the new town (Census and Statistics Department 2014). Seven districts in Hong Kong Island and Kowloon have a land area of 110.61 km^2 and a total population of around 2.92 million persons (Table 1). The average population density is 32,100 persons/km^2. New towns have relatively more open town plans. Around 3.68 million persons live in nine new town districts with covering 796.61 km^2, with average population density at 6180 persons/km^2 (Table 1).

Tree survey

The field study followed several stages: (1) identifying target rental public housing estates; (2) preparing large-scale digital maps of individual estates; (3) collecting basic information about target estates such as area, age and population; (4) assessing all trees in level sites and adjoining accessible slopes in each estate with reference to species name, tree number, location and habitat condition. In this study, a 'tree' was defined as a woody plant with a trunk diameter

Table 1 The 102 public housing estates selected in this study, grouped as urban core and new town, and characterized by development history, land area and population density

District	Development history	Land area (km^2)	Population density (10^3 persons/km^2)	Number of selected estates
Urban core: Hong Kong Island (HKI)				
Central & Western	Urban core	12.55	20.04	1
Eastern	Urban core	18.71	31.43	8
Southern	Urban core	39.40	7.07	5
Total		70.66	58.54	14
Average		–	19.51	–
Urban core: Kowloon (KL)				
Kowloon City	Urban core	10.02	37.66	2
Kwun Tong	Urban core	11.27	55.20	16
Sham Shui Po	Urban core	9.36	40.69	7
Wong Tai Sin	Urban core	9.30	45.18	14
Total		39.95	178.73	39
Average		–	44.68	–
New town: New Territories (NT)				
Islands	New town	175.03	0.81	5
Kwai Tsing	New town	21.82	23.43	13
North	New town	137.31	2.23	3
Sai Kung	New town	136.39	3.20	2
Sha Tin	New town	69.46	8.84	10
Tai Po	New town	148.05	2.18	2
Tsuen Wan	New town	60.70	5.02	4
Tuen Mun	New town	84.45	5.77	6
Yuen Long	New town	138.43	4.18	4
Total		796.61	55.66	49
Average		–	6.18	–

of 95 mm or more measured at a height of 1.3 m above the ground level. Tree species identification and nomenclature followed Hong Kong Herbarium (2012).

Site factors as surrogates of urbanization effects

Urban compactness in Hong Kong, expressed as high population density, mixed land use, high accessibility, high residential density, presents the most important limitation to tree growth (Jim 1998, 2000). Thirteen site factors, serving as surrogates of urbanization effects (Burton 2002), have been grouped under estate, landform and habitat scales (Table 2). They were measured or computed to assess the relationship between species composition and site conditions.

Basic estate factors, including the number of high-rise residential buildings, estate age and estate population, were collected from the Housing Department. Acquired by the Map Library of the Department of Geography, the University of Hong Kong, the B5000 (1:5000 scale and E00 format) digital topographic government maps dated 2011 with 0.5×0.5 m resolution were

Table 2 Site factors measured or calculated with reference to estate, landform and habitat scales

Site factor	Description	Mean (range)
Estate scale		
Estate area (m²)	Total area of each estate, provided by Housing Department	7.60 (0.69–23.18)
Open space area (m²)	All open spaces with hard and green cover of each estate, to be measured by GIS 5000 map	5.67 (0.10–19.23)
Number of buildings (count)	Number of high-rise residential buildings of each estate, provided by Housing Department	7.88 (1.00–20.00)
Estate age (year)	Age of each estate since it was built, provided by Housing Department	30.07 (16.00–55.00)
Estate population (person)	Total population of each estate, provided by Housing Department	12,093.14 (800.00–35,900.00)
Landform scale		
Estate absolute elevation (m)	The highest spot height within or on the edge of each estate, to be measured by GIS 5000 map	42.16 (0.00–150.00)
Estate relative relief (m)	Highest spot height–lowest spot height, to be measured by GIS 5000 map	13.84 (0.00–90.00)
Habitat scale		
Shannon index (H′) at container	Shannon index (H′) at container habitat for each estate	0.29 (0.00–2.26)
Shannon index (H′) at level planting bed	Shannon index (H′) at level planting bed habitat for each estate	1.94 (0.00–3.48)
Shannon index (H′) at planting strip	Shannon index (H′) at planting strip habitat for each estate	2.61 (0.00–3.75)
Shannon index (H′) at slope	Shannon index (H′) at slope habitat for each estate	1.47 (0.00–3.23)
Shannon index (H′) at tree pit	Shannon index (H′) at tree pit habitat for each estate	1.58 (0.00–2.86)
Tree site quality index	(Total number of trees in level planting bed and planting strip and slope for each estate–total number of trees in container and tree pit for each estate)/total tree number for each estate	0.50 (−1.00–1.00)

used to digitize estate area, open space area, estate absolute elevation and estate relative relief. The estate area, building area and open area were measured by ArcGIS 9.2. The building features in B5000 digital maps included building block outline, building outline under elevated structure, open-sided structure, proposed building block outline, podium line and podium line under elevated structure, which provided data layers to define building area for each estate. Open space area (potentially plantable area) was calculated from the difference between estate area and building area. The contour lines in B5000 digital maps were used to analyze the landform-scale factors (absolute elevation and relative relief) by ArcGIS 9.2. Field trips helped to verify and refine the map and GIS analysis results.

