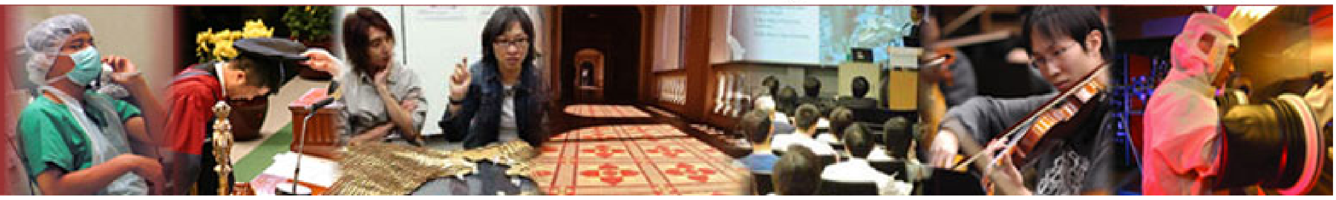

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Original article

Heterogeneity and differentiation of the tree flora in three major land uses in Guangzhou City, China

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Abstract – The tree flora of humid-tropical Guangzhou city in south China was studied to understand its composition and variations. Aerial photographs identified three major urban-forest types in three land uses: institutional, park and roadside. Data on 115 064 trees in 246 species were statistically analyzed. Park and roadside areas have lower species richness than institutional forest. Park habitat has relatively more rooms for species, biomass and floral enrichment. Roadside leads in tree density with full utilization of plantable space, whereas institutional forest has the highest species density index and the most rare natives. Commonality of species amongst forests limits to 91 species, with park and institutional sharing 68 species, and road sharing merely 8 and 1 species respectively with institutional and park. Institutional forest has distinct composition and character, with less domination by popular species and more solitary or rare species. Native species exceed exotics at roadside; institutional and park have a reverse trend. Practical implications for urban-forest management are discussed.

urban forest / urban tree / species diversity / species association / tree management

Résumé – Hétérogénéité et différenciation de la flore arborée dans trois principaux types d'occupation des sols dans la ville de Guangzhou, Chine. La flore arborée de la ville de Guangzhou du sud de la Chine, caractérisée par un climat tropical humide, a été étudiée dans le but de comprendre sa composition et ses variations. Les photographies aériennes ont permis d'identifier trois types majeurs de forêts urbaines dans trois types d'occupation des sols : institutionnel, parc et bord de route. Les données sur 115 064 arbres de 246 espèces ont été analysées statistiquement. Les aires de parcs et de bords de route sont moins riches en espèces que ne le sont les forêts institutionnelles. L'habitat des parcs laisse plus de place à un enrichissement en espèces, biomasse et flore. Le bord de route conduit à une densité d'arbres utilisant pleinement les espaces plantables, alors que la forêt institutionnelle a l'index de densité d'espèces le plus élevé et le plus d'espèces autochtones rares. Dans la forêt, les espèces courantes se limitent au nombre de 91, dont 68 communes aux parcs et aux forêts institutionnelles, les bords de route n'ayant en commun que 8 et 1 espèces, respectivement, avec les forêts institutionnelles et les parcs. La forêt institutionnelle présente une composition et un caractère spécifiques, avec une prédominance moindre des espèces de peuplier et d'avantage d'espèces solitaires ou rares. Les espèces autochtones sont plus nombreuses que les espèces exotiques le long des routes tandis que la tendance inverse est observée pour les parcs. Les implications pratiques pour l'aménagement des forêts urbaines sont discutées.

forêt urbaine / arbre urbain / diversité des espèces / association d'espèces / aménagement des arbres

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1. INTRODUCTION

Vegetation in cities usually differs greatly from undisturbed natural areas. The varied urban flora (synanthrophytes) contains a complex mixture of plants [32], including natives in natural habitats, natives in modified habitats (apophytes), aliens naturalized in natural habitats (agriophytes), and aliens naturalized in modified habitats (epoecophytes). The aliens that arrived before 1500 (archeophytes) are differentiated from those reaching afterwards (neophytes). The early arrivals are adapted mainly to agricultural habitats, whereas recent ones exploit principally urbanized sites. Whether native or alien, urban plants could spontaneously colonize a site (ruderals or adventives), or be planted (cultivated). For the same area, it is well known that cities accommodate more species than the natural countryside [6, 33]. The heterogeneity of urban conditions, from natural to semi-natural to artificial types, furnishes a broad range of conditions to suit different species requirements. The resultant spectrum of species alliances has been expressed through the encompassing hemeroby concept [17].

