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FLORISTICS, PERFORMANCE AND PROGNOSIS OF HISTORICAL TREES IN THE URBAN FOREST OF GUANGZHOU CITY (CHINA)

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Abstract. Outstanding historical trees embedded in cities constitute pertinent environmental assets, yet they are widely threatened in third-world cities. Inadequate understanding of this valuable natural-cum-cultural heritage hinders proper conservation. A case study of Guangzhou in south China evaluated floristic composition, age profile and biomass structure of historical trees, assessed their performance in major habitats (institutional, park and roadside), and established a prognosis for future growth and management. The 348 historical trees examined belonged to only 25 species, vis-à-vis 254 trees in the entire urban forest, dominated by five species and native members. Roadside had more trees, followed by institutional and park, with merely the most common four species shared by all habitats. The limited commonality reflected tree-performance differentiation by habitats exerting selection pressure on species. The institutional growth-regime was more conducive to nurturing high-caliber specimens, whereas park is less capable. Individual species achievement by habitats, derived from tree-count ranking and relative-abundance indices, could inform species choice and tree conservation. Few trees exceeded 300 years of age in the millennium-old city, echoing a history of intense tree–city conflicts. Potential life-span, trunk and crown diameters indicated ample opportunities for further expansion of biomass and landscape impacts, which would be straitjacketed by the tightening urban fabric.

Keywords: urban trees, urban forest, historical trees, tree habitat, tree performance, tree protection, Guangzhou, China

1. Introduction

In the course of a city's development, pre-urbanization natural features such as individual or groves of outstanding trees could sometimes be preserved *in situ* and subsequently became embedded within built-up areas (Jim 1989; Nowak, 1993). Some trees could survive the trying transition from a natural forest habitat to a stressful, fragmented and isolated urban habitat; others might be emaciated or even perish in the alien environs (Dorney *et al.*, 1986; Swenson and Franklin, 2000). Their occasional presence in the otherwise artificial city environment denotes the remnant bequest of a former natural lineage. The relatively higher degree of naturalness and collateral ecological and environmental benefits, in comparison with other urban greenery, signifies their pertinent if not unique functions in the city. As it is usually the large and exceptionally robust and beautiful trees that were chosen for preservation, their vivid contrast with the surrounding developments tends to accentuate their landscape impacts. The inheritance of the cream of nature's remnants is indeed a windfall for the landscape enhancement of a development area. Where and when development pressure was not too acute, more so in the past than the present, more chances were afforded for the expression of the innate human propensity to protect outstanding and aesthetic natural objects.

Trees could also be planted after the advent of urban growth, to co-exist with more pervasive if not overwhelming buildings and artificial surfaces. The unfavorable growth conditions are often inimical to the nurturing of fine specimens trees (Bradshaw *et al*., 1995; Grey, 1996). A small cohort of such cultivated members, by virtue of the chance concurrence of genetic superiority and suitable site characteristics, could subsequently achieve meritorious performance by virtue of age, dimension and vigor, and they are often accorded historical and commemorative status. Some local residents literally grow up together with these trees which usually began their urban existence as small and feeble saplings. Unlike pre-urbanization inheritance, these planted trees have witnessed the vicissitudes of the city fabric and the constituent inhabitants, and experienced the harsh treatments imposed on them by people and the stressful environs (Gilbertson and Bradshaw, 1985; Loeb, 1992). Such outstanding denizens often instill emotional attachment of the community and trigger the protective instinct of citizens and governments. It is not uncommon in different cultures to elevate such respect to the level of veneration or even worship (Hughes, 1984), extending to assiduous guarding of the city's natural gems.

Enlightened official policies, combined with sympathetic developers and a green-conscious citizenry are required to usher their preservation and subsequent protection. The success of this endeavor necessitates the confluence of the minds all three partners in the tripartite. In old cities that have often experienced some episodes of development and redevelopment, existing trees of high quality could be lost by felling, or so badly damaged by construction activities that they are no longer worthy of conservation (Goldsmith, 1988; Watson and Neely, 1995). Intensification of development is a particularly destructive force that tended to eliminate both cultural and natural heritage in a clean-slate mode, and the problem is often more acute in private lands (Coughlin *et al*., 1988). The infilling of brown fields and the incursion into green fields are reducing the green cover of many fast-growing cities (Arnold and Gibbons, 1996). In many cities in the developing world, the lack of an effective heritage preservation policy and an adjunct enforcement institution has allowed important historical relics to be eradicated or gravely degraded (Olembo and Rham, 1987).

In the face of development pressure, cities and citizens are increasingly alarmed by the loss of precious and familiar amenity vegetation, furnishing the impetus to enhance the protection of such living and venerable companions (Bowers, 1999). Many municipal authorities regarded them as prized possessions and bestowed statutory protection and special care (Duerksen and Richman, 1993; Department of the Environment, 1994). It is common for cities to establish official registers to foster their management and to publicize their heritage and environmental–ecological values as the oldest natural-cum-cultural heritage. They have been accorded special epithets to echo their importance to the community, namely ancient, beautiful, big, champion, elite, famous, heritage, historic, old, outstanding, remarkable, specimen, and veteran trees (Randall and Clepper, 1977; May, 1990; Mitchell *et al.*, 1990; Alderman and Stevenson, 1993; Jim, 1994a,b; Pelt, 1996; Parkenham, 1997; Lewington and Parker, 1999; Read, 2000; Browne, 2001; Meyer, 2001).

In some cities, such emblem urban trees hitherto have been catalogued in official registers but have seldom been subjected to detailed scientific analysis. A comprehensive evaluation of the exemplary arboreal population will serve the following objectives: (1) throw light on the fundamental characteristics of floristic composition and biomass structure; (2) permit an understanding of the underlying factors that contribute to their above- and below-par performance in a regime of intense tree–environment interactions; (3) contribute to the effective protection and management of the present cohort, and a planting and management strategy to nurture future candidates in new development areas. This study focuses on the in-depth assessment of the historical trees of a rapidly growing city in developing China, using Guangzhou in south China as a case study.

2. Study Area and Methods

2.1. Study area

The project is based in Guangzhou which is the largest metropolis in south China with a total population of about 7 million people. The study area, covering eight main urban districts of Guangzhou with 116 km^2 of developed area, has about 4 million residents (Guangzhou Statistical Bureau, 2001). The city is situated strategically at the head of the Pearl River Estuary, serving as the gateway and the principal administrative, commercial and industrial hub of south China. With a history of over 2500 years, the city is a mix of old neighborhoods with a typical tight town plan, and new developments with a more open cityscape. Similar to other Chinese cities, population, building and road densities are high, being typical of the compact-city morphology. Since the inception of the official open and reform policy in 1978, the city has undergone a rapid phase of redevelopment of brown fields, infilling of occluded green fields, and sprawling into the surrounding countryside.

Located in the north subtropical zone, the city has a well-defined seasonal pattern of warm-humid summers and cool-dry winters, with annual precipitation reaching 1690 mm and mean air temperature of 21.8 °C (Huang *et al.*, 1994). The typical monsoon weather regime is occasionally punctuated by thunderstorms and typhoons accompanied by high winds exceeding 100 km/h and torrential downpours (Jim and Liu, 1997). The topography is mainly alluvial plains laid down by the river, accompanied by scattered coastal wetlands, low terraces and residual hills. The low-lying flats are covered by immature alluvial soils, whereas the slopes and hills carry a mantle of tropical red earth. The pristine natural vegetation is believed to be the remnant of tropical rainforests with primarily evergreen broadleaved trees plus some deciduous elements, dominated by three botanical families (Lauraceae, Moraceae and Caesalpiniaceae; Jim, 2002b). The original vegetation mantle has been almost completely eradicated by centuries of agricultural and recently urban-industrial activities. Some native species, however, have managed to survive in various semi-natural and ruderal habitats in the city.

