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Multipurpose Census Methodology to Assess Urban Forest Structure in Hong Kong

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Abstract. Surveys of urban forests in the compact city environment of Hong Kong were initiated in 1985 and regularly updated thereafter. Roadside trees were evaluated first in a tree census and reported in this article followed by urban parks, public housing estates, and special habitats such as old stone walls or special specimens such as heritage trees. The survey method aimed at collecting comprehensive data to echo both tree conditions and tree–environmental interactions. Detailed information was gleaned, with the help of well-trained assistants, on tree sites, tree growing space, tree structure, and tree defects and disorders. A field record form was designed, pilot-tested, and refined to solicit responses to multiple choices or direct measurements to minimize subjectivity and errors in data recording and entry. The study also identified potential planting sites, registering suitability for tree growth, site characteristics, and dimensions. Data fields were designed to be quantitative or convertible to ordinal ranks to facilitate statistical analysis. Locations of trees and planting sites were marked on large-scale maps to permit spatial analysis. Besides statistical analysis, community ecology attributes and custom-designed indices were used to assess urban forest structure. The multipurpose method could be appropriately adjusted for use in other compact city areas.

Key Words. Compact city; forest structure; heritage tree; Hong Kong; planting plan; species composition; species diversity; tree census.

Tree surveys have been widely used by urban foresters to collect objective and quantitative data on trees and their growth environment (Johannsen 1975; Weinstein 1983). Understanding the resource base provides the initial step to improve and rationalize urban forest management and raise the cost–benefit efficiency of tree programs (Tate 1985). The data could facilitate in-depth research into the tree–habitat relationship and evaluate the benefits and functions of urban greening. Whereas researchers are satisfied with a representative sample, many municipal authorities would adopt the inventory or census approach to study every tree within their jurisdiction.

The use of computer technology to store and analyze data was reported initially by McPherson et al. (1985) and Warrick and Williams (1993). Subsequently, developments in information technology triggered the application of the geographic information system (GIS) spatial analysis tools (Dwyer and Miller 1999; Pauleit and Duhme 2000). Street and park tree inventory has been conducted in different cities, exemplified by Chacalo et al. (1994) in Mexico City, Poracsky and Scott (1999) in Portland, Cheng et al. (2000) in Tokyo, Banks and Brack (2003) in Canberra, and Frank et al. (2006) in Greater Melbourne. Good-quality tree information gleaned from tree surveys is a key ingredient of sustainable urban forestry (Dwyer et al. 2003).

The urban forest in Hong Kong has been studied since the early 1980s. It began with roadside trees. The tree survey methodology was applied to trees planted or growing spontaneously in special ecologic habitats. They include trees of heritage value (Jim 1994a, 2004a, 2005), old stone retaining walls (Jim 1998a), urban parks (Jim 2000), new towns, institutional grounds, recreational beaches, and indoor shopping malls. Detailed data on approximately 40,000 urban trees have thus far been collected and used for research and management. A study on 40,000 trees in approximately 100 public housing estates is due for completion in mid-2008. The arboricultural and urban forestry research experience gained in Hong Kong has been applied to other Chinese cities, including Guangzhou, Nanjing (Jim and Liu 2001; Jim and Chen 2003), Shenzhen, and Taipei (Jim and Chen 2008).

The intensive urban tree studies in Hong Kong have yielded valuable data and insights into the conditions and constraints for tree growth in one of the most compact cities in the world. The findings contribute to the understanding of arboriculture and urban forestry in tropical cities. They have been used by tree managers and informed official policies on tree planting, protection, and management. This article has chosen the broad-based generic studies of roadside trees, complemented where appropriate by studies in other habitats, to illustrate the comprehensive assessment of urban forests in Hong Kong. It evaluates the objectives, scope, principles, methods, approaches of urban forestry research, and applications in Hong Kong. Besides biomass structure and species composition, the study explored the interplay between trees and the tight urban fabric and the potential to improve the quantity and quality of urban trees. The specific research objectives are: 1) to survey existing street trees; 2) to search for potential street-tree planting sites; 3) to interpret the results and offer recommendations; and 4) to design a master planting and management plan.

The survey covered all the public roads in the study area. Because the sampling intensity was 100%, the study denoted a tree census.

STUDY AREA AND METHODS

Where and When Was the Assessment Performed?