The unique species assemblages are studied from the temporal, spatial and ecological dimensions. Species richness (total number of species) tends to increase with the area and population size of urban settlements [16]. Within a city, heterogeneous land-use zones and development history [23] have engendered a diverse intra-urban species pattern. Urban complex stresses [27] affect plants in different ways, causing declines in some but enhancements in others. Whereas the growth of some natives is dampened and overall indigenous composition pauperized to different degrees, ample opportunities exist for alien introduction via intentional and unintentional means. The alien-to-native ratio increases with city size in European case studies [19], suggesting that big urban agglomerations favour immigration and range expansion of exotics. Moreover, less urban aliens are threatened in comparison with the natives [1], indicating their pre-adaptation and plasticity in coping with the urban milieu.

The determinants of species composition have been evaluated as within-site alpha diversity, between-site beta diversity, and to a lesser extent between-geographical-area gamma diversity. A combination of natural, semi-natural and artificial factors, biotic and abiotic, extending from the past to the present, has helped to decipher the botanical complexities. The continued existence of resident natives, and the survival of alien immigrants, depend on dynamic interplays amongst the contributing factors [36]. The accompanied actions and reactions entail a fluid reassortment process that characteristizes the changing flora of cities. An understanding of urban floristic can throw light on the complex phenomenon and help urban vegetation management.

Some researches cover the broad range of plant growth forms, including vascular as well as non-vascular members (summarized in [1, 6, 33]). Others concentrate on a particular growth form, such as woody vegetation, or just on trees. Urban forestry has been developed as a branch of knowledge that deals with tree growth, characteristics, ecology and management in cities [2, 5]. Whereas plant species in temperate cities runs into hundreds, that in tropical cities amounts to thousands. Consequently, a single study that includes the complete gamut of plants in tropical cities is uncommon. This project evaluates the species composition and diversity of the tree flora in a humid-tropical city of Guangzhou in South China. It attempts to assess the heterogeneity of tree species in three major habitats, namely institutional grounds, urban parks, and roadsides.

2. STUDY AREA AND METHODS

The study focuses on the central built-up areas of Guangzhou, the capital of the South China Guangdong Province [15]. It accommodates a population of 3.6 million in 116 km^2 of land. Five districts covering a total of 56.9 km^2, encompassing most of the built-up areas and 59% population, formed the study area. The chosen districts represent a range of development history, land use patterns, urban morphology, and landscape types. In 2900 years of urban growth, Guangzhou has nurtured a greening tradition initiated in private gardens from 100 BC [39]. Thereafter, the planting culture gradually spread to other parts of the city, culminating by AD 300 with half of the land covered by green-landscape enclaves. Temple grounds and related religious pockets, in particular, harbour many of the city’s rare, unusual and exotic species. Some native tree species have been adopted for amenity use over 2000 years ago, serving as principal amenity plants. Outside private lots, however, there were little communal trees until 1910s when the new republican government then (after toppling the imperial Qing Dynasty) began to set up public parks and introduce greenery into roadside niches in the European tree-planting tradition [22]. Since 1970s, the city has experienced rapid expansion and redevelopment.

A reconnaissance of the urban-tree cover in Guangzhou was made by monochrome vertical aerial photographs at 1:10 000 scale. The aerial-survey findings formed a basis to demarcate the urban forest into three major types with reference to land use and location, namely institutional, park and roadside. A stratified sampling strategy was designed based on this subdivision. The study area has 21 urban parks covering 370.7 ha, large institutional grounds (each over 1 ha) covering 580 ha, and 110 ha of roadside amenity area covered by trees [8]. All trees in urban parks and roadsides were censused, whereas 14 large institutional grounds covering a total of 226.4 ha (denoting a 39.0% sampling intensity in terms of area) were selected for evaluation to represent the main types of large institutional grounds in the city. All trees in the samples areas have their species identified with the help of treatises on local and regional flora [9, 12].

Data analysis was aided by Microsoft Excel 2000 and SPSS/PC 9.0. The Shannon-Wiener, Simpson, Maximum equitability and Equitability species indices were calculated using standard formulae [7, 18, 25] listed in the footnote of *table I*. Shannon-Wiener and Simpson diversity indices are derived from the aggregation of relative proportions of individual species, and they provide a synoptic summary of the diversity of species in a given flora. Maximum equitability is derived directly from species richness. Equitability is a ratio between Shannon-Wiener and Maximum equitability indices to depict the relationship between species diversity and richness, and a high value denotes that the constituent species are more evenly represented. Four indices were calculated in an attempt to assess their differences in detecting species heterogeneity in the urban-forest context. The chi-square test yielding Cramer's V statistic, and the Spearman's Rank Correlation, were adopted to evaluate statistical association between categorical and ranked attributes respectively.