Guangzhou has established a sound foundation of urban forest, with a good tree cover mainly found in three habitat types, namely greenspaces, institutional grounds and roadsides (Jim and Liu, 2001a). Centuries of massive human disturbances and modifications have left their imprints on the urban forest, which, however, still decidedly carries a strong native character in species composition. The entire city, including occluded enclaves of undeveloped areas, has an exceptionally rich biodiversity of 1400 vascular plant species, reflecting its inherent tropical biodiversity treasure augmented over the millennia by plant introductions from different parts of China and other lands. As one of the earliest Chinese cities opened to other countries, many exotic species, notably from Southeast Asia and Australia, have been introduced into Guangzhou (Wang *et al*., 1994; Hou, 1956). Gauged by the common yardsticks of tree coverage, tree count and species composition, Guangzhou joins the rank of the meritorious green cities of China (Guangzhou Municipal Government, 1928; Yang, 1991). Recent intensive developments have damaged some urban trees and degraded the quantity and quality of the growth conditions of others. An extensive field survey of the study area in 1995 established that a population of 115,140 trees occurred within the study area, representing 254 species in 62 botanical families; 40.8% by roadsides, 38.2% in parks, and 21.0% in institutional grounds (Jim and Liu, 2001b). Many native species, especially by roadsides, dominate the cityscape in terms of species count and tree number.

2.2. Methods

Two approaches were adopted to study historical trees in the study area, namely official records and field assessment. An official register of old trees established by the municipal government in 1985 and updated in 1995 recorded 348 specimens. Targets were selected principally by age >100 years regardless of species and provenance, and secondarily on trees with special official commemorative value. The species, locations and environs of individual historical trees were gleaned through field surveys. Individual trees were evaluated for tree dimensions (Philip, 1994), habitat, and constraints to growth. Three tree dimensions were measured: crown diameter measured by taping the projected drip line; tree height measured with the help of an Abney level; and trunk diameter at 1.4 m (DBH) calculated from girth obtained by a measuring tape. *Ficus* trees required special attention due to the common occurrence of lignified aerial roots entwining around the trunk; if contiguous with the trunk they were measured as part of the trunk diameter.

For trees with multiple stems, the DBH were the aggregated values of constituent trunks.

Habitat characteristics were determined by reference to main land use types (roadside, park, government, education, religious, and other institutional grounds), and to development history. Major artificial growth constraints were recorded as the presence or absence of items such as adjacent infrastructural development or urban renewal, vandalism, poor care and major natural phenomena, e.g. typhoon, thunderstorm, disease and insects. Tree age was estimated using tree-ring analysis, correlation with the history of road and neighborhood development, experience of tree size–age relationships, and evidence from historical photographic and historical records. The botanical nomenclature of South China Institute of Botany (1987, 1991, 1995) was adopted. Statistical analysis was performed using SPSS/PC Version 10 and Microsoft Excel 2000.

3. Results and Discussion

3.1. Species composition and habitat variations

A total of 348 historical trees were identified in Guangzhou, of which 338 were over 100 years old; the remaining 10 were officially labeled as "famous trees" due to association with distinguished persons or events. The entire urban-tree population (UTP) in Guangzhou includes 254 species, dominated by 29 common species that constitute 75% of the population. The historical-tree population (HTP) is represented very unevenly by 25 species (Table I), with the top five contributing 87.4% of the trees, and with overwhelming presence of *Ficus microcarpa* at 41.4%. The next four species together took up merely 6.0%. A significant number of UTP species, ranging from common to rare, failed to attain the top-notch performance.

The three major habitats had dissimilar HTP species distributions (Table II). More HTP trees are found in roadside habitat (44.3%), followed by institutional (31.6%) and park (24.1%). In the UTP, the sequence was roadside, park and institutional. Institutional and park had similar number of historical species (at 16 and 17, respectively), whereas roadside had a much lower diversity (only seven species). For the HTP, only the top four species are common to all three habitats; six species are common to two and as many as 14 species are found in only one habitat. In contrast, the UTP had 15, 7 and 3 species in the same groups. The low level of commonality in the HTP indicated the selective effect of habitats in fostering the development of elite trees. Only a handful of species had generalist (versus specialist) ecological requirement to excel in all three habitats and to sustain the excellence over tenure of decades to centuries.

Comparing the municipality's UTP and HTP provides insights on the species composition of the latter. The 25 HTP species represent 16 botanical families

TABLE I
Species composition, botanical affiliation and abundance of historical trees

Species	Common name	Family	Count	%[f]
Ficus microcarpa[a,e]	Chinese Banyan	Moraceae	144	41.38
Ficus virens[a,e]	Big-leaf Banyan	Moraceae	49	14.08
Cinnamomum camphora[a,e]	Camphor Tree	Lauraceae	47	13.51
Bombax malabaricum[b,c,e]	Red Kapok	Bombacaceae	38	10.92
Cinnamomum burmanii[a,e]	Cinnamon Tree	Lauraceae	26	7.47
Ficus religiosa[c,d]	Peepul	Moraceae	9	2.59
Bischofia javanica[a,b,c]	Chinese Honey Locust	Caesalpiniaceae	4	1.15
Gleditsia sinensis[a,b]	Flat Mango	Caesalpiniaceae	4	1.15
Mangifera persiciformis[b,d]	Autumn Maple	Anacardiaceae	4	1.15
Adenanthera pavonina[b,c]	Red Sandalwood	Mimosaceae	2	0.57
Dimocarpus longan[b]	Longan	Sapindaceae	2	0.57
Ficus altissima[a]	Mountain Fig	Moraceae	2	0.57
Litsea monopetala[a]	Persimmon-leaf Litsea	Lauraceae	2	0.57
Michelia alba[a,b,d,e]	White Champak	Magnoliaceae	2	0.57
Prunus mume[b,d]	Flowering Plum	Rosaceae	2	0.57
Vitex quinata[c]	Orange-bark Vitex	Verbenaceae	2	0.57
Artabotrys hexapetalus[d]	Climbing Ilang-Ilang	Annonaceae	1	0.29
Cassia siamea[a,b,d]	Kassod Tree	Caesalpiniaceae	1	0.29
Celtis sinensis[a,e]	Chinese Hackberry	Ulmaceae	1	0.29
Dracontomelon duperreanum[a,b,c]	Yanmin	Anacardiaceae	1	0.29
Ficus gibbosa[a]	Humped Fig	Moraceae	1	0.29
Pinus massoniana	Chinese Red Pine	Pinaceae	1	0.29
Quercus robur[c,d]	English Oak	Fagaceae	1	0.29
Sterculia nobilis[a,b]	China Chestnut	Sterculiaceae	1	0.29
Terminalia chebula[c,d]	Chebulic-myrobalan	Combretaceae	1	0.29
Total			348	100.00

[a]Shading function (with dense and large fully-grown crown >10 m diameter).
[b]Vivid flowers (with conspicuous and ornamental blooms).
[c]Attractive tree form.
[d]Exotic species.
[e]Species found in the top ranking 29 speices in the urban-tree population of Guangzhou city, collectively contributing 75% of the trees.
[f]The following frequency classes are used in the text: > or = 100 tree per species is abundant, 40–99 is frequeny, 10–39 is occasional, 2–9 is rare, and 1 is solitary