The study was initiated in 1985 as a preliminary investigation (Jim 1986), in 1994 as a comprehensive tree census (Jim 1994b), and repeated in 2004 as a detailed study of a sample. In the intervening time, surveys were conducted on new roads and existing roads with newly planted trees or notable tree replacements. The study area covered the built-up parts of the core around Victoria Harbor. It included ten urban districts with 124 km^2 (49.6 mi^2) containing 3.28 million people in 0.94 million households. The exceptionally high development density in the compact city reaches an average of 26,452 persons/km^2, and peak spots exceed 100,000 persons/km^2. The city was founded in 1841, but most parts have been redeveloped to a high intensity, especially in the last four decades.

The developed areas have high coverage by buildings and roads with little spaces for greening. Built-up areas are often completely sealed by concrete, asphalt, or buildings and most roadsides have no planting strips or tree pits. Many development sites have 100% site coverage with no room left for intralot trees. Urban renewal tended to increase the site coverage and building density and eliminate existing trees and plantable spaces. Continual infilling of low-density sites often obliterated on-site trees. Pavements are narrow and heavily used with little chance for tree planting. Frequent road excavations and trenching regularly injure tree roots. The survey focused on roadside trees, which are the most cramped and stressful tree sites.

What Data Were Collected?

The study collected two sets of data. The first covered existing roadside trees with the help of a field record form (Table 1). It was pilot-tested and refined before actual data collection. It gathered detailed data on the roadside microhabitat, including general site conditions and specific tree growth space characterization. It then measured tree structural attributes followed by systematic assessment of critical morphologic symptoms of growth problems.

It was necessary to define the scope of the study to focus on the target trees. Roadside trees included those found in the following habitats: 1) pavement; 2) planting spaces in the form of tree lawn, tree strip, or raised planting bed that are situated between the curb and the property line; 3) incidental plots of public land that are physically contiguous to the pavement and construed as part and parcel of a street; 4) central divider or road–median positions; 5) traffic islands and roundabouts surrounded by carriageways but not designed as gardens or other formal amenity open spaces; 6) spaces below flyovers or foot bridges; and 7) planters, both fixed and movable types, placed on the previously mentioned habitats.

Trees in the following types of habitats were excluded from the survey: 1) slopes adjacent to roads; 2) along nonbuilt-up stretches of roads; 3) roads with restricted access to the general public; and 4) trees lying within building land lots.

The second part of the study searched for potential tree planting sites at roadsides based on a separate record form (Table 2). The same inclusions and exclusions listed previously were adopted. As a result of the tight roadside spaces, the three-dimensional volume and shape of the potential planting site were emphasized. Each potential planting site was assessed according to building setback, land use, and adjacent surface type (sealed by concrete, porous pavers, or open soil). The dimensions of the plantable corridor were measured, including ground width, building awning width, awning height, site length, number of traffic lanes, and presence of adjacent car parking space (Figure 1). The boundaries of all potential planting sites were drawn on large-scale (1:1,000) maps. The findings were used to design a 5-year planting plan.

How Were the Data Collected?

The tree survey was preceded by a reconnaissance of roadside trees in different kinds of sites in the study area to learn about tree growth, environmental impacts, and tree responses. The rather common physical and physiological constraints to tree growth were emphasized. Knowledge about the acute limitations at roadsides helped to design the field record form (Table 1).

University students in geography or ecology with field work experience were trained as research assistants. Each team with two members was assigned a work area. The study was labor-intensive and time-consuming, demanding many hours of field assessments. It was important to minimize subjectivity and to calibrate judgment, especially regarding tree defects and disorders.

Training began as induction lectures to expound basic concepts in arboriculture, urban forestry, and site and tree characteristics. The lectures were abundantly illustrated with color slides of local roadside trees. Visual images were far more effective in conveying information and leaving recallable imprints. Essential visual guides to common arboricultural problems (e.g., Matheny and Clark 1994; Lonsdale 2000) and key reference books (e.g., Grey and Deneke 1986; Shigo 1991; Bradshaw et al. 1995; Miller 1996; Watson and Himelick 1997; Harris et al. 2004) were available to the assistants.

After acquiring the basic knowledge, the assistants were shown slides of tree–environment and tree defects–disorders scenarios listed in the record form and practice assessment in the classroom. Relevant concepts were explained to ascertain that data would be collected with good understanding of the underlying rationales. The helpers also learned the capabilities and limitations of the field observation and measurement methods. It was important to ensure that data collection would be a well-considered and fully understood exercise rather than a mechanical and prosaic routine. As an essential part of the interactive and collective learning process, they were encouraged to raise queries, discuss, and jointly fill in the record forms. A problem-oriented approach was adopted to learn by questions and answers and through active discussions, participation, engagement, and interactions. The coherent group of 12 students facilitated intensive coaching and direct person-to-person communication.