3. RESULTS AND DISCUSSION

3.1. Tree abundance and species richness

A total of 115 064 trees were evaluated, represented by 246 species from 64 families (*table I*). As park and roadside trees were censused, whereas institutional trees were sampled, the latter tree population upon extrapolation could reach 61 172 trees, which makes it the most abundant group amongst the forest types. The inclusion of extrapolation will raise the study area's tree population to 152 379 trees. The tree frequency at roadside forest exceeds that of park by a small margin.

By quantity and variability, the study area has a substantial tree stock well distributed in different land uses and locations. Despite the high development density and a cramped city ambience, plantable sites are generally available and quite fully utilized. Planting niches have been exhausted in tightly-packed old districts (Yuexiu, Liwan and Dongshan), with little potential for additional greenery. Furthermore, existing trees there are threatened by massive redevelopment and infrastructural projects. Recently developed districts (Haizhu and Tianhe), however, have a more spacious town plan with wider roads and larger land lots for future increase in tree cover. The land ownership pattern has a bearing on species selection and planting. All lands in mainland China are owned by the state, not by private citizens. Land is allocated to, used and managed by government and public institutions. A municipal authority looks after greenery in public areas, including public parks, gardens and roadsides. Vegetation in institutional grounds exists under different personnel and regime, managed by the land users who have been entrusted to take care of landscaping.

For an area of 5519 ha, species richness at 246 in the study area is high comparing with temperate-latitude cities (e.g. [20, 27, 37]). Institutional grounds harbour the largest cohort of species, followed by park and roadside. Compared to nearby Hong Kong with a similar humid-tropical climate and tight urban morphology, and with 149 roadside and 271 park tree species [14], the tree diversity of Guangzhou is slightly lower. A large repertoire of tropical species is available for adoption, including natives largely confined to Guangzhou and nearby cities, and an exotic pool shared by tropical cities [13]. The hot-humid summer and cool-dry winter are ideal for continuous plant growth. The occasional typhoon onslaught, however, imposes a destructive element [15]. Recent air-quality deterioration is an additional stress. The natural climax vegetation, semi-evergreen tropical forest, has high diversity dominated by Lauraceae, Moraceae and Caesalpinaceae. They furnish a solid foundation to establish a varied tree population, the potential of which has been realized to different degrees in the forest types. The long and continuous urban history and regular contacts with other cultures, have provided opportunities and impetus to admit alien species. The long history of urban-forestry practice has accumulated experience in planting and care of a large species pool.

Whereas species selection in public lands of roadside and park is concentrated in government landscape agents, that in institutional grounds is dispersed amongst many land users. The centralized decision-making managers provide a fair range of species in park and roadside, but the magnitude of variations pales before the collective-multiple efforts of institutional managers. The latter is analogous to the verified hypothesis that disparate ensembles of species are selected by individual property owners in other countries [31]. That park forest has less species than institutional grounds is somewhat unexpected, for the open and genial habitats should accommodate a varied tree flora. The habitat heterogeneity and favourableness factors [3] have not been fully utilized, despite the occurrence of inherited woodland which could augment species richness. Whereas urban nature provides ample opportunities in park, urban culture has not been able to fully exploit them. On the other hand, the lower diversity in cramped and stressful roadside falls within expectation. In institutional forest, Zhongshan University campus is a treasure trove of plant endowment. With a lineage of over a century and continual floristic enrichment by generations of local and overseas botany academics, the grounds contain a surprising range of exotic species from nearby and distant lands.

3.2. Species density and diversity

For the whole study area, a small number of popular species dominates the tree population, with the remainder making limited contributions (*table IV*). The top 5 species account for one quarter of the trees, top 13 for half, and top 30 for three quarters. Some 73 species have less than 10 individuals each, and 20 species have solitary existence. High-ranking species are not equally represented in the forest types. Domination by popular species is extreme at roadside where the top 6 species reach the 50% mark; the same threshold is attained by 8 species in institutional and 14 species in park. The most abundant species, *Ficus virens* (Moraceae), has 9146 trees mainly at roadside (taking up 17.2%). Park forest has the largest number of species with high frequency (> 999) (*table II*); institutional has the least. All three forests have a large proportion of species with low frequencies (< 100), with institutional (82.2%) leading by a wide margin. Regarding species with solitary specimens, again institutional has the most (30). Overall, institutional forest has relatively subdued domination by popular species and a more even representation by many uncommon to rare ones. It can be hypothesized that multiple decisions on species selection in a varied habitat have enriched the species composition. Park and roadside forests have similar frequency distributions that are pronouncedly skewed towards the popular species. Fewer decision-makers who are officials in these two forests, and restrictive habitat conditions, tend to favour heavy planting of popular species. The tree management system [30] has taken precedence over natural and habitat factor in determining forest composition.