(Table I), and accounted for 28.1% of the 64 families found in the UTP. The Moraceae is the most dominant plant family in both HTP and UTP with five species and 205 trees. The genus *Ficus* accounted for 20.0% of HTP species and 59.0% of HTP trees, but less presence at 7.9 and 16.3%, respectively of

TABLE II
Abundance of historical-tree species in comparison with the urban-tree population

	Historical tree									Urban tree							
	Count					%				Count				%			
Species	Institutional	Park	Roadside	Total	Rank	Institutional	Park	Roadside	Total	Institutional	Park	Roadside	Total	Institutional	Park	Roadside	Total
Ficus microcarpa	31	43	70	144	1	8.9	12.4	20.1	41.4	271	996	3296	4563	0.9	3.2	10.6	14.7
Ficus virens	33	4	12	49	2	9.5	1.1	3.4	14.1	392	682	8072	9146	1.3	2.2	26.1	29.5
Cinnamomum camphora	5	1	41	47	3	1.4	0.3	11.8	13.5	376	477	306	1159	1.2	1.5	1.0	3.7
Bombax malabaricum	20	17	1	38	4	5.7	4.9	0.3	10.9	297	650	2253	3200	1.0	2.1	7.3	10.3
Cinnamomum burmanii	1	0	25	26	5	0.3	0.0	7.2	7.5	175	1409	141	1725	0.6	4.6	0.5	5.6
Ficus religiosa	6	3	0	9	6	1.7	0.9	0.0	2.6	3	74	98	175	<0.1	0.2	0.3	0.6
Bischofia javanica	2	1	1	4	7	0.6	0.3	0.3	1.1	58	97	298	453	0.2	0.3	1.0	1.5
Gleditsia sinensis	1	3	0	4	7	0.3	0.9	0.0	1.1	1	4	0	5	0.0	<0.1	0.0	0.0
Mangifera persiciformis	0	1	3	4	7	0.0	0.3	0.9	1.1	0	1	353	354	0.0	0.0	1.1	1.1
Adenanthera pavonina	2	0	0	2	8	0.6	0.0	0.0	0.6	28	3	0	31	0.1	<0.1	0.0	0.1
Dimocarpus longan	2	0	0	2	8	0.6	0.0	0.0	0.6	166	297	45	508	0.5	1.0	0.1	1.6
Ficus altissima	2	0	0	2	8	0.6	0.0	0.0	0.6	59	224	595	878	0.2	0.7	1.9	2.8
Litsea monopetala	1	0	1	2	8	0.3	0.0	0.3	0.6	26	803	2	831	0.1	2.6	<0.1	2.7
Michelia alba	0	2	0	2	8	0.0	0.6	0.0	0.6	1091	1184	1087	3362	3.5	3.8	3.5	10.9
Prunus mume	0	2	0	2	8	0.0	0.6	0.0	0.6	0	2	0	2	0.0	<0.1	0.0	<0.1
Vitex quinata	1	1	0	2	8	0.3	0.3	0.0	0.6	1	1	0	2	0.0	0.0	0.0	<0.1

(*Continued on next page*)

TABLE II
Continued

Species	Historical tree									Urban tree							
	Count					%				Count				%			
	Institutional	Park	Roadside	Total	Rank	Institutional	Park	Roadside	Total	Institutional	Park	Roadside	Total	Institutional	Park	Roadside	Total
Artabotrys hexapetalus	0	1	0	1	9	0.0	0.3	0.0	0.3	0	1	0	1	0.0	0.0	0.0	0.0
Cassia siamea	1	0	0	1	9	0.3	0.0	0.0	0.3	14	1	125	140	0.0	0.0	0.4	0.5
Celtis sinensis	1	0	0	1	9	0.3	0.0	0.0	0.3	202	1511	0	1713	0.7	4.9	0.0	5.5
Dracontomelon duperreanum	0	1	0	1	9	0.0	0.3	0.0	0.3	72	132	45	249	0.2	0.4	0.1	0.8
Ficus gibbosa	0	1	0	1	9	0.0	0.3	0.0	0.3	3	2	0	5	<0.1	<0.1	0.0	0.0
Pinus massoniana	0	1	0	1	9	0.0	0.3	0.0	0.3	135	2148	6	2289	0.4	6.9	0.0	7.4
Quercus robur	0	1	0	1	9	0.0	0.3	0.0	0.3	0	1	0	1	0.0	0.0	0.0	0.0
Sterculia nobilis	0	1	0	1	9	0.0	0.3	0.0	0.3	76	70	5	151	0.2	0.2	0.0	0.5
Terminalia chebula	1	0	0	1	9	0.3	0.0	0.0	0.3	11	1	0	12	<0.1	0.0	0.0	<0.1
Total number of species	16	17	7	25						21	25	16	25				
Total number of trees	110	84	154	348		31.6	24.1	44.3	100.0	3457	10771	16727	30955	11.2	34.8	54.0	100.00
Per cent of urban-tree population[a]	0.1	0.1	0.1	0.3						3.0	9.4	14.5	26.9				

[a]Total tree count in the urban-tree population is 115,070 trees, of which 30,955 trees belong to the 25 historical tree species.

the UTP. Other important families include Lauraceae and Bombacaceae, together contributing 21.6% of HTP species and 10.9% of HTP trees. Collectively, these three families represent 91.5% of HTP trees. Some common families and species in the UTP did not occur as champions. For example, Palmae and Myrtaceae accounted respectively for 13.0 and 12.0% of UTP, and had no HTP representation.

Only 7 of the 29 common UTP species were represented among the historical trees, namely the five top-ranking HTP species (*Ficus microcarpa*, *F. virens*, *Cinnamomum camphora*, *Bombax malabaricum*, and *C. burmanii*), plus two lower ranking ones (*Michelia alba* and *Celtis sinensis*). Most HTP species are also uncommon in the UTP; 16 HTP species have $<1\%$ frequency, 10 of which also had $<1\%$ frequency in UTP. Common UTP species, *Aleurites moluccana*, *Bauhinia purpurea*, *B. variegata, Caryota mitis*, *Casuarina equisetifolia* and *Melaleuca leucadendra*, were absent from the HTP. However, some rare UTP species, *Artabotrys hexapetalus*, *Prunus mume*, *Quercus robur*, *Sterculia nobilis* and *Terminalia chebula*, were recognized as champions. Native species dominated the HTP; 68.0% of species and 94.0% of trees, and the major historical-tree species, *F. microcarpa*, *F. virens*, *C. camphora*, *C. burmanii,* and *B. malabaricum*, were native (Table I). These species have been domesticated for urban planting for over 1000 years in southern Chinese cities (Qu, 1670; Hou, 1956). Unlike the HPT, the UTP has comparable number of exotic and native species. Exotic species were uncommon in the HTP, but some members have general religious significance, such as *Ficus religiosa* and *Terminalia chebula*.

3.2. Habitat differentiation of tree performance

Dominated by native species, the performance of most historical trees indicated adaptation to the climate and soil conditions of the city. However, recent rapid urban development and rising building density had significantly degraded habitat quality and affected their growth and performance. Since the first inventory conducted in 1986 (Landscape Bureau, 1995), 45 trees out of the 209 identified had perished by 1995, and another 92 showed decline. Major threats are urban development, natural hazards and vandalism.