On satisfactory completion of classroom training, the assistants were taken to different sites to rehearse real-world studies. Their field assessment skills were further honed by hands-on training. Most importantly, misconceptions could be promptly explained, rectified, or dispelled. The critical concern of standardization was gradually inculcated. Thereafter, they proceeded to collect live data. Initially, the author took turns accompanying different groups in the field to observe their work and provide comments and advice. They also recorded queries encountered in the survey and discussed these with the author on a regular basis. All initial data were checked for accuracy and consistence. Gradually the need for monitoring was reduced as they gained experience and confidence.

As a result of the diverse roadside tree flora in the tropical city, species identification presented challenges. Students learn to recognize common species in an urban park. Each group was equipped with reference books with tree photographs, botanical descriptions, and a dichotomous identification key (Thrower 1988; Jim 1990). Botanical references of the nearby cities of Guangzhou (Hou 1956; South China Botanical Institute 1987, 1991, 1995, 2000, 2003, 2005, 2006) and Taiwan (Lin 1960),

Table 1. Record form for the field survey of roadside trees in urban Hong Kong.

(A) Basic information

Group ____________________

Date (D) _____(M)_____ (Y)_____

Map ref. ____________________

Street ____________________

____

Tree no. ____________________

Species ____________________

____

Species code ______________

(B) Site characteristics

Building setback:

1. Building with setback
2. Building without setback
3. No building

Land use:

1. High density—commercial
2. High density—commercial and residential
3. High density—residential
4. Medium density—residential
5. Low density—residential
6. Government, institutional, and community
7. Industrial
8. Temporary use
9. Open space
10. Hillside
11. Other ________________

Adjacent surface:

1. Sealed
2. Pervious pavers
3. Open soil

(C) Growing space

Roadside location:

1. Pavement
2. Road edge—vehicle side
3. Road edge—building side
4. Road center
5. Center of lane or street
6. Terrace
7. Cul-de-sac
8. Traffic island
9. Incidental plot
10. Other ________________

Type:

1. Tree pit—with grille
2. Tree pit—no grille
3. Irregular opening
4. Paved to trunk base
5. Tree strip
6. Planter—movable
7. Planter—fixed
8. Other ________________

Protection:

1. Level—with enclosure
2. Level—no enclosure
3. Raised—with enclosure
4. Raised—no enclosure

Guard or support:

1. Tree guard
2. Permanent support
3. Temporary support
4. Nil

Site dimensions:

Ground width ____________m

Awning width ____________m

Awning height ___________m

Soil width _______________m

Trunk-to-curb ____________m

Traffic lanes ___________(no.)

Parking space __________(0/1)

(D) Tree structure

Dimensions:

Girth __________________cm

Height __________________m

(D = __________________m)

(Angle = _____________deg.)

(Observer ht. ___________m)

Crown __________________m

Crown restriction:

1. No restriction
2. Property side
3. Road side
4. Both sides

(E) Defects and disorders

Surface or roots:

1. Cracked paving
2. Heaved paving
3. Exposed roots
4. Girdling roots
5. Adventitious sprouts
6. Low soil level
7. Compacted soil

Trunk:

8. Leaning
9. Curved or crooked
10. Large wound (>1/2 diameter)
11. Cavity—good cover
12. Cavity—poor cover
13. Cavity—no cover
14. Tree-tie injury
15. At or beyond curb
16. Vandal evidence

Branching:

17. Low branches (<2 m [6.6 ft])
18. Multiple stems
19. V-crotch
20. Embedded bark
21. Crossed branches
22. Branch stub
23. Lost limb
24. Fungal stool

Crown or foliage:

25. Sparse crown/foliage
26. Unbalanced crown
27. Stunted crown
28. Leaf wilting/yellowing
29. Leaf damage/deformation
30. Advertisement sign conflict

Hindrance to growth:

31. Trunk
32. Crown headroom
33. Crown lateral room

Overall rating:

1. Excellent
2. Good
3. Fair
4. Poor
5. Dying

(F) Special features

(G) Sketch

with similar tree flora, were consulted. For uncommon species, foliage samples were taken for identification in the laboratory. Difficult cases were handled by government or university herbarium staff.