Data and statistical analysis

Thus far, 18 estate designs have been used in the past 60 years, including: (a) mark IV in the 1960s; (b) old slab, single tower and twin tower in the 1970s; (c) cruciform, double H, single H, triple, trident and ziggurat in the early 1980s; (d) linear, new slab, single aspect building and small household block in the late 1980s; and (e) harmony, housing for senior citizen, new cruciform and new harmony in the 1990s (Hong Kong Housing Authority 2014). The above five estate designs in chronological order were assigned an ordinal score scale of 1–5. Hierarchical cluster analysis using the group average method assessed Bray-Curtis similarities according to estate ages and values of estate types among 102 estates.

The species richness estimators were employed to assess whether the sampling efforts were adequate for different estate groups (Colwell 2012). Sampling efforts were considered sufficient if the estimated value of species richness did not significantly increase with the increasing sample sites, or the standard deviation (SD) of diversity index was very small (Colwell 2012; Zhou et al. 2012).

Five types of urban tree habitats in Hong Kong (Jim 2004) were identified during the tree survey by the authors in 102 estates, including container, level planting bed, planting strip, slope, and tree pit (Table 2). Shannon index (H′) of species diversity was calculated for each tree-habitat type as: $H' = -\Sigma\ p_i\ (\ln\ p_i)$, where p_i = relative number of species i at each tree-habitat (Shannon and Weaver 1963; Magurran 1988). A tree-site quality index was calculated as: (total number of trees in level planting bed and planting strip and slope for each estate – total number of trees in container and tree pit for each estate) / total tree number for each estate. Species richness, diversity and evenness of each estate were evaluated, from which mean values for the estate groups were calculated. The diversity index of the species in each estate was calculated by Shannon index (H′) (Shannon and Weaver 1963; Magurran 1988) and Evenness index as: $J' = H'/\ln\ (S)$, where H′ = Shannon diversity index, and S = total number of species (Pielou 1966). Species diversity, total tree and native tree densities were compared between different estate groups, using independent-sample Mann–Whitney U-test for non-normally distributed data (Zhou et al. 2012).

The differences in species composition among estate groups were tested using Multiresponse Permutation Procedures (MRPP) (McCune and Grace 2002; Peck 2010). For each species, the relative abundance and Sorensen (Bray-Curtis) distance and a natural group weighting method were used in MRPP analysis. The test statistic (T) of MRPP analysis described the separation between two groups, with bigger separations denoted by greater negative values. The chance-corrected within-group agreement (A) described the homogeneity within group, and all items are identical when A = 1; heterogeneity equals expectation by chance when A = 0 (McCune and Grace 2002; Zhou et al. 2012).

The responses of species at the estate scale were analyzed using Nonmetric Multidimensional Scaling (NMDS) (McCune and Grace 2002; Peck 2010; Zhou et al. 2012). The relative abundance for each species was calculated. To ordinate different estate groups in species space, Sorensen (Bray-Curtis) distance with the final best solution as 2-D was selected (McCune and Grace 2002; Zhou et al. 2012). Spearman's correlation test was analyzed to find the relationships between thirteen estate scale factors and two NMDS axes. At the estate scale, factors highly correlated with ordination scores (joint plot cutoff $r^2 > 0.20$) as vectors were plotted to interpret the factors of species distribution for different estate groups (Zhou et al. 2012). The MRPP and NMDS analyses were conducted by PC-ORD 5.32 for Windows (MjM Software, Oregon, USA), and other statistical tests by SPSSPC version 11.5 (SPSS Inc., Chicago, IL) and MS Excel 2000 (Microsoft, Redmond, WA).

Results

Estate grouping and basic tree profile

Based on similarity of estate age and type, cluster analysis of 102 estates yielded two clusters based on a cut-off line set at 90 % (Fig. 1). Accordingly, the estates were divided into two groups, namely older estates (1958–1981) and newer estates (1982–1997), which denoted temporal change. Based on development history of districts and estate distribution in districts, estates were further divided into older estates respectively at urban core and new town, and newer estates at urban core and new town, which represented combined spatial-temporal changes.

Cumulative species estimates (ACE mean±SD) indicated that estimated species richness did not increase notably with the number of sample sites, or the SD of diversity index was lower than 0.02 for the maximum sample size. The results showed that the sampling efforts were adequate for the four estate groups, namely older estates at urban core, older estates at new town, newer estates at urban core, and newer estates at new town, as well as for all 102 sampled estates (Fig. 2), indicating that the estate groups were justified and could be used in the further data analysis.
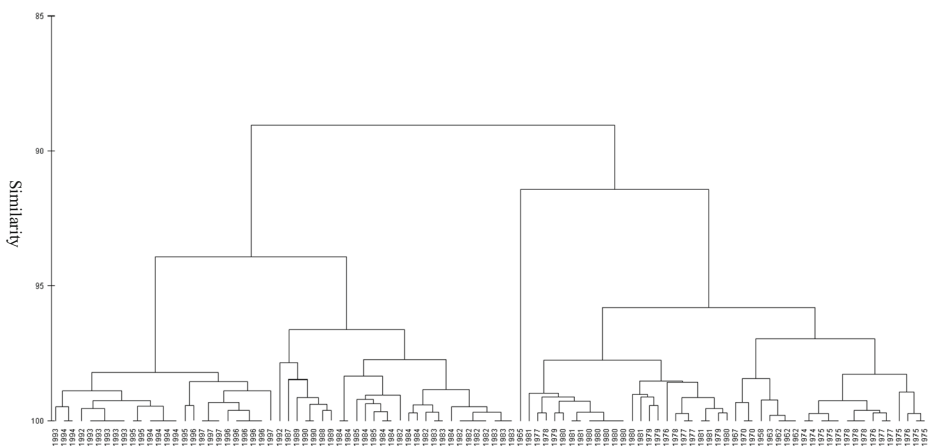