Comparison between UTP and HTP by the three major habitat types indicated differential site conditions in nurturing high-caliber trees (Table II). Institutional contributed 31% of the HTP trees, notably higher than the 11.2% in UTP, suggesting conditions conducive to the development of fine specimens. On the contrary, park and roadside had lower percentage of HTP trees (24.1 and 44.25%, respectively) than UTP (34.8 and 54.0%, respectively), suggesting that these two habitats are relatively less amenable to excellent tree growth. That park overall had a smaller proportion of high-quality trees than institutional is somewhat unexpected, and pointed to the need to improve tree management in public greenspaces to maximize their potential to raise meritorious trees. The physical and institutional limitations to superior tree performance in the relatively genial environment should be thoroughly explored and ameliorated. Despite the stressful roadside habitat (Bassuk and Whitlow, 1988; Jim, 2003), the largest share (44.3%) of the HTP trees dwelt there. Roadside trees endured more physical and physiological constraints, especially in old districts with narrow streets (Jim and Liu, 2001b). The tight growing space sandwiched between the carriageway and adjacent buildings would curtail future expansion of roadside trees, many of which are yet to attain their final dimensions. Champion trees at roadside could provide more prominent landscape and environmental benefits to compact cities.

Finer comparison showed the involvement of individual species in habitat differentiation (Table II). In institutional, three common HTP species, *Ficus microcarpa*, *F. virens* and *Bombax malabaricum*, outperformed their UTP counterparts by a wide margin. In park, *F. microcarpa* and to a lesser extent *B. malabaricum* in HTP also surpassed the UTP. Different species were found in roadside; besides the ubiquitous *F. microcarpa, Cinnamomum camphora* and *C. burmanii* in HTP performed better than UTP. Some species achieved notably below par performance. In park, the common *F. virens* and *C. burmanii* did poorly in HTP. In roadside, the common *F. virens* and *B. malabaricum* were the under-performers in HTP. Three common UTP species were also poor achievers in HTP. *Michelia alba* was substandard in all three habitats, whereas *Celtis sinensis* and *Pinus massoniana*, rarely planted at roadside, were weak in park. The choice of species in future urban planting endeavors could take into account the suitability of species in different habitats after decades of field testing in real-world situations.

Comparing the ranking of species in different habitats could provide a quantitative indicator of species performance (Table III). Except park, the Spearman correlations between the HTP and UTP species ranks were significant (institutional $\rho = 0.46$, $p < 0.015$, roadside $\rho = 0.58$, $p < 0.01$, total $\rho = 0.51$, $p < 0.01$). In institutional, *F. virens* ranked first in HTP, and *B. malabaricum* ascended to the third position. An extreme contrast was found in *M. alba* which ranked first in UTP but last in HTP, showing that most trees failed to achieve well. Of the 3362 trees of *M. alba* in UTP, only two were enlisted as historical trees in parks, with none in institutional and roadside. Other species with a similar polarized performance included *C. burmanii* and *Celtis sinensis*. *Ficus religiosa* did exceptionally well in institutional, with an eight-step climb on the relative-rank league, mainly assiduously protected in temple grounds as a Buddhism sacred tree. Comparing with other habitats, park had the largest number of species, 11 out of 25, experiencing a rise in rank. Two common species had an elevated relative rank, namely *F. microcarpa*, which preserved its premier position in the HTP, and *B. malabaricum*, which ranked second. Eight other uncommon species had different degrees of ascendancy, suggesting that the park habitat was favorable to the growth of some species. *Pinus massoniana* ranked first in UTP cohort but had a significant drop to 17th rank in HTP; *C. burmanii* also had a big drop from third to 20th. In roadside, all seven HTP

TABLE III
Comparison of urban and historical tree species by tree-count ranking in their respective populations

Species	Institutional					Park					Roadside					Total				
	Urban tree[a]	Urban-tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]	Urban-tree[a]	Urban-tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]	Urban-tree[a]	Urban-tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]	Urban-tree[a]	Urban-tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]
Ficus microcarpa	23	5	2	5.0	0.0	16	5	1	2.9	2.1	4	2	1	2.4	−0.4	6	2	1	2.6	−0.6
Ficus virens	13	2	1	2.5	−0.5	22	7	3	8.6	−1.6	1	1	2	4.9	−3.9	1	1	2	5.1	−4.1
Cinnamomum camphora	14	3	5	12.5	−9.5	31	9	6	17.1	−8.1	21	7	3	7.3	−0.3	29	8	3	7.7	0.3
Bombax malabaricum	18	4	3	7.5	−3.5	25	8	2	5.7	−2.3	8	3	4	9.7	−6.7	11	4	4	10.2	−6.2
Cinnamomum burmanii	29	7	7	17.5	−10.5	7	3	7	20.0	−17.0	37	9	5	12.1	−3.1	19	6	5	12.8	−6.8
Ficus religiosa	162	18	4	10.0	8.0	74	14	4	11.4	2.6	46	11	7	17.0	−6.0	75	15	6	15.3	−0.3
Bischofia javanica	59	13	6	15.0	−2.0	64	13	6	17.1	−4.1	22	8	6	14.6	−6.6	50	12	7	17.9	−5.9
Gleditsia sinensis	184	19	7	17.5	1.5	147	16	4	11.4	4.6	118	17	7	17.0	0.0	197	21	7	17.9	3.1
Mangifera persiciformis	214	20	8	20.0	0.0	230	20	6	17.1	2.9	19	6	7	17.0	−11.0	54	13	7	17.9	−4.9
Adenanthera pavonina	86	14	6	15.0	−1.0	152	17	7	20.0	−3.0	118	17	7	17.0	0.0	132	18	8	20.4	−2.4
Dimocarpus longan	30	8	6	15.0	−7.0	37	10	7	20.0	−10.0	65	12	7	17.0	−5.0	46	11	8	20.4	−9.4
Ficus altissima	57	12	6	15.0	−3.0	47	11	7	20.0	−9.0	16	5	7	17.0	−12.0	39	9	8	20.4	−11.4
Litsea monopetala	87	15	7	17.5	−2.5	20	6	7	20.0	−14.0	98	16	6	14.6	1.4	40	10	8	20.4	−10.4
Michelia alba	5	1	8	20.0	−19.0	13	4	5	14.3	−10.3	12	4	7	17.0	−13.0	9	3	8	20.4	−17.4
Prunus mume	214	20	8	20.0	0.0	157	18	5	14.3	3.7	118	17	7	17.0	0.0	217	22	8	20.4	1.6

(*Continued on next page*)

TABLE III
Continued

Species	Institutional					Park					Roadside					Total				
	Urban tree[a]	Urban tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]	Urban-tree[a]	Urban-tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]	Urban-tree[a]	Urban-tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]	Urban-tree[a]	Urban-tree subset[b]	Historical-tree[c]	Scaled historical-tree[d]	Relative rank[e]
Vitex quinata	184	19	7	17.5	1.5	166	19	6	17.1	1.9	118	17	7	17.0	0.0	217	22	8	20.4	1.6
Artabotrys hexapetalus	214	20	8	20.0	0.0	166	19	6	17.1	1.9	118	17	7	17.0	0.0	227	23	9	23.0	0.0
Cassia siamea	113	16	7	17.5	−1.5	166	19	7	20.0	−1.0	39	10	7	17.0	−7.0	84	17	9	23.0	−6.0
Celtis sinensis	27	6	7	17.5	−11.5	6	2	7	20.0	−18.0	118	17	7	17.0	0.0	21	7	9	23.0	−16.0
Dracontomelon duperreanum	51	11	8	20.0	−9.0	56	12	6	17.1	−5.1	66	13	7	17.0	−4.0	64	14	9	23.0	−9.0
Ficus gibbosa	162	18	8	20.0	−2.0	157	18	6	17.1	0.9	189	18	7	17.0	1.0	196	20	9	23.0	−3.0
Pinus massoniana	36	9	8	20.0	−11.0	3	1	6	17.1	−16.1	91	14	7	17.0	−3.0	15	5	9	23.0	−18.0
Quercus robur	214	20	8	20.0	0.0	166	19	6	17.1	1.9	118	17	7	17.0	0.0	227	23	9	23.0	0.0
Sterculia nobilis	50	10	8	20.0	−10.0	76	15	6	17.1	−2.1	92	15	7	17.0	−2.0	80	16	9	23.0	−7.0
Terminalia chebula	124	17	7	17.5	−0.5	166	19	7	20.0	−1.0	118	17	7	17.0	0.0	168	19	9	23.0	−4.0
Spearman rank correlation[f]			0.46 ($p < 0.05$)					0.07 (n.s.)					0.58 ($p < 0.01$)					0.51 ($p < 0.01$)		