The institutional and park forests occupy more land than roadside, but a good proportion is devoted to non-tree uses. There is acute contest for space in institutional grounds between trees and artificial structures-cum-surfaces. In park forest, the management has assigned considerable areas to recreational and other non-tree covers. Roadside amenity strips and associated sites, on the contrary, have been heavily filled by trees. The highly confined roadside space cries out for maximum amelioration by greenery. Tree density results echo the interactions between site potentials and limitations (*table I*). The dense roadside forest at 426.6 trees/ha exceeds those of institutional and park by nearly three orders of magnitude. For roads with trees, the density at 196.2 trees/km, with trees normally on both sides, is equivalent to 1 tree/10 m. This is a heavy stocking rate by any yardstick [28], considering that roadside trees are strongly represented by *Ficus* species with large final dimensions. The compact urban morphology limits the potential to increase roadside trees, which may find relief in new development areas with a more porous built form. For institution and park, the stocking rate is about 90 m^2/tree. Much scope exists to increase tree density in park, whereas in institutional characterized by dispersed and confined interstitial plantable space, such potential is limited.

Species stocking rate, denoted by species density indices (*table I*), provides another perspective on arboreal diversity. On the basis of both tree frequency (N) and area (A), institutional forest takes a clear lead, followed by park and roadside. The sequence is in reverse order of tree density discussed above. Thus institutional forest has less trees per unit area but a more varied tree flora. The converse is true for roadside. Park occupies an intermediate position. Site restrictions in institutional lots may have stifled tree quantity, but amends have been made by a diversified species assemblage. The difficulties encountered at roadside sites are echoed by the subdued species density. The case for park is somewhat disappointing in view of its generally genial and open habitat conditions, and its purported objective of serving as a repository and showcase for floristic assortment.

Species diversity indices have been calculated to depict relativity amongst forest types (*table I*). The more elaborate Shannon-Wierner and Simpson functions [7] suggest that park forest is more diversified. Both indices for the three forest types, however, fall within limited ranges. In institutional forest, more species with solitary specimen and low frequency, and the rather uneven frequency distribution (*table II*), has engendered lower indices which include the equitability component. Uneven frequency distribution and low species count has also brought down roadside values. The equitability indices (E) [18] furnish collaborative support to the more even spread of park species. The maximum equitability value (H_{max}) ranks institutional forest first, followed by park and roadside, that is the same sequence as the species density indices. There is divergence in planting practice, with park more prone to multiple planting of both common and uncommon species.

3.3. Species commonality and uniqueness

Whereas some species are shared amongst two or three forest types, others are unique to one (*tables III and IV*). A

Table I. Basic and derived quantitative attributes of the three urban forest types in Guangzhou.

Quantitative attributes	Institutional	Park	Roadside	Whole study area
Basic statistics:				
Tree frequency, N	23 857	44 277	46 930	11 5064
Tree frequency, N_x (extrapolated) [a]	61 172			15 2379
Species richness, S	213	175	117	246
Area, A (ha)	226.4	370.7	110.0	707.1
Road length, L (km)			239.20	
Tree statistics:				
Native tree,%	47.8	44.0	62.1	56.9
Tree density (area), N/A (tree/ha)	105.4	119.4	426.6	162.7
Tree density(road length), N/L (tree/km)			196.2	
Species indices:				
Native species,%	44.2	47.2	53.3	52.0
Species density (tree frequency), $S/\log_{10} N$	48.66	37.67	25.05	48.61
Species density (area), $S/\log_{10} A$	90.45	68.12	57.31	86.33
Species density (road length), $S/\log_{10} L$			49.19	
Species indices [b]:				
Shannon-Wiener diversity, H	5.46	5.80	4.68	5.87
Simpson diversity, D	0.95	0.97	0.93	0.97
Maxmum equitability, H_{max}	7.73	7.45	6.87	7.94
Equitability, E	0.71	0.78	0.68	0.74

[a] Since 39.0 per cent of institutional land area was sampled (whereas park and roadside trees were censused), the institutional tree population could be extrapolated by (23 857/39) × 100 = 61 172 trees.
The tree frequency for the whole study area has been adjusted accordingly to 152 379 trees.