Tree height and crown width were measured by an electronic range finder and an Abney level (using the trigonometric method). Trunk girth was measured at 1.3 m (4.3 ft) from the ground by a diameter tape. The vertical and horizontal dimensions of existing tree sites and potential planting sites were also measured. The locations of the trees and planting sites were plotted initially on paper maps and transferred to digital maps. Subsequently, an infrared beam hypsometer requiring attaching a transponder on the tree trunk was used to measure height. Recently, an improved laser beam hypsometer eliminated the need for a transponder and permitted faster and more accurate measurements. The use of a pocket computer to record data directly in digital form has been tested.

How Were the Data Analyzed?

A database structure was designed and the raw data of approximately 20,000 trees were entered into a Microsoft Excel (Microsoft, Redmond, WA, U.S.) database with the help of numeric codes to facilitate statistical analysis. The qualitative variables were converted into ordinal ranks to permit nonparametric sta-

Table 2. Record form for the field survey of potential roadside tree planting sites in urban Hong Kong.

(A) Basic information

Group______________________
Date (D) _____(M)____19____
Map ref. __________________
Street_____________________
____
Street no. _________________
to _______________________
Site code __________________

(B) Potential suitability

Classification:
1. Impossible—1 2 3
2. Acceptable—4 5 6
3. Ideal—7 8 9

Width of plantable corridor:
1. >2 m (6.6 ft)
2. <2 m (6.6 ft)

Roadside parking space:
1. Yes
2. No

(C) Site characteristics

Building setback:
1. Building with setback
2. Building without setback
3. No building

Land use:
1. High density—commercial
2. High density—commercial and residential
3. High density—residential
4. Medium density—residential
5. Low density—residential
6. Government, institutional, and community
7. Industrial
8. Temporary use
9. Open space
10. Hillside
11. Other _________________

Adjacent surface:
1. Sealed
2. Porous paver
3. Open soil

(D) Growing space

Roadside location:
1. Pavement
2. Road edge—vehicle side
3. Road edge—building side
4. Road center
5. Center of lane or street
6. Terrace
7. Cul-de-sac
8. Traffic island
9. Incidental plot
10. Other ______________________

Dimensions:
Ground width _________________ m
Awning width_________________ m
Awning height ________________ m
Traffic lanes ________________ (no.)
Parking space _______________ (0/1)
Length ________________________ m

(E) Remarks

(F) Sketch

tistical analysis. Drop-down menus were designed for most data cells to facilitate data entry and minimize input errors. After thorough checking and correction, the database was read by the SPSS PC software (SPSS Inc., Chicago, IL) for statistical analysis. Tables were constructed to show the frequency of individual species with reference to tree dimensions, site conditions, and tree performance. Tables were also compiled for individual districts and streets. Pearson's correlation coefficients and χ^2 contingent coefficients were computed, respectively, for continuous and categorical data. Principal component (factor) analysis was used to probe the multivariate relationships.

Species diversity was analyzed by indices used in community ecologic and vegetation science (Mueller-Dombois and Ellenberg 1974; Greig-Smith 1983), including species richness, Shannon-Wiener diversity index, Simpson diversity index, and Evenness index. Species similarity between tree communities, namely among districts, road categories, and land use types, was computed by the Jaccard similarity index (Seaby and Henderson