[a]Ranking of speices in the entire urban-tree population with 254 species.
[b]Ranking of the subset of 25 urban-tree species that are present as historical trees.
[c]Ranking of the 25 historical-tree species.
[d]Ranking of historical-tree species scaled such that the maximum equals the maximum rank of the urban-tree subset.
[e]Relative rank, R = (urban-tree subset rank – scaled historical-tree rank); positive value indicates rise in rank, and negative drop in rank.
[f]Spearman rank correlation between the urban-tree rank and historical-tree rank.

species had a drop in rank, notably *B. malabaricum* which was unable to perform well in this habitat.

The relative abundance of the 25 HTP species in comparison with UTP could throw light on performance by species and habitats (Table IV). Thirteen species were rated to have above-par performance, including four of the five common species, of which *F. microcarpa* had outstanding achievement in institutional and secondarily in park but less so in roadside, whereas *C. camphora* did exceptionally well in roadside but less so in institutional and park. The common *F. virens* was overall rated as poor in performance; although it did well in institutional, its below-par development in roadside and to a lesser extent in park (UTP in Table I) needs to be addressed. *B. malabaricum*, the emblem flower of Guangzhou, stood out in institutional, but it was moderate in park and very feeble in roadside; its highly popular planting in roadside deserved a review. *C. burmanii* superior attainment in roadside posed a pointer to more common use in this habitat. For the remaining species that were uncommon, the three species rated very poor need attention. *Michelia alba*, heavily planted in all three habitats, was a disappointment. Similarly, *Celtis sinensis* and *Pinus massoniana*, widely planted in park, yielded merely 0 and 1 historical tree respectively in this habitat.

3.3. Tree age, dimensions and landscape prospects

Historical-tree age distribution spans 15–450 years. The oldest trees are native species, especially *Ficus* and *Cinnamomum* species, *Bombax malabaricum* and *Gleditsia sinensis*, and the exceptional 450 years *Ficus gibbosa*. Despite a millennium of development history, most of Guangzhou's historical trees (75%) especially the common species were 100–200 years old. The vicissitudes of urban growth have imposed constraints against long-term survival of trees planted in earlier times. Species and tree age are statistically associated by Chi-square analysis (Figure 1; Cramer $V = 0.55$, $p < 0.001$). As only 25 of the city's 254 species could attain historical status, a rigorous sieving effect of the city's evolving fabric and town plan was in effect. The intense conflicts between trees and city structures have existed for centuries, and the recent episode of tree losses was but a continuation of this historical trend. Most historical species have a long maximum life span of 300–600 years in local habitats (Hou, 1956). Many trees with a potential life span of 600 years are at present 100–200 years old (Figure 2; Cramer's $V = 0.35$, $p < 0.001$), indicating that they could continue to serve landscape and environmental functions for centuries to come if the ubiquitous and intensifying urban stresses could be overcome.

Tree age and DBH are strongly correlated (Pearson, $r = 0.83$, $p < 0.001$). For common species, tree age and LIC were closely related, whereas more rare and solitary species tended to be outliers (Figure 3). Six of the 13 trees older than 300 years were rare and solitary species. The cluster of species of 100–200 years

TABLE IV
Comparison of urban and historical tree species by relative abundance

	Relative abundance[a]								
	Index A[b]				Index B[c]				
Species	Institutional	Park	Roadside	Total	Institutional	Park	Roadside	Total	Overall performance[d]
Ficus microcarpa	10.18	3.84	1.89	2.81	0.90	0.74	0.47	0.64	+
Ficus virens	7.49	0.52	0.13	0.48	0.87	−0.92	−6.56	−1.10	−−
Cinnamomum camphora	1.18	0.19	11.92	3.61	0.15	−4.36	0.92	0.72	+
Bombax malabaricum	5.99	2.33	0.04	1.05	0.83	0.57	−24.33	0.05	+
Cinnamomum burmanii	0.51	0.00	15.77	1.35	−0.97	n.a.	0.94	0.26	+
Ficus religiosa	177.90	3.61	0.00	4.60	0.99	0.72	n.a.	0.78	+
Bischofia javanica	3.07	0.92	0.30	0.75	0.67	−0.09	−2.35	−0.33	−
Gleditsia sinensis	88.95	66.71	n.a.	68.10	0.99	0.99	n.a.	0.99	+++
Mangifera persiciformis	n.a.	88.95	0.76	0.96	n.a.	0.99	−0.32	−0.04	−
Adenanthera pavonina	6.35	0.00	n.a.	5.99	0.84	n.a.	n.a.	0.83	+
Dimocarpus longan	1.07	0.00	0.00	0.37	0.07	n.a.	n.a.	−1.74	−−
Ficus altissima	3.02	0.00	0.00	0.21	0.67	n.a.	n.a.	−3.73	−−
Litsea monopetala	3.42	0.00	44.48	0.22	0.71	n.a.	0.98	−3.47	−−
Michelia alba	0.00	0.15	0.00	0.06	n.a.	−5.66	n.a.	−17.10	−−−
Prunus mume	n.a.	88.95	n.a.	92.87	n.a.	0.99	n.a.	0.99	+++

(*Continued on next page*)

TABLE IV
Continued

Species	Relative abundance[a]								Overall performance[d]
	Index A[b]				Index B[c]				
	Institutional	Park	Roadside	Total	Institutional	Park	Roadside	Total	
Vitex quinata	88.95	88.95	n.a.	92.87	0.99	0.99	n.a.	0.99	+++
Artabotrys hexapetalus	n.a.	88.95	n.a.	92.87	n.a.	0.99	n.a.	0.99	+++
Cassia siamea	6.35	0.00	0.00	0.66	0.84	n.a.	n.a.	−0.51	−
Celtis sinensis	0.44	0.00	n.a.	0.05	−1.27	n.a.	n.a.	−17.45	−−−
Dracontomelon duperreanum	0.00	0.67	0.00	0.37	n.a.	−0.48	n.a.	−1.68	−−
Ficus gibbosa	0.00	44.48	n.a.	18.57	n.a.	0.98	n.a.	0.95	++
Pinus massoniana	0.00	0.04	0.00	0.04	n.a.	−23.15	n.a.	−23.65	−−−
Quercus robur	n.a.	88.95	n.a.	92.87	n.a.	0.99	n.a.	0.99	++
Sterculia nobilis	0.00	1.27	0.00	0.62	n.a.	0.21	n.a.	−0.63	−
Terminalia chebula	8.09	0.00	n.a.	7.74	0.88	n.a.	n.a.	0.87	+
Average	2.83	0.69	0.82	1.00	0.65	−0.44	−0.22	0.00	

[a]Species abundance data are taken from Table I.
[b]Relative abundance, Index A = historical tree count%/urban-tree count%.
[c]Relative abundance, Index B = (historical-tree count% – urban-tree count%)/historical-tree count%.
[d]Individual species are rated as follows: (+++) Excellent, Index A > 30. (++) Good, Index A 10–30. (+) Fair, Index A 1–10. (-) Slightly poor, Index B < –1. (−−) Poor, Index B –1 to –10. (−−−) Very poor, Index B > –10.