[b] Formulae (p_i refers to the proportion that an individual species occupies in the sample):
Shannon-Wiener diversity, $H = -\Sigma p_i \log_2 p_i$
Simpson diversity, $D = \Sigma p_i^2$
Maximum equitability, $H_{max} = \log_2 S$
Equitability, $E = H/H_{max}$.

Table II. Tree frequencies of individual species in the three urban forest types, and their statistical associations.

Frequency class	Tree count / species	Institutional	Park	Roadside
Tree frequency in each species:				
0	nil	33	71	129
1	1	30	10	13
2	2 to 9	55	47	20
3	10 to 49	65	36	23
4	50 to 100	22	20	17
5	100 to 249	15	19	19
6	250 to 499	16	14	9
7	500 to 999	5	14	4
8	> 999	5	15	12
Total (all classes)		246	246	246
Total (except class 0)		213	175	117

	Institutional	Park	Roadside
Spearman's rank correlation rho:			
Institutional	1.00		
Park	0.69***	1.00	
Roadside	0.43***	0.25**	1.00

** Significance level < 0.05.
*** Significance level < 0.001.

subset of 91 out of the total 246 species is found in all three types, denoting that divergence in species choice has circumscribed the ubiquitous group. For the paired group, it is notable that the institutional-park couple shares a considerable pool of species (68), vis-à-vis the restricted sharing in the institutional-roadside (8) and park-roadside (1 only) pairs (*table V*). Each forest type carries some unique species, with institutional having the most (46 species), and park (15) and roadside (17) much less.

The ubiquitous group collectively contributes 103 266 trees, that is 89.7% of the sampled trees in the study area (*table V*). The proportion of roadside trees in this category attains 94.7%, including the five most populous roadside species, *Ficus virens*, *Bauhinia purpurea*, *Aleurites moluccana*, *Bauhinia variegata*, and *Ficus microcarpa*. The two native *Ficus* contain a small element of apophytes; the other species are cultivated. Only four of the 46 top-ranking species (with tree frequency 500) are not ubiquitous, the first three of which are restricted to institutional and park: (a) *Bridelia monoica* is a native that often invades ruderal habitats as apophytes; (b) *Celtis sinensis* is a native that is both cultivated and apophyte; (c) *Pinus elliottii* is a cultivated exotic; and (d) *Cleidiocarpon cavalieri* is a native that has recently been adopted widely as a neophyte for roadside planting, but its use has not spread to other habitats. The forest types overall extensively share a common pool of popular species that impart a similar physiognomy and treescape in different sites (*tables VI and VII*).

Only about 10% of the trees make up the remaining paired or unique species, which help to differentiate the forest types or species alliances, with unique ones playing a key role. Whereas most unique members have low frequency (< 100 trees), three recently adopted roadside species (neophytes) stand out, namely the native *Cleidiocarpon cavalieri* mentioned above, exotic *Mangifera persiciformis*, and exotic *Aphanamixis polystachya*. These three species denote that some

Table III. Unique and solitary species in institutional and park forests (roadside forest has none).

Species	Family
(a) Institutional forest: Native spontaneous	
Acmena acuminatissima	Myrtaceae
Euryodendron excelsum	Theaceae
Pygeum topengii	Rosaceae
Sindora glabra	Caesalpiniaceae
Strychnos umbellata	Loganiaceae
Zanthoxylum avicennae	Rutaceae
Ziziphus mauritiana	Rhamnaceae
(b) Institutional forest: Exotic cultivated	
Araucaria cunninghamii	Araucariaceae
Ceiba pentandra	Bombacaceae
Eucalyptus seeana	Myrtaceae
Hevea brasiliensis	Euphorbiaceae
Koelreuteria paniculata	Sapindaceae
Tamarindus indica	Caesalpiniaceae
Terminalia hainanensis	Combretaceae
(c) Park forest: Native spontaneous	
Duranta repens	Verbenaceae
(d) Park forest: Exotic cultivated	
Ulmus pumila	Ulmaceae
(e) Roadside forest: Native cultivated	
Hibiscus rosa-sinensis	Malvaceae
(f) Roadside forest: Exotic naturalized	
Leucaena glauca	Mimosaceae
(g) Roadside forest: Exotic cultivated	
Platanus acerifolia	Platanaceae
Xanthoceras sorbifolium	Xanthorrhoeaceae

hitherto non-amenity species are being actively selected for landscape planting in the city. Field testing the performance of these live samples should in due course provide useful data to gauge suitability for common use. The four unique roadside species are native cultivated *Hibiscus rosa-sinensis*, common naturalized exotic *Leucaena glauca* widely invading disturbed sites, cultivated exotic *Platanus acerifolia* commonly planted in warm-temperate Chinese cities in provinces north of the study area, and exotic cultivated *Xanthoceras sorbifolium*. For comparison, no unique species in institutional and park forests exceed 100-trees frequency. Some 14 unique institutional species are solitary specimens, including seven natives in natural sites and seven exotics in disturbed or man-made sites (epoecophytes) (*table III*). Two unique solitary species are found in park, namely *Duranta repens* which is a common spontaneous growth in disturbed land, and the cultivated exotic *Ulmus pumila*. Overall, the unique group forms a subset that remains uncommon if not obscure, planted more as curios according to personal whims especially in institutional grounds.