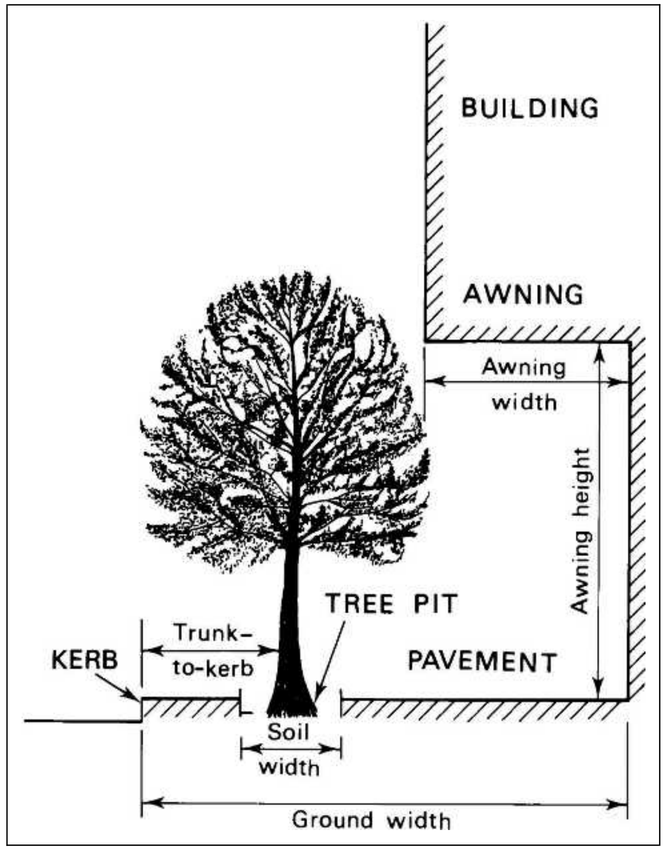

Figure 1. The definitions of five linear measurements that were made at each roadside tree site to detect the present and future physical limitations to tree growth.

2004). Four new urban tree indices to denote tree pattern in the linear habitat were developed, namely linear tree density (number of trees per kilometer of road length), linear species density (number of species per kilometer of road length), linear tree cover (aggregate tree canopy cover in square meters per kilometer of road), and linear tree biomass (aggregate crown volume in square meters per kilometer of road).

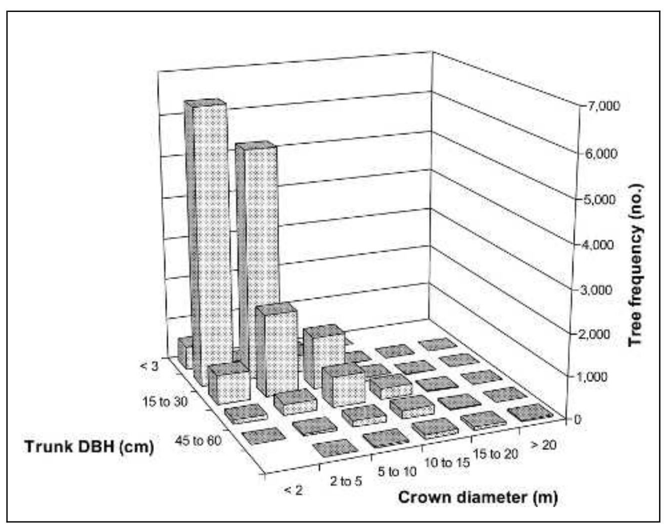

Figure 2. The frequency of roadside trees in relation to trunk diameter at breast height and crown diameter.

The capacity of each potential planting site to hold trees was evaluated. The data on land use, general environmental quality, three-dimensional site geometry, and existing species frequencies were used to develop an elaborate site-by-site matching exercise to find the optimal species. The sites were divided into five lots for implementation over a 5-year period. Neighborhoods at present with fewer trees were given priority. A planting material demand profile was developed for advanced ordering to trigger their timely production in nurseries. A key purpose of giving advanced notification to the landscape industry was to facilitate a transformation from the deeply ingrained supply-led to a demand-led situation.

Why Were Data on Individual Trees Collected?

A comprehensive range of qualitative and quantitative information was collected (Tables 1 and 2). As far as practicable, multiple-choice answers were given on the record form to minimize subjectivity, ensure consistency, and facilitate data entry. Non-multiple-choice answers were confined to unambiguous attributes such as street name, species names, tree number, distance and angle measurements, or simple counting. The following types of data were solicited for each target tree (Table 1):

(1) Basic information:
Research assistant group identification number,
Field survey date,
Map reference,
Street name,
Tree serial number,
Species name in Latin binomial, and
Abbreviated species code;

(2) Site characteristics:
Building setback, recording whether adjacent building was set back from the property boundary to permit tree crown expansion,
Land use, choosing one of the ten choices based on official classification, and
Adjacent surface, evaluating access of the soil around the tree to moisture, aeration, and fertilization, including the undesirable sealed surface (concrete, cement, or asphalt), less restrictive pervious pavers, and open soil;