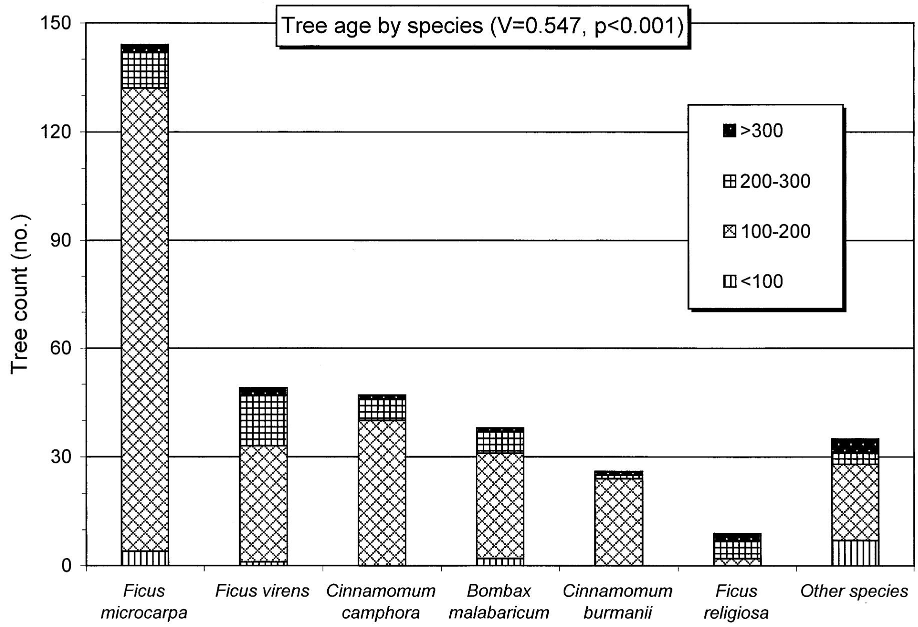


Figure 1. Distribution of tree-age groups by historical-tree species (Chi-square Cramer's *V* statistic is shown).

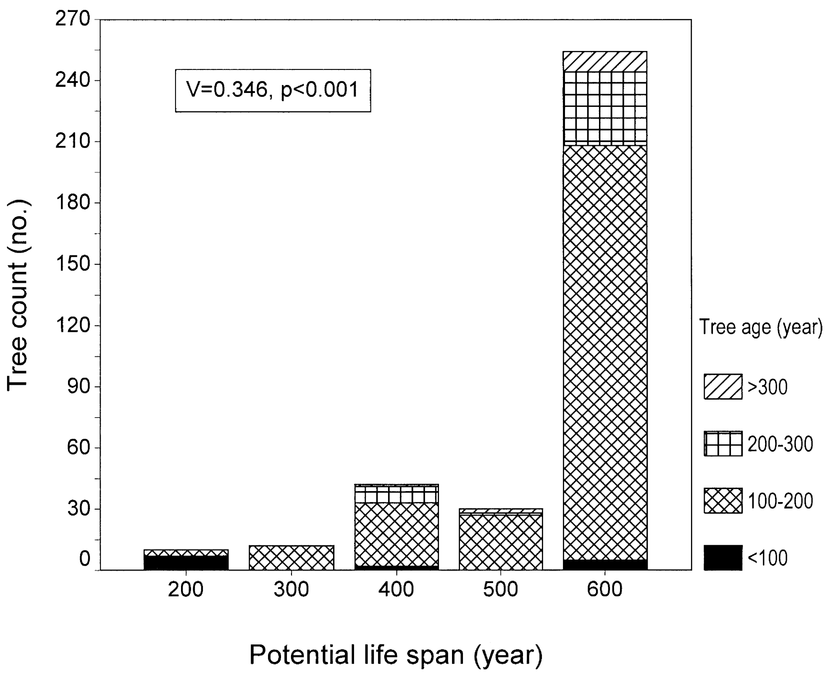


Figure 2. Association between tree age and potential life span of the historical trees (Chi-square Cramer's *V* statistic is shown).

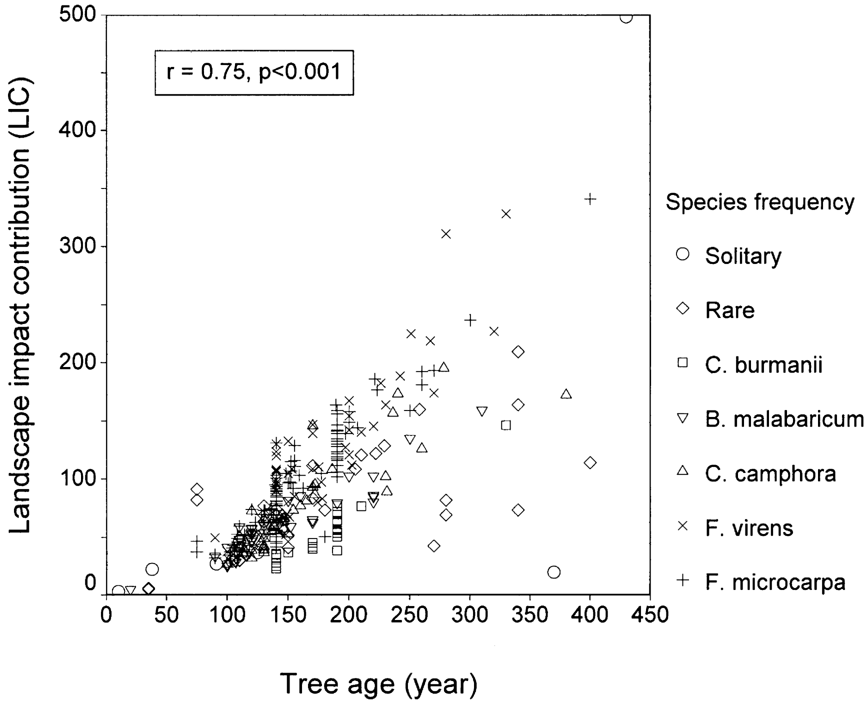


Figure 3. Correlation between tree age and landscape impact contribution (LIC, formula given in Section 2.2) of the historical trees classified in seven species-frequency groups (Pearson correlation coefficient is shown).

old, mainly the common species, was the principal contributor of LIC. Tree-age distribution varied with habitats (Figure 4). Institutional had more individuals in the oldest classes (>200 years). Roadsides had the highest number and proportion of medium-aged trees (100–200 years). Trees planted recently in parks contributed to the younger champions. The institutional habitat has been more conducive to old-tree preservation in the more secluded and protected grounds, and it has more stable land use that is less converted to high-density development. With rapid urban growth, some institutional lots are under immense pressure to convert to high-value and high-density uses. The recent tendency to infill institutional sites or to redevelop them to a higher intensity poses a threat to historical trees. As road alignment in cities has a remarkable inertia against change, roadside sites until recently were quite stable and resistant to change. The latest episode of road widening and underground railway developments, however, has degraded the growth conditions and threatened historical trees. Park has much potential to nurture the future generation of outstanding trees. A strategy to enhance species selection, planting-site design and preparation, and arboricultural care, could be established to realize this ambition.