The interplay of habitat conditions and species choice helps to explain the varied species pattern. Overall, institutional forest stands out by harbouring many unique members due to the exercise of free choice. The commonality between institutional and park forests reflects similarity in habitat conditions with open sites relatively free from physical and physiological strains. Different decision-makers given similar habitats to a certain extent tend to choose similar species. The relative want of commonality between roadside versus institution and park denotes wide differences in site conditions for trees, with roadside being for more restrictive as well as serving different functions.

3.4. Native and exotic species

By tree frequency, natives lead the exotics by a 13.8% margin for the whole study area (*table I*). The magnitude of exotic domination is less than neighbouring Hong Kong. Roadside has more natives at 62.1%, with an exotic/native ratio of 0.61. Both institutional and park demonstrate an opposite trend with more exotics than natives (ratios at 1.09 and 1.27 respectively). In terms of species richness, a similar pattern is observed. Parks are often dominated by natives [4], whereas other urban sites are mainly inhabited by exotics. Urban parks in neighbouring Hong Kong are similar to Guangzhou, with a heavy dosage of aliens [14]. The three forest types have different top five ranking species, with only *Livistona chinensis* (Palmae) shared between institutional and park.

In the whole study area, of the top 25 species which collectively contribute 70% of the trees, 15 are exotic taking 39.7% of the trees. The 10 principal natives are listed in *table IV*. The common occurrence of ruderals in cities has been well documented in European cities (e.g. [17, 19]), and they serve to denote the common availability of wild habitats in cities [34]. Overall, there

Table IV. Frequency distribution and ranking of the common native and exotic tree species in the entire study area and the three urban forest types.

		Entire study area			Institutional		Roadside		Park		
Species	Family	Count	%	Rank	Count	Rank	Count	Rank	Count	Rank	Remarks
Ficus virens	Moraceae	9039	7.9	1	305	13	8072	1	662	21	Most common native
Caryota mitis	Arecaceae	6034	5.3	2	4759	1	280	15	995	16	Most common palm
# *Melaleuca leucadendra*	Myrtaceae	6033	5.3	3	2023	2	2678	7	1332	8	Most common exotic
Bauhinia purpurea	Caesalpi-niaceae	4987	4.3	4	68	27	4244	2	675	20	Most common flowering sp.
# *Aleurites moluccana*	Euphorbiaceae	4665	4.1	5	595	8	3485	3	585	23	
Ficus microcarpa	Moraceae	4552	4.0	6	270	17	3286	4	996	15	
Bauhinia variegata	Caesalpiniaceae	3783	3.3	7	250	19	3094	5	439	25	
# *Casuarina equisetifolia*	Casuarinaceae	3602	3.1	8	628	7	2016	9	958	17	
# *Michelia alba*	Magnoliaceae	3312	2.9	9	1071	5	1077	12	1164	13	Most common exotic flowering sp.
Livistona chinensis	Arecaceae	3309	2.9	10	1221	4	375	13	1713	4	
Bombax malabaricum	Bombacaceae	3201	2.8	11	298	14	2253	8	650	22	Emblem tree of Guangzhou City
Chukrasia tabularis	Meliaceae	3198	2.8	12	277	16	2880	6	41	29	
Acacia confusa	Mimosaceae	3058	2.7	13	260	18	247	16	2551	2	
# *Eucalyptus tereticornis*	Myrtaceae	2933	2.6	14	108	25	51	23	2774	1	Most common Australian gum
Pinus massoniana	Pinaceae	2289	2.0	15	135	24	6	25	2148	3	Most common conifer
# *Mangifera indica*	Anacardiaceae	2023	1.8	16	516	9	1260	10	247	27	Most common fruit-tree species
# *Roystonea regia*	Arecaceae	1997	1.7	17	1494	3	82	21	421	26	
Broussonetia papyrifera	Moraceae	1814	1.6	18	297	15	242	17	1275	10	Fugitive-adventitive mainly in park
Cinnamomum burmanii	Lauraceae	1725	1.5	19	175	22	141	19	1409	7	
Bauhinia blakeana	Caesalpi-niaceae	1714	1.5	20	790	6	96	20	828	18	
Celtis sinensis	Ulmaceae	1713	1.5	21	202	20	0	28	1511	6	Fugitive-adventitive mainly in park
Bridelia monoica	Euphorbiaceae	1649	1.4	22	58	28	0	29	1591	5	Fugitive-adventitive mainly in park
# *Syzygium jambos*	Myrtaceae	1512	1.3	23	187	21	1	27	1324	9	
# *Taxodium distichum*	Taxodiaceae	1396	1.2	24	165	23	8	24	1223	11	Most common exotic conifer
# *Araucaria heterophylla*	Araucariaceae	1395	1.2	25	320	12	55	22	1020	14	
# *Eucalyptus maculata*	Myrtaceae	1321	1.2	26	399	10	197	18	725	19	
Ficus hispida	Moraceae	1286	1.1	27	96	26	3	26	1187	12	Fugitive-adventitive mainly in park
# *Acacia auriculiformis*	Mimosaceae	1285	1.1	28	17	29	1177	11	91	28	
Cinnamomum camphora	Lauraceae	1159	1.0	29	376	11	306	14	477	24	
Total [Average]		85984	[2.6]		17360		37612		31012		