(3) Growing space:
Roadside location, recording whether the tree was situated within the confines of the pavement, carriageway, property front, road median, street center, terrace or a cul-de-sac, traffic island, incident roadside plot, or other location,
Growing space, characterizing the microhabitat of a tree, including tree pit with or without a grille, irregular opening in the paved area, no opening (with concrete or asphalt paving up to the trunk base), planting strip, movable or fixed planter, and other types,
Protection of growing space such as level or raised edges in relation to the surrounding ground surface and the presence or absence of enclosure,
Guards or support such as tree guard, permanent or temporary tree stake or a similar structure, or no support, and
Site dimension, recording the linear horizontal or vertical measurements shown in Figure 1, the number of traffic lanes perpendicular to the tree, and whether on-street car parking space was available adjacent to the tree;

(4) Tree structure:
Trunk girth, measuring at 1.3 m (4.3 ft) from the ground; if branching height was lower than 1.3 m (4.3 ft), the girth was measured immediately below the first branch; for multiple stemmed trees, the girths of the trunks were summed,
Tree height using the trigonometric approach,
Crown diameter measured by an electronic range finder; for evidently asymmetric crowns, the average of the maximum and minimum diameters was recorded, and
Gap between crown and adjacent structure; if it was less than three-fourths of the crown diameter, the location of crown restriction (property, carriageway side, or both) was recorded;

(5) Defects and disorders:
Detailed evaluation of individual trees was made according to 33 common physical and physiological ailments placed under five groups, and
Overall rating of tree performance, classifying a tree according to a 5-point scale (excellent, good, fair, poor, and dying);

(6) Special features/remarks:
Any unusual observation not solicited in the record form was recorded; and

(7) Sketch:
Where necessary, a simple sketch of the tree and its immediate environs was drawn to explain unusual observations.

Why Were Data on Potential Planting Sites Collected?

The search for potential planting sites followed Table 2. Some attributes were similar to the tree survey, and only those unique to the site survey would be explained:

(1) Basic information:
Street number, referring to the starting and end point of the potential planting site, and
Site code, a serial identification number;

(2) Potential suitability:
Site classification aided by a synoptic diagram of different roadside configuration vis-à-vis tree planting and growth potential,
Width of the plantable corridor, which should be greater than 2 m (6.6 ft), and
Roadside parking space, indicating opportunities to insert trees outside the curb line between the ends of parking spaces, where awning and other restrictions often did not allow planting inside the curb line; it could provide more room for tree crowns to expand above the carriageway without causing unacceptable traffic or sightline obstructions;

(3) Site characteristics:
The same attributes for the tree survey were recorded;

(4) Growing space:
Two attributes, namely roadside location and site dimensions, were recorded using the same format as the tree survey;

(5) Underground constraints:
Undertaken by government tree management staff in conjunction with other departments and utility companies when the sites were actually used for tree planting;

(6) Remarks:
Unusual features not solicited in the previously mentioned attributes were recorded; and

(7) Sketch:
Where it helped to illustrate special observation, a sketch would be drawn.

RESULTS AND DISCUSSION

Advantages and Disadvantages of the Data Collection Approach

The data collection approach has the advantage of covering all target trees in the study area in a census. It could avoid possible sampling errors and problems of representation of different population strata (Jaenson et al. 1992; Alvarez et al. 2005). The data were either quantitative or could be converted into ordinal ranks to facilitate statistical analysis. Plotting the locations of trees and potential planting sites on digital maps permitted spatial analysis of the distribution pattern. Detailed information covered not just individual trees, but also planting sites and the immediate environs. Information on physical constraints to tree growth, including present and future restrictions, and symptoms of main tree defects and disorders could help tree managers design the tree maintenance strategy and program.

The information on potential planting sites allowed advanced planning to improve the geographic spread, species diversity, and landscape contribution of roadside trees in different districts. The implementation of the synoptic planting plan is firmly based on in-depth understanding of ground truths at the potential planting sites. The recommended species could take into consideration existing species makeup and projection of the landscape, amenity, and environmental and ecologic needs of the area in the future. Different neighborhoods could be allotted a certain signature species to accentuate local landscape identity.

The findings could assist tree managers to identify the strengths and weaknesses of the existing urban tree program and design the future management plan according to the identified problems, priorities, and resource envelope. More importantly, the systematic data analysis could yield useful hints to avoid past pitfalls in site preparation, species selection, and tree care; reinforce the good choices and practices; and find new or alternative ways to tighten and enhance the urban tree management package. Overall, the method is comprehensive in scope and depth to serve multiple purposes. The tree survey could be expanded to include a questionnaire survey of citizens' preferences (Schroeder et al. 2003) and attitudes (Schroeder et al. 2006) so that the urban forestry program could be adjusted to the community's wishes. Opinions of professional urban foresters could also be explored to identify institutional factors and predictors of better tree performance and management (D'Amato et al. 2002; Lewis and Boulahanis 2008).