The biomass structure of the historical trees is depicted in Figure 5. The historical trees are dominated by species of sizeable final dimensions, with potential

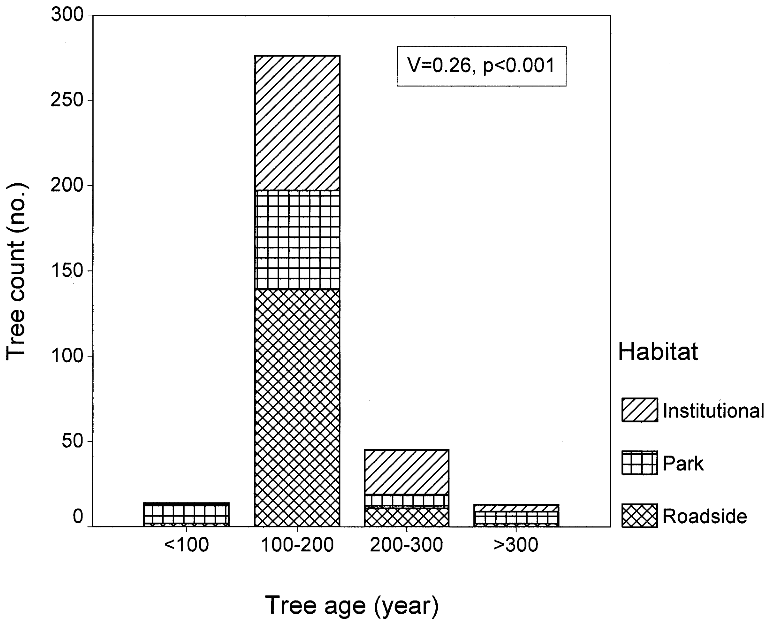


Figure 4. Association between tree age and three major habitat types of the historical trees (Chi-square Cramer's *V* statistic is shown).

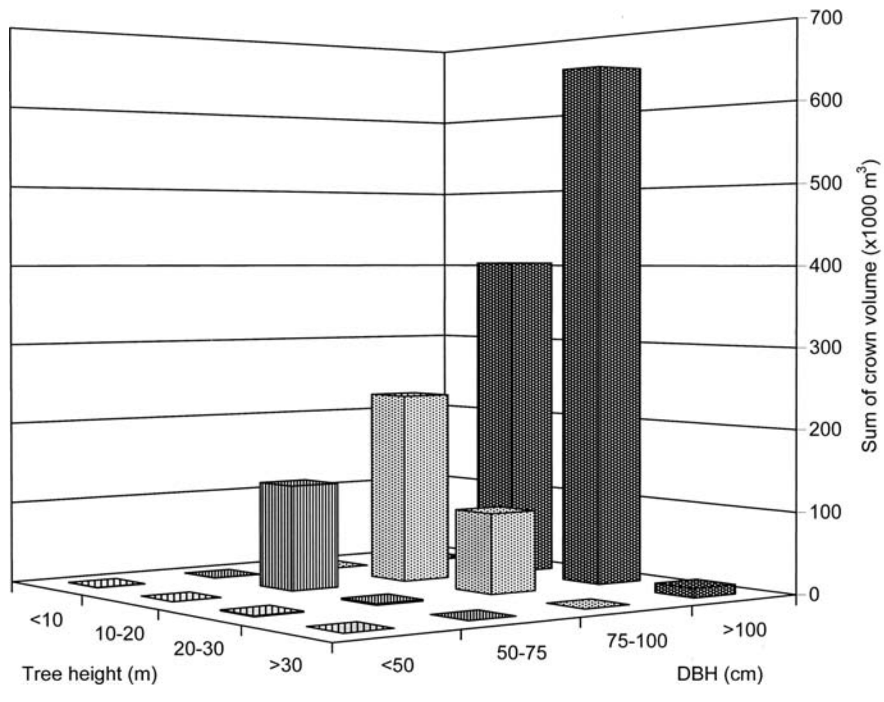


Figure 5. The biomass structure of the historical trees indicated by three-dimensional attributes of trunk diameter (DBH), tree height and crown volume.

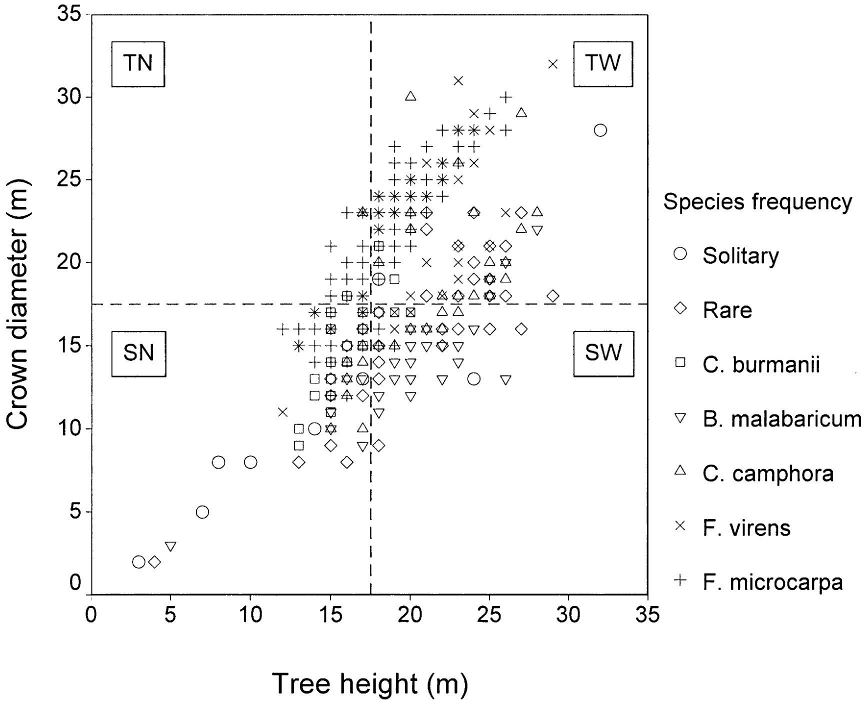
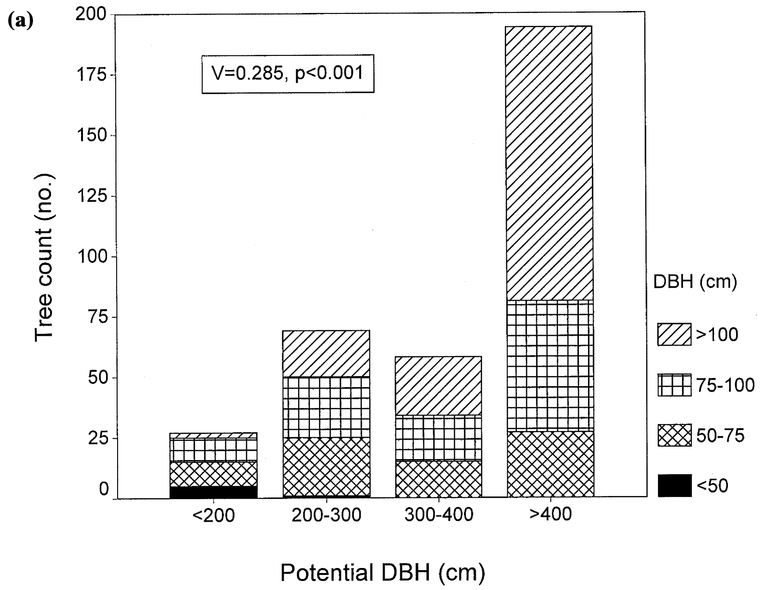


Figure 6. The demarcation of the historical trees into four tree-from classes according to tree height and crown diameter, with TN for tall-narrow, TW for tall-wide, SN for short-narrow, and SW for short-wide.