Fig. 1 Cluster analysis dendrogram of 102 public housing estates based on the similarity of estate ages and types
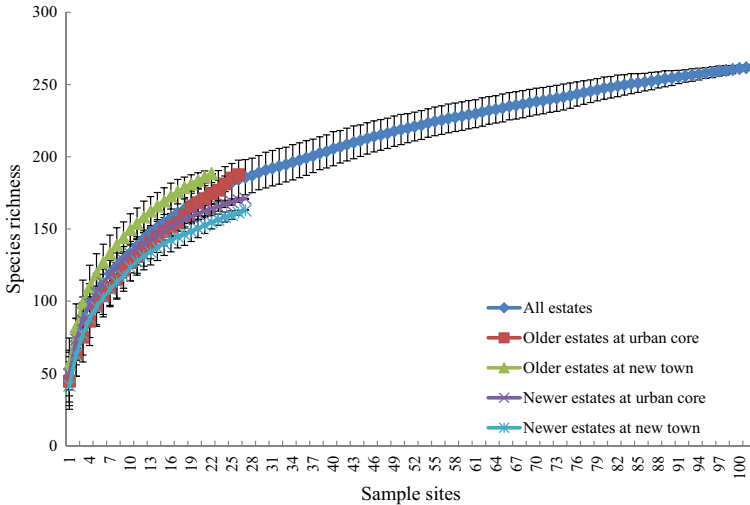
Fig. 2 Cumulative estimated species richness-sample site curve for older and newer estates, respectively in urban core, new town and all (102) estates. Estimated species richness is based on Abundance-based Coverage Estimator (ACE), and error bars denote standard deviation (SD)

A total of 48,823 trees distributed among 232 species were found in 102 estates. The 69 native species constitute 10,837 trees, accounting for 29.74 % of species and 22.20 % of trees. The 163 exotic species contributed 37,986 trees, accounting for 70.26 % of species and 77.80 % of trees. The overall species profile is evidently skewed towards exotic species and trees.

Differentiation in tree density

Total tree densities and native tree densities in estate groups are shown in Fig. 3. Tree densities in newer estates (1797.76 trees/ha) were significantly higher than older estates (1387.16 trees/ha) ($p < 0.05$) (Fig. 3a). For older estates, tree densities were significantly higher in new town (1507.06 trees/ha) than urban core (1267.29 trees/ha). For newer estates, there was no significant difference between urban core and new town. Native tree densities had a similar pattern as total tree densities, with higher density in newer estates (446.49 trees/ha) than older estates (345.66 trees/ha) ($p < 0.05$) (Fig. 3b). For newer estates, the difference of native tree densities between urban core and new town was significant ($p < 0.05$). However, for older estates, no significant difference of native tree densities was found between urban core and new town.

Differentiation in species diversity

For older estates, species richness in new town (45.09) was significantly higher than urban core (34.85) ($p < 0.05$) (Table 3). However, there was no significant difference of species richness between older and newer estates, and between newer estates at urban core and new town. Consistent similarity with no biodiversity difference for native species richness was also found between sites (Table 3). For Shannon index (H′) and evenness index (J′), no significant
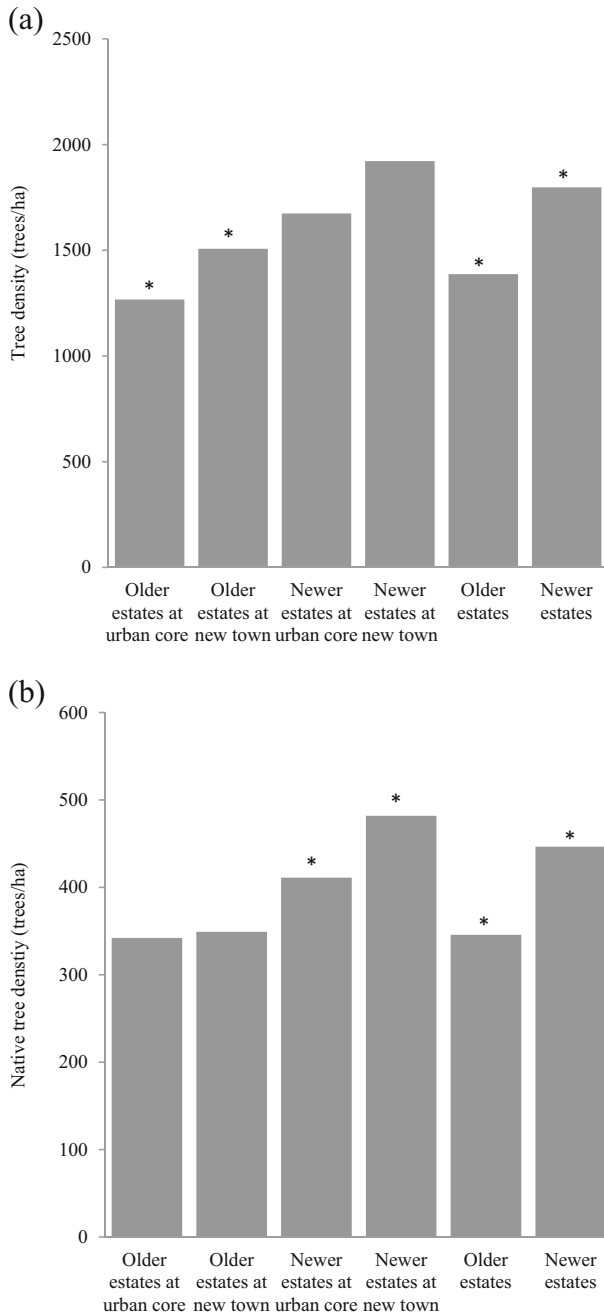
Fig. 3 Total tree density (a) and native tree density (b) of older and newer estates, in urban core or new town in Hong Kong (* Mann–Whitney U-test, $P<0.05$)