Exotic species.

Table V. Species count in the seven species commonality classes.

Species commonality	Species count	Tree frequency			
		Institutional [I]	Park [P]	Roadside [R]	Total
I only	46	317	0	0	317
P only	15	0	219	0	219
R only	17	0	0	1633	1633
I + P	68	2195	6417	0	8612
I + R	8	167	0	806	973
P + R	1	0	2	42	44
I + P + R	91	21178	37639	44449	103266
Total	246	23857	44277	46930	115064

Table VI. Chi-square association[a] amongst the three urban forest types with reference to species count and tree frequency in each botanical family[b].

	Institutional	Park	Roadside
Species count in each family:			
Institutional	1.00		
Park	0.66***	1.00	
Roadside	0.57***	0.67***	1.00
Tree frequency in each family:			
Institutional	1.00		
Park	0.50***	1.00	
Roadside	0.49***	0.48***	1.00

*** Significance level < 0.001.
[a] The Cramer's V statistic is computed.
[b] Refer to *table V* for the class limits.

is domination by shade-foliage species, with limited flowering ones rather monotonously composed of many *Bauhinias*. For the entire study area, the notable popular exotics are given in *table IV*. Unlike some European cities (e.g. [29]), the naturalization of exotic trees in Guangzhou has been limited.

The institutional forest has overwhelming domination by three exotics, including three palms and two broadleaves in its top five (*table IV*). Except *Michelia alba*, these dominants have narrow crown spread, reflecting the prevalence of cramped planting space sandwiched between buildings and at roadside. There is a lack of attractive blossoms and seasonal changes (all five being evergreen). The institutional grounds provide home to 85 rare species (with very low frequency trees), far more than park (57) and roadside (33). Most trees in this group are natives, of which three, namely *Podocarpus imbricatus* (Podocarpaecae), *Sindora glabra* (Caesalpinaceae) and *Toona ciliata* (Meliaceae), are officially listed as endangered [38].

In park forest, the top five species contain a mixture of exotic and native species (*table IV*). Except *Livistona chinensis*, these species are either planted or spontaneous invasion in woodlands on hillslopes of parks, and they play a collective landscape-ecological role that differ from other amenity species. The spontaneous growth affords a bioindicator [35] of the low-stress park environment, and the possibility of successional development [11] towards more natural woodlands. The dearth of ornamental blooms and deciduous seasonal variations are quite conspicuous and somewhat surprising in view of the greenspace setting. For roadside, the top five are mainly natives (*table IV*). Roadside has the largest proportion of natives as dominants, and is the only forest with a native at the top position. Roadside also has the largest proportion of flowering trees as dominants.

4. MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Some generalities and their management implications can be distilled from the study. Species composition varies between forest types, hinting that fewer decision makers in species selection could entail fewer species. Official decision makers appear to have an inclination to

Table VII. Degree of similarity in species composition amongst the three urban forest types[a].