DBH of 60–460 cm and potential crown diameter of 12–60 m. Actual DBH of historical trees vary greatly from 10 to 350 cm, and actual crown diameter from 2 to 32 m. Major natives such as *Ficus* and *Cinnamomum* species have potential DBH exceeding 300 cm. The oldest tree, a 450-year-old *Ficus gibbosa* growing in a park (a former temple), reached 360 cm DBH. The large DBH classes of 75–100 cm and >100 cm were dominant. Tree height clustered in the 10–20 and 20–30 m categories. Trees in these leading DBH and height classes contributed the bulk of the HTP's crown volume, which is most notable biomass attribute accounting for shading, environmental amelioration and landscape-scenic impacts. Thus, the typical or modal historical tree is 20–30 m tall with >100 cm DBH, accompanied by a 15–25 m crown.

Shade trees with a wide crown are preferred in the subtropical city (Landscape Bureau, 1995). The popular *Ficus microcarpa*, *F. virens* and *Cinnamomum camphora*, had the widest crowns, accounting for most of the spreading crowns (>18 m). Tall-wide (TW) trees were the dominant tree form, followed by short-narrow (SN) and short-wide (SW); tall-narrow (TN) trees are uncommon although they could fit into tight growing spaces well (Figure 6). Most trees older than 200 years had canopies wider than 25 m, with the maximum attaining 35 m. A comparison between



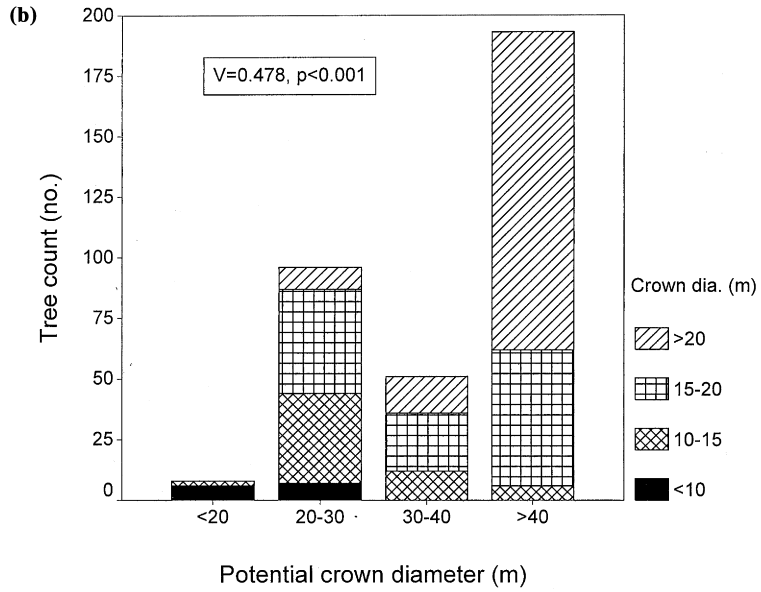


Figure 7. Associations between: (a) trunk diameter (DBH) and potential trunk diameter, and (b) crown diameter and potential crown diameter (Chi-square Cramer's V statistic is shown).

actual DBH and crown diameter with their potential counterparts hinted much opportunities for the present historical trees to expand their biomass (Figure 7). Such potentials could only be materialized if the expansion rooms are available and not usurped or degraded in the fullness of time. Alternatively, rooms for their future expansion could be made available in the course of urban renewal. The roadside and institutional habitats, holding 76% of HTP, have great difficulty furnishing the ample growing space needed by the present modal historical trees to attain their biological maximum dimensions. Trees in cramped sites cannot realize their potential dimensions, and recent urban redevelopments have reduced available growing space. The increasing use of species with smaller final dimensions in recent years, in response to the general shrinkage in plantable space, would in the long run deprive the city of veritable successors to the present cohort of outstanding trees. The further tightening of Guangzhou's town plan in central areas fuels the gloomy prognosis that many existing historical trees will be straitjacketed, harmed or eradicated.

4. Management Implications and Conclusions

As cities in the developing world are growing rapidly, there is a tendency and the temptation to take the expedient path of facilitating development at the expense of environmental quality. The presence of greenery and their accompanied greenspaces furnishes a pertinent indicator if not the surrogate of the environmental health of urban areas. The willingness and the ability of municipal governments to preserve greenery, and to provide for more and better of it in new developments, provide a common yardstick to judge official environmental performance. The success of such endeavors has potential far-reaching repercussions on the quality of life of millions of inhabitants. As the cream of the urban-tree population, the historical trees can serve as sensitive litmus of the tree-preservation policies and actions of a city. Historical trees often draw the attention and the heart of the citizens, and a responsible and responsive government would not ignore their plight and fate. Urban trees in many Chinese cities are threatened by massive infrastructural and housing developments. Their constituent amenity vegetation, including the finest specimens, desperately needs proper protection.

Guangzhou city is acutely aware of the intense development impacts on its rich arboreal endowment and other cultural heritage (Feng, 1992). Its new development areas demand an ecologically-sound and sustainable environmental strategy which needs the company of generous greenery in compatible landscape designs. Despite its millennium-old lineage, the city has bequeathed few trees older than 300 years. Trees in cities are notorious for their truncated life span, and trees in developing cities such as Guangzhou often fail to last and co-exist with the physical fabric (Jim, 2002a). In the course of an urban-renewal cycle, the construction, use, repair and demolition of buildings, roads, utilities and installations could impose deleterious impacts on constituent trees. Only a tiny subset of the diversified urban-tree species assemblage has been able to escape from harms to join the superior league; merely 348 trees or 0.3% of the urban-tree stock could qualify. Different habitats exercise strong control on the species that could pass the stringent selection process. Performance indicators of species in the present urban-tree population provide useful hints to avoid the under-achievers in future planting programs. Meanwhile, historical trees continue to be injured or removed. Although the dimensions and age of the present historical-tree cohort have vast potentials to expand and flourish, the prognosis is not promising as the present growing sites could hardly accommodate their maximum crown volume or trunk DBH.

There is no short-cut to the nurturing of champion-caliber urban trees. The conditions that foster the realization of biological potential should continue to be provided so that they can remain in harmony in the city fabric. The same conditions could be provided proactively in the course of urban development and redevelopment to rear future champions. The present age-profile of historical trees suggests that the failure to provide sustainable conditions for urban trees to prosper has been a recurrent historical problem. The continued growth of the historical trees will generate a quandary if not a dilemma to the municipal authority, begging hard decisions on a living heritage purportedly protected by statute. It is a challenge that cannot be shirked, for the decision on every historical tree will determine the fate, survival or demise, of a living-heritage entity. There is an urgent need to augment their protection, especially by reinforcing tree laws and their effective enforcement (Jim and Liu, 2000). Incentives to developers and land users to preserve outstanding trees and penalties for infringements should be beefed up to lend teeth to the legislation. The fundamental research and data requirements have been established as a backdrop for improvement in the administrative and statutory set-up (Grey, 1996). The community's collective attitude and behavior, expectation and wishes, and above all the encompassing value accorded to high-quality amenity greenery (Gold, 1972; Dwyer *et al.*, 1992; Arboricultural Association, 1994), will evolve in time. How they evolve will determine the direction and pace of tree protection and nurturing in the rapidly growing city. An understanding of the historical-tree resource base and how it will fare in the future could provide the scientific basis for an augmented urban-tree management in cities in the developing world.

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