The approach has its disadvantages. It demanded much labor input and the corollary of a sizeable financial compensation to tree surveyors over an extended period. It required assistants with good knowledge and skills of urban forestry and arboriculture and competence in species identification. It necessitated many hours of laborious evaluation of trees and tree sites in the field, filling in a detailed record form and inputting the data into a computer database. Over an extended period, experienced team members would leave and new members had to be recruited and trained.

For attributes involving open-ended (nonmultiple choices) answers, inconsistency in judgment by different surveyors may lower data quality. The possible sources of errors are registration of wrong records in the field and erroneous judgment, measurements, and species identification. Additional errors could also be introduced at the data entry stage.

The database could be stored centrally in a network server with access rights assigned to tree managers at the central and district levels. Data collected in this manner have a certain life span. Updating could be coordinated at the management level. Each district's tree manager will modify the database on a monthly basis to record tree felling, planting, major maintenance operations, changes in tree performance, and alterations in planting site conditions. A continually and diligently updated database could maintain its usefulness for many years. It is recommended that the tree survey should be repeated once every 10 years to overhaul the information, which will offer chances to introduce new tree survey methods and attributes associated with the latest research findings and practices.

The positions of the individual trees were plotted on maps with the help of the AutoCAD program (Autodesk Inc., San Rafael, CA). Because global positioning satellite (GPS) programs are now widely available at a reasonable cost, the technology could be integrated into the field survey methodology to record the locations of trees with reference to a local coordinate system. The spatial data could be transferred to a GIS program to facilitate research and planning for tree management. Once digitized in a GIS setting, the spatial data of trees and potential planting sites could be efficiently analyzed and depicted. The integration of GIS and GPS technologies in urban tree surveys was initiated in the late 1990s (Widdicombe and Carlisle 1999) with recent emergence of some proprietary software products.

Photographic records of individual trees or tree groups taken at different times, using the repeat photography method, could yield useful information on changes in urban vegetation. Sequential aerial photographs could trace the changes in urban tree cover in response to urbanization effects (Jim 1989; Nowak 1993).

Species Composition and Diversity

The census recorded approximately 20,000 trees from 149 different species. Considering the size of the study area and the human population, the number of street trees was rather limited. Comparison with other south Chinese cities such as Guangzhou and Taipei indicates the lack of street trees in Hong Kong (Table 3). It signified an improvement in comparison with approximately 10,000 trees found in the 1985 survey. The severe constraints to roadside trees in the cramped urban environment were reflected by the survey results. The large number of species represented a surprisingly high botanical diversity uncommonly found in other city streets. The 149 species have been classified into five groups with respect to frequencies (Table 4).

The roadside trees were dominated by a small cohort of common species with the top eight taking up 50% and the top 14 comprising approximately two-thirds of the total stock. A similar pattern of dominance was found in Guangzhou and Taipei (Table 3). Only the top 17 species had individual frequencies exceeding

Table 3. Frequency of occurrence of the top 20 common street trees in three south Chinese cities.