differences were found between older estates and newer estates, both in urban core or new town (Table 3).

Table 3 Comparison of species richness, Shannon index (H′) and evenness index (J′) of tree species communities between older and newer estates, respectively in urban core or new town in Hong Kong

Species diversity index	Older estates[a]		Newer estates		All estates	
	Urban core (n=26)	New town (n=22)	Urban core (n=27)	New town (n=27)	Older estates (n=48)	Newer estates (n=54)
Species richness	34.85*	45.09*	42.11	40.33	39.97	41.22
Native species richness	10.04	12.41	11.74	10.89	11.13	11.31
Shannon index (H′)	2.82	2.97	2.98	2.92	2.89	2.95
Evenness index (J′)	0.82	0.79	0.81	0.81	0.81	0.81

[a] * Mann–Whitney U-test, P<0.05

Differentiation in species composition

MRPP results showed significant differences in species composition between older estates and newer estates (T=−7.224, A=0.011, P<0.001) (Table 4). For older estates, the species composition in urban core differed significantly from new town (T=−3.575, A=0.013, P<0.001). For newer estates, however, no significant difference was detected in species composition between urban core and new town (T=−0.729, A=0.002, P=0.204). At both urban core and new town, the differences between older and newer estates were also significant (P<0.001). Greater negative values of test statistic (T) denoted wider separation between the two groups, indicating marked differences in species composition between older and newer estates (T=−7.224). The older and newer estates in urban core had the second widest separation in species composition (T=−5.727).

The top 65 species are listed by tree frequency in Table 5. They contributed 93.02 % of the trees in 102 estates. They accounted for respectively 39.13 and 53.89 % of the total trees in older and newer estates. *Acacia confusa* with 9.99 % relative abundance was the most abundant in both older and newer estates. The next four species, i.e., *Dypsis lutescens*, *Aleurites moluccana*, *Ficus microcarpa*, and *Livistona chinensis*, had 5–8 % relative abundance. Nineteen species had 1–5 % relative abundance, and 15 species had 0.5–1 %. The remaining 26 species had less 0.5 % relative abundance.

Mann–Whitney U-test showed 22 species had significant differences in relative abundance between older and newer estates (Table 5). Four species, *Aleurites moluccana*, *Bauhinia variegate*, *Erythrina variegata* and *Ficus elastica*, had descending adoption trend from older estates to newer estates. The remaining 18 species had ascending adoption trend. For older

Table 4 Test statistic (T) and chance-corrected within-group agreement (A) between estate groups based on tree species composition by multi-response permutation procedures (MRPP) analysis

	Older estates at urban core vs. Older estates at new town	Older estates at urban core vs. Newer estates at urban core	Older estates at new town vs. Newer estates at new town	Newer estates at urban core vs. Newer estates at new town	Older estates vs. Newer estates
T	−3.575	−5.727	−3.375	−0.729	−7.224
A	0.013	0.017	0.012	0.002	0.011
P	<0.001	<0.001	<0.001	0.204	<0.001

Table 5 The relative abundance (%) of the top 65 dominant species reckoned by tree frequency between older and newer estates, respectively in urban core or new town in Hong Kong (chosen out of 232 species), arranged in descending order of relative abundance across all sites