A	B	C	D	E	F	G	H	I
Institutional (I) versus Park (P):								
I total	P total	I and P	I only	P only	Non-I non-P	Similarity index[b]	Uniqueness index[c]	Absence index[d]
213	175	159	53	16	17	0.82	0.43	0.11
Institutional (I) versus Roadside (R):								
I total	R total	I and R	I only	R only	Non-I non-R	Similarity index [b]	Uniqueness index [c]	Absence index [d]
213	117	99	114	18	15	0.60	1.33	0.15
Park (P) versus Roadside (R):								
P total	R total	P and R	P only	R only	Non-P non-R	Similarity index [b]	Uniqueness index [c]	Absence index [d]
175	117	92	83	25	46	0.63	1.17	0.50

[a] Numbers in columns A to F are species counts.
[b] Similarity index = 2C/(A+B) (Greig-Smith, 1983).
[c] Uniqueness index = (D+E)/C.
[d] Absence index = F/C.

favour popular species, whereas non-official ones prefer unusual and exotic species. Stressful roadside habitat imposes constraints on species choice, but the relatively genial park habitat has not been fully utilized to maximize species diversity. Roadside plantable space, where available, has been heavily utilized. Different decision-makers, given similar habitats, to a certain extent tend to choose similar species.

A small subset of popular species contributes the bulk of the urban forest stock, with the remaining playing a minor role in biomass but a notable role in landscape, ecological and botanical dimensions. Domination by popular species is especially strongly expressed in park forest. By tree density, roadside is the best endowed, followed by park and institutional. By species density, the sequence is reverse, with institutional the best endowed, followed by park and roadside. Both tree density (tree stocking rate) and species density (species stocking rate) are not directly related to site condition and restrictions; rather they are more related to management decision.

Commonality of species composition amongst the three forest types is somewhat limited, although they form the core for the association between types. Only 91 out of 246 species are ubiquitous, that is found in all three forest types. A good proportion of species is paired, that is confined to two forest types, with sharing between roadside and other types particularly restricted. Every type has a unique species pool, with institutional having the most unique components. They help to give identity to individual forest types and add interest and variety to them. The unique solitary specimens play a special role in this regard, reflecting the disparate species choice and its associated decision-making process which varies by habitats and through time.

The ratio between native and exotic species differ between forest types. Although native trees exceed exotics for the whole study area, institutional and park forests show an opposite trend. Each forest type has its unique combination of natives and exotics especially in popular species, fulfilling different landscape, ecological and environmental-amelioration functions. Institutional forest has a sizeable number of rare native species. Park forest has a component of spontaneous growth mainly of adventive natives but also some naturalized exotics. The roadside forest has the largest number of native trees. The overall lack of species with showy blooms and seasonal changes is conspicuous, especially for park.

There is a case to diversify the species-selection decision process to encourage more thorough utilization of the rich humid-tropical floristic inheritance. The park forest in particular could be substantially enhanced with both native and introduced species to augment both the diversity and biomass of the greenery. The conditions for roadside trees could be improved by better site design with special reference to soil quality and volume and above-ground space for crown expansion. The conspicuous lack of high-quality flowering trees, and the narrow reliance on a few such species, could be rectified by a conscious effort to broaden the choice to cover many worthwhile candidates. The heavy adoption of popular species could be diluted by others of high ornamental and amenity values. A systematic programme of species evaluation and trial may form a rational basis for this exercise which could include native species hitherto not used in amenity situations. The performance of the existing urban-tree stock could provide objective hints on their suitability in different habitats. The use of species with spontaneous growth habit may lay the foundation for a naturalistic approach to greenspace design [21].

A city-wide urban forest planting and management plan could be instituted with a view to maximizing the amenity and environmental benefits [24]. This mission is of necessity in the city's attempt to ameliorate its deteriorating air quality. Different neighbourhoods could be given distinct arboreal identities [26] by suitable combination of common and unique species. With widespread infrastructural development, rapid urban growth and renewal, it is necessary to guard against the loss of valuable specimens and species, and against the simplification of species composition that has happened elsewhere. The sprawling of the city into its fringe natural areas should be preceded by a landscape plan that identify and preserve the high-quality wooded and other vegetated areas to avoid their fragmentation or degradation into woodland slums [10].

This study hopes to trigger similar evaluation of urban forests in other cities, a field that hitherto has received scanty attention. Other than satisfying academic enquiry, such research could engender earnestly needed practical implications and applications. With increasing emphasis on urban environmental quality, tree planting is likely to be given more attention and resources by municipal authorities in the future. In due course, the upsurge in tree variety and biomass, and their spatial spread into different habitats, call for improvement in management, which in turn requires objective data and assessment of the resource base. The practice of urban forestry could be upgraded and brought into the mainstream of forestry science. It will therefore be of interest to evaluate the forests of other cities in both the developed and developing realms, and gauge the validity of the above observations under different natural and cultural regimes.

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