Species[a]	Older estates[b]		Newer estates		All estates	
	Urban core	New town	Urban core	New town	Older estates	Newer estates
Acacia confusa	1.33	3.56	2.60	2.50	4.89	5.10
Dypsis lutescens	0.91*	1.87*	2.44	2.47	2.78*	4.91*
Aleurites moluccana	1.49	2.25	0.70	1.16	3.74*	1.85*
Ficus microcarpa#	1.17*	1.40*	1.52	1.48	2.56	3.00
Livistona chinensis	0.91	0.93	1.91	1.41	1.84*	3.32*
Melaleuca cajuputi subsp. cumingiana	0.30*	1.15*	0.71	1.92	1.44*	2.62*
Bauhinia 'Blakeana' #	0.31*	1.43*	1.11	1.01	1.74	2.12
Delonix regia	0.57*	1.04*	0.69	0.94	1.61	1.64
Macaranga tanarius var. tomentosa#	0.87	0.59	0.91	0.70	1.47	1.61
Leucaena leucocephala	0.51	0.74	0.67	0.49	1.25	1.16
Rhus succedanea#	0.17*	0.44*	0.70	1.08	0.61*	1.78*
Bauhinia variegata	0.28*	1.35*	0.22	0.41	1.63*	0.63*
Ficus benjamina	0.21	0.28	0.73	1.01	0.49*	1.74*
Caryota mitis	0.11*	0.40*	0.99	0.69	0.51*	1.68*
Archontophoenix alexandrae	0.32*	0.40*	0.43	0.95	0.72*	1.38*
Bombax ceiba	0.40*	0.80*	0.52	0.35	1.19	0.87
Ficus virens#	0.15*	0.41*	0.47	0.62	0.55*	1.09*
Bauhinia purpurea	0.21	0.56	0.29	0.34	0.76	0.63
Celtis sinensis#	0.35	0.33	0.28	0.37	0.68	0.65
Casuarina equisetifolia	0.30	0.25	0.15	0.59	0.54	0.74
Senna alata	0.22	0.09	0.39	0.46	0.31*	0.85*
Cinnamomum burmanii#	0.06	0.14	0.31	0.61	0.20*	0.92*
Erythrina variegata	0.24	0.36	0.28	0.21	0.60*	0.49*
Araucaria heterophylla	0.23	0.20	0.17	0.39	0.43	0.57
Lagerstroemia speciosa	0.08	0.11	0.53	0.25	0.19*	0.78*
Plumeria obtusa	0.04	0.10	0.52	0.29	0.14*	0.82*
Ficus elastica	0.21*	0.33*	0.24	0.10	0.54*	0.35*
Cinnamomum camphora#	0.25	0.13	0.28	0.16	0.38	0.44
Acacia auriculiformis	0.02	0.10	0.48	0.21	0.12*	0.69*
Hibiscus tiliaceus#	0.10*	0.14*	0.29	0.26	0.24	0.55
Thespesia populnea#	0.06*	0.30*	0.13	0.29	0.36	0.42
Michelia x alba	0.13	0.16	0.26	0.23	0.29	0.48
Ficus rumphii	0.06	0.21	0.13	0.37	0.26	0.50
Senna surattensis	0.12	0.25	0.19	0.19	0.37	0.39
Albizia lebbeck	0.07*	0.34*	0.15	0.18	0.41	0.33
Melia azedarach	0.09	0.07	0.31	0.10	0.16	0.41
Phoenix roebelennii	0.09	0.14	0.13	0.19	0.22	0.32
Peltophorum pterocarpum	0.08	0.17	0.13	0.15	0.25	0.28
Callistemon viminalis	0.06	0.03	0.17	0.26	0.09*	0.43*
Elaeocarpus hainanensis	0.01	0.02	0.27	0.19	0.03*	0.46*

Table 5 (continued)

Species[a]	Older estates[b]		Newer estates		All estates	
	Urban core	New town	Urban core	New town	Older estates	Newer estates
Syzygium cumini	0.04	0.02	0.31	0.11	0.06	0.42
Acacia mangium	0.05	0.01	0.24	0.14	0.07*	0.38*
Liquidambar formosana#	0.04	0.09	0.16	0.16	0.12	0.32
Grevillea robusta	0.12	0.09	0.06	0.16	0.22	0.22
Crateva unilocularis	0.13	0.02	0.05	0.22	0.15	0.27
Terminalia arjuna	0.14	0.05	0.14	0.07	0.19	0.21
Eucalyptus robusta	0.03	0.06	0.21	0.05	0.10	0.26
Swietenia mahagoni	0.01	0.04	0.11	0.16	0.05	0.26
Bischofia javanica#	0.04	0.07	0.05	0.15	0.11	0.19
Polyscias balfouriana	0.01	0.05	0.09	0.14	0.06	0.23
Araucaria cunninghamii	0.02	0.02	0.19	0.06	0.04*	0.25*
Senna spectabilis	0.05	0.05	0.10	0.08	0.09	0.18
Eucalyptus tereticornis	0.02	0.01	0.22	0.00	0.03	0.22
Eucalyptus citriodora	0.08	0.04	0.08	0.05	0.11	0.14
Dimocarpus longan	0.07	0.09	0.05	0.04	0.16	0.09
Caryota maxima	0.03*	0.10*	0.08	0.03	0.13	0.11
Plumeria rubra	0.06	0.05	0.06	0.07	0.11	0.13
Ficus hispida#	0.07	0.01	0.09	0.06	0.08	0.15
Mangifera indica	0.05	0.02	0.08	0.07	0.08	0.15
Litsea glutinosa#	0.07	0.06	0.06	0.02	0.14	0.08
Schefflera actinophylla	0.03	0.04	0.09	0.06	0.07	0.15
Hyophorbe lagenicaulis	0.08	0.04	0.02*	0.08*	0.12	0.10
Ficus religiosa	0.04	0.00	0.09	0.08	0.04*	0.17*
Ficus altissima	0.07	0.00	0.04	0.10	0.07	0.14
Morus alba#	0.10	0.04	0.05	0.02	0.13	0.07
Total	14.52	24.61	26.12	27.77	39.13	53.89

[a] # denotes native species

[b] * Mann–Whitney *U*-test, $P < 0.05$

estates, significant differences in relative abundance were found in 16 species with ascending adoption trend. However, only one species in newer estates had significant difference in relative abundance between urban core and new town.

Responses of species composition to estate factors

NMDS results showed that 77 % of the variance in the original species matrix could be explained by a final 2-D ordination space. Spearman's correlation analyses showed estate area, open space area, estate age, Shannon index (H′) at slope and tree pit correlated significantly with both NMDS axes (Table 6). The vectors at the estate scale plotted in the estates ordination graph showed that estate area, open space area, estate population, Shannon index (H′) at planting strip and tree pit, estate age and tree site quality index weighed more than other study

Table 6 Variations in plant species distribution represented by the two axes of the Nonmetric Multidimensional Scaling (NMDS) ordination, and Spearman's correlation between site factors and NMDS axes

	NMDS 1[b]	NMDS 2
Variance represented (R^2)		
Increment R^2	0.48	0.29
Cumulative R^2	0.48	0.77
Correlation with site factors (r_s)[a]		
Estate area	−0.53**	0.21*
Open space area	−0.48**	0.22*
Number of buildings	−0.39**	0.11
Estate age	0.27**	0.47**
Estate absolute elevation	0.09	0.18
Estate relative relief	0.07	0.23*
Estate population	−0.54**	0.08
Shannon index (H′) at container	−0.06	0.22*
Shannon index (H′) at level planting bed	−0.36**	0.12
Shannon index (H′) at planting strip	−0.58**	0.08
Shannon index (H′) at slope	−0.25*	0.24*
Shannon index (H′) at tree pit	−0.43**	0.38**
Tree site quality index	−0.14	−0.46**

[a]Refer to Table 2 for descriptions of site factors
[b]Values are coefficients of Spearman's correlation analysis.
* $P < 0.05$; ** $P < 0.01$

scales (Fig. 4). The joint plot illustrated that estates at the left of the ordination were positively correlated with estate area, open space area, estate population and Shannon index (H′) at planting strip, most of which were in newer estates in both urban core and new town. Many older estates were distributed at the top of the ordination space, and they were positively associated with estate age and Shannon index (H′) at tree pit. Many newer estates at the bottom of the ordination space were positively associated with tree site quality index.

Discussion

Tree provision in public housing estates

The quantity and quality of urban trees in Hong Kong were contingent upon urbanization impacts. Few pre-urbanization trees could be retained in the urban matrix (Jim 2000). The estates were mainly built on two types of land, namely terraced from hillslopes and reclaimed from the sea. Both types incurred drastically disturbance with unfavorable initial habitat conditions for plant growth, such as soil and microclimate (Craul 1992; Jim 1993, 2000). Tree planting in estates tended to adopt a 'clean slate' approach with negligible existing vegetation.

In total, 232 species with 48,823 trees were enumerated, which represented 59.5 % of total tree species in Hong Kong (Zhuang and Corlett 1997; Zhuang et al. 1997; Zhang and Jim 2013). The species count in estates was comparable nominally to urban trees in Guangzhou (254 species) and urban-park trees in Hong Kong (272 species), but higher than urban trees in Taipei (164 species) and roadside trees in Hong Kong (149 species) (Jim 2000; Jim and Liu 2001; Jim and Chen 2008). A surprisingly rich arboreal diversity was found in estates despite
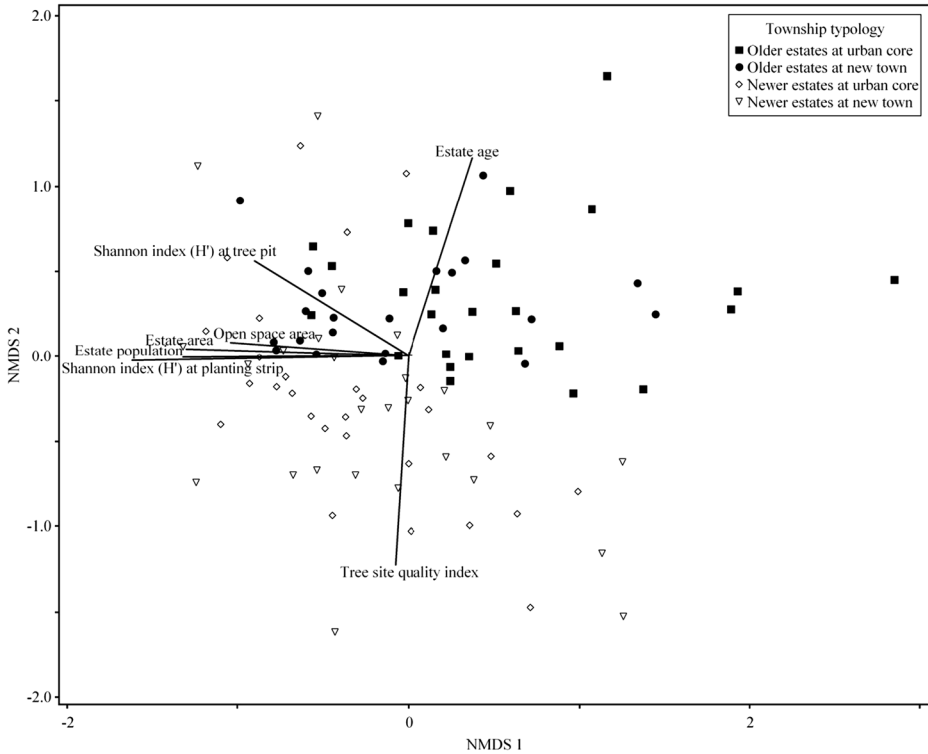
Fig. 4 NMDS ordination for older and newer estates in urban core or new town, and the joint plot of NMDS scores with site factors ($r^2 > 0.2$). The first and second axes represent respectively 48 and 29 % of the total variation

relatively small total land area (total 813 ha), high-density development, and only 60 years of development. A heavy bias towards dominant species was found, with the top 65 species contributing 93 % of the tree stock (Table 5). The occasional and rare species with a small collective frequency included 167 species. Domination by a small number of popular species is also common in North American and European cities (Kunick 1987; Freedman et al. 1996). Regarding geographical origin, some 70.26 % of species and 77.80 % of trees were exotic, indicating limited adoption of native species. The urban forests in Hong Kong and other tropical cities have potentials for species enrichment by enlisting native members (Zhang and Jim 2013).

Tree community structure in different estate groups

Cities are important centers for the import and naturalization of exotic species (Foley et al. 2005; Kareiva et al. 2007). To improve urban habitat conditions and meet aesthetic objectives, exotic species with the fast-growing, stress-tolerant and showy flower characteristics have been widely used in urban horticulture, forestry and landscaping (Reichard and White 2001; Mack and Erneberg 2002; Martin and Stabler 2004; Wittig 2004; Sullivan et al. 2005; Dehnen-Schmutz et al. 2007). Urbanization is regarded as a main cause of biotic homogenization

(McKinney 2006; Olden et al. 2006). Exotic-species proportion in human settlements tends to increase through time (Zerbe et al. 2003; Foley et al. 2005; McKinney 2006, 2008). For example, in the last century, New York City and Massachusetts in USA gained over 200 exotic species (Standley 2003; DeCandido et al. 2004). European and Australian cities experienced increase of over 200 exotic species in the last 120 years (Chocholoušková and Pyšek 2003; Tait et al. 2005). In this study, the species profile skewed pronouncedly towards exotic species and trees.

Newer estates had significantly higher tree density than older ones, suggesting more earnest recent planting efforts. The lack of significant difference in species richness and diversity between older and newer estates indicated persistence of landscaping fashion of planting more species and more exotics throughout the estates landscaping tenure. It tallies with findings that older urban areas could accommodate more diversified tree species than newer ones (Jim 2008; Jim and Zhang 2013). Therefore, the first hypothesis that species richness and diversity are higher in newer than older estates was rejected (Table 7). For older estates, the difference in tree density between urban core and new town was significant; it was not significant for newer estates (Fig. 3). This result indicated that the number of planted tree species was not related to urban development history in newer estates, but was related in older ones. The recent consolidated tree management of estates has contributed to floristic convergence in newer estates.

Some studies found that increasing urbanization could usher replacement of many existing plant species in urban areas by a small number of widespread and aggressive species, leading to the loss of native species (Ricketts and Imhoff 2003; Zerbe et al. 2003; Foley et al. 2005; McKinney 2006, 2008; Olden et al. 2006; Kareiva et al. 2007). Increasing urbanization could suppress the abundance and richness of native species (McKinney 2006), because urban activities could alter the natural selection regime and put native species at a competitive disadvantage (Byers 2002). Detailed comparisons of plant inventories recorded at different times showed that native plant species richness declined between 3 and 46 % in a span of 50–150 years for 13 towns and cities (Bertin 2002; Standley 2003; DeCandido et al. 2004; Tait et al. 2005; McKinney 2006). In this study, native tree density between older and newer estates was significantly different. However, no significant difference in native species richness between older and newer estates was found. The results indicated that tree managers of newer estates have planted more native trees but not more native species. Hence, the second hypothesis that native species richness is higher in newer than older estates was rejected (Table 7).

In south China, many species have been widely adopted and tested in real-world urban habitats for decades to form a shared species pool (Zhang and Jim 2013). Local urban foresters have adhered to the inertia of choosing species from a familiar cohort rather than venturing into less-known native species (Jim 2000; Zhang and Chu 2011, 2013; Zhang et al. 2013). The somewhat aberrant behavior could be attributed to the lack of knowledge or awareness of alternative native species, and their inadequate supply in the regional landscape market which remains largely supply-led rather than demand-guided. This study found significant differences in species composition between older and newer estates, and between urban core and new town for older estates (Table 4), which supported the third hypothesis. However, no significant difference was found between urban core and new town for newer estates, which indicated that species selection by urban foresters was confined to a familiar shared species pool. Favored species tended to be widely and persistently planted in many settlements (Mack and Lonsdale 2001).

Only 22 dominant species had significant differences in relative abundance between older and newer estates, in which 18 species had ascending adoption trend and 4 species had descending trend (Table 5). The remaining 43 dominant species were evenly adopted in older

Table 7 Explanations of six hypotheses tested in this study, and the associated testing methods and results

	Hypothesis	Method for testing hypothesis	Results
Effects of urbanization on tree communities in public estates			
1	Species richness and diversity are higher in newer than older estates	Comparison of species richness and diversity by significance tests	No significant differences found; hypothesis is rejected
2	Native species richness is higher in newer than older estates	Comparison of native species richness by significance tests	No significant differences found; hypothesis is rejected
3	Species composition is different between older and newer estates	Comparison of species composition using Multi-response Permutation Procedures	Hypothesis is supported
Relationship between site factors and species distribution			
4	Estate scales, such as estate area, open space area, estate age and residents population, affect species distribution	Analyses of response of species communities to site factors in older estates and newer estates using Nonmetric Multidimensional Scaling	Hypothesis is supported
5	Landform scales, such as estate absolute elevation and relative relief, affect species distribution	Analyses of response of species communities to site factors in older estates and newer estates using Nonmetric Multidimensional Scaling	No significant differences found; hypothesis is rejected
6	Habitat scales, such as tree site quality index, affect species distribution	Analyses of response of species communities to site factors in older estates and newer estates using Nonmetric Multidimensional Scaling	Hypothesis is supported

and newer estates with little changes through time. This result further indicated that these 43 species were the main shared species repertoire in the estates. After 60 years of cultivation and field trial, some trees in the estates are mature enough to judge their performance in different habitats to yield practical hints on species selection. However, little attempt has been made to optimize the match between species ecological characteristics and site conditions. In-depth assessment of growth performance of 65 dominant species could refine species selection to better match site conditions.

Responses of tree community structure to site factors

City-level landscapes and land uses have notable differences in physical and ecological conditions to generate the finely mixed and small-scale habitat mosaic in urban areas (Pyšek 1998; Müller and Werner 2010). Understanding species composition variations by landscape and habitat types could explain responses of urban flora to diverse site conditions. Some recent studies investigated the connection between urban form and biological diversity, and found that urban morphology can determine the distribution and abundance of species (Tratalos et al. 2007; Werner 2007). In this study, tree communities in older and newer estates were notably associated with estate-scale attributes, such as estate area, open space area, estate age and resident population. Therefore, the fourth hypothesis was supported (Table 7).

Some studies found species-area relationship in urban habitats, suggesting that site area is an important determinant of species richness and diversity in urban areas (Angold et al. 2006). In this study, the increase in estate area and open space area provided more rooms and opportunities to realize an innate proclivity to adopt more species. Open space shortage was particularly acute in the study area. The compact urban form did not permit most estates to accommodate a large number of trees. The open spaces had to compete with non-green uses requiring paving or exclusion of trees. Open space area was more inadequate in older estates, both in urban core and new town.

A positive correlation usually exists between habitat age and species diversity (Werner and Zahner 2010). In this study, the changing species preference over the years had been applied rather uniformly to estates in urban core and new town. The centralized administration of estates including tree matters would have contributed to this convergence. The change in species composition with estate age reflected changing species preference or fashion. The landform-scale factors did not have effect on the differences in species composition between older and newer estates. Therefore, the fifth hypothesis was rejected (Table 7).

The structural diversity of urban habitats has been regarded as a good predictor of biological diversity (Whitford et al. 2001). Small-scale structures have been recognized as important for habitat quality (Byrne 2007). In this study, strong association of tree-site quality index with NMDS axes was found. Hence, the sixth hypothesis that the habitat-scale factors affect species distribution was supported (Table 7).

Compared with container and tree pit, more spacious planting strip, level planting bed and slope have relatively less physical and physiological constraints. They provide better growth space in terms of open (unsealed) soil, large soil volume, and good soil quality. Therefore, these habitats accommodate more trees in the estates. This study found positive correlation between Shannon index (H′) at planting strip with species composition in newer estates, and between Shannon index (H′) at tree pit with species composition in older estates. The results indicate that providing high-quality habitat is crucial to urban-forest planning.

Management implications and conclusion

Urban biodiversity to a notable extent is determined by planning, design and management of the urban environment, and influenced by economic, social and cultural values and dynamics of the human population (Wu et al. 2011). The patterns of urban development and their landscape characteristics could affect the composition of urban vegetation, resulting in different plant communities and varied diversities (Walker et al. 2009). The excessively high-density urban development mode in Hong Kong has greatly altered the original habitats and circumscribed the development tree communities. The city core, urbanized since the 1840s, is filled with high-rise buildings and dense road networks with meager interstitial open spaces. New towns have relatively lower population and building density, and more plantable spaces, greenery and remnant forest patches. Due to basic differences in development age, density, town plan and pre-urbanization land cover, urban core and new towns have different landscape, habitat and floristic ingredients. The variations in the mode of urbanization have resulted in dissimilar urban forms with different opportunities and constraints for arboreal vegetation.

In urban areas with varied development modes, differences in species composition echoed the diverse impacts of urbanization, although the differences in species richness and diversity were not notable. It is necessary to treat the tree-habitat-forest as a continuum, as an integrated system for rational management. The key insight provided by biotic homogenization findings is preservation and restoration of native species biodiversity. In Hong Kong, the tree community in public housing estates is dominated by exotic species, indicating chronic and widespread neglect of native species. The estates inherited few native trees from the pre-urbanization landscape, and subsequently received few planted native trees after development. To reinforce the appreciation of native species and increase potential planting sites especially in older estates, landscape designers and policy makers could move away from entrenched thinking and practices and add a new dimension to the urban-forest program. Further tree selection and enrichment in urban habitats could gradually dilute the excessive reliance on exotic species by adopting more suitable native species (Zhang and Jim 2013).

With rapid urban development, the livable-city imperative has yielded to relentless development pressures, which have imposed physical and institutional constraints on urban trees. The availability of growth spaces both above and below the ground is critical in nurturing healthy and unobstructed tree growth. It also permits planting of species with large final dimensions to bestow more environmental and landscape benefits. Based on the results, increasing the area of open space and provision of more spacious habitats such as planting strip, level planting beds and slopes with open soil in the estates could facilitate diversified tree species adoption. The effect of tree-site quality index verifies that a site free from physiological stresses and physical constraints could notably benefit tree growth. The need to provide high-quality planting sites constitutes a crucial link in urban-forest planning. Moreover, open spaces at the ground level in the estates could offer proximal and easily accessible outdoor recreational grounds to residents, to promote more salubrious encounters with surrogates of nature in a safe and pleasant ambience.

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