Rank		Species[z]	Family	Growth form[y]	Final height[x]	Frequency	Percent	Cumulative percent
(a) Hong Kong (total 19,154 trees)								
1		*Aleurites moluccana*	Euphorbiaceae	BLE	Medium	2,474	12.92	12.92
2		*Melaleuca quinquenervia*	Myrtaceae	BLE	Medium	1,444	7.54	20.46
3		*Phoenix roebelenii*	Arecaceae	Palm	Small	1,337	6.98	27.44
4		*Livistona chinensis*	Arecaceae	Palm	Medium	1,325	6.92	34.36
5		*Caryota ochlandra*	Arecaceae	Palm	Medium	1,018	5.31	39.67
6		*Archontophoenix alexandrae*	Arecaceae	Palm	Medium	688	3.59	43.26
7	#	*Bombax malabaricum*	Bombacaceae	BLD	Large	648	3.38	46.65
8		*Delonix regia*	Caesalpiniaceae	BLD	Large	647	3.38	50.02
9		*Cassia siamea*	Caesalpiniaceae	BLE	Large	573	2.99	53.02
10		*Cassia surattensis*	Caesalpiniaceae	BLE	Small	520	2.71	55.73
11	#	*Ficus microcarpa*	Moraceae	BLE	Large	476	2.49	58.22
12		*Washingtonia robusta*	Arecaceae	Palm	Medium	473	2.47	60.69
13		*Ficus benjamina*	Moraceae	BLE	Large	445	2.32	63.01
14	#	*Hibiscus tiliaceus*	Malvaceae	BLE	Medium	437	2.28	65.29
15		*Crateva unilocularis*	Capparidaceae	BLD	Medium	429	2.24	67.53
16		*Thevetia peruviana*	Apocynaceae	BLE	Small	421	2.20	69.73
17		*Acacia confusa*	Mimosaceae	BLE	Medium	415	2.17	71.89
18	#	*Bauhinia blakeana*	Caesalpiniaceae	BLE	Small	382	1.99	73.89
19		*Roystonea regia*	Arecaceae	Palm	Large	363	1.90	75.78
20	#	*Albizia lebbeck*	Mimosaceae	BLD	Large	312	1.63	77.41
						14,827	77.41	
(b) Taipei (total 37,612 trees)								
1	#	*Cinnamomum camphora*	Lauraceae	BLE	Large	6,792	18.06	18.06
2	#	*Ficus microcarpa*	Moraceae	BLE	Large	5,873	15.61	33.67
3	#	*Koelreuteria elegans*	Sapindaceae	BLD	Small	3,675	9.77	43.44
4		*Melaleuca quinquenervia*	Myrtaceae	BLE	Medium	2,122	5.64	49.09
5	#	*Bischofia javanica*	Euphorbiaceae	BLD	Large	2,042	5.43	54.51
6	#	*Liquidambar formosana*	Hamamelidaceae	BLD	Large	1,907	5.07	59.58
7		*Roystonea regia*	Arecaceae	Palm	Large	1,767	4.70	64.28
8	#	*Ulmus parvifolia*	Ulmaceae	BLD	Small	1,208	3.21	67.49
9		*Bombox malabaricum*	Bombacaceae	BLD	Large	1,110	2.95	70.45
10		*Ficus religiosa*	Moraceae	BLD	Large	1,065	2.83	73.28
11		*Peltophorum pterocarpum*	Caesalpiniaceae	BLD	Medium	764	2.03	75.31
12		*Lagerstroemia speciosa*	Lythraceae	BLD	Small	751	2.00	77.31
13		*Alstonia schloaris*	Apocynaceae	BLE	Medium	739	1.96	79.27
14		*Terminalia mantalyi*	Combretaceae	BLD	Medium	562	1.49	80.76
15		*Ficus elastica*	Moraceae	BLE	Large	455	1.21	81.97
16		*Erythrina indica*	Fabaceae	BLD	Medium	418	1.11	83.09
17		*Pongamia pinnata*	Fabaceae	BLD	Medium	309	0.82	83.91
18		*Mangifera indica*	Anacardiaceae	BLE	Large	259	0.69	84.60
19		*Phoenix roebelenii*	Arecaceae	Palm	Small	235	0.62	85.22
20	#	*Pistacia chinensis*	Anacardiaceae	BLD	Medium	188	0.50	85.72
						32,241	85.72	
(c) Guangzhou (total 46,930 trees)								
1	#	*Ficus virens*	Moraceae	BLD	Large	8,072	17.20	17.20
2		*Bauhinia blakeana*	Caesalpiniaceae	BLE	Small	4,244	9.04	26.24
3		*Aleurites moluccana*	Euphorbiaceae	BLE	Medium	3,485	7.43	33.67
4	#	*Ficus microcarpa*	Moraceae	BLE	Large	3,296	7.02	40.69
5	#	*Bauhinia variegata*	Caesalpiniaceae	BLD	Small	3,094	6.59	47.29
6		*Chukrasia tabularis*	Meliaceae	BLE	Large	2,880	6.14	53.42
7		*Melaleuca quinquenervia*	Myrtaceae	BLE	Medium	2,678	5.71	59.13
8	#	*Bombax malabaricum*	Bombacaceae	BLD	Large	2,253	4.80	63.93
9		*Casuarina equisetifolia*	Caesalpiniaceae	BLE	Large	2,016	4.30	68.23
10		*Mangifera indica*	Anacardiaceae	BLE	Large	1,260	2.68	70.91
11		*Acacia auriculiformis*	Mimosaceae	BLE	Medium	1,177	2.51	73.42
12		*Michelia alba*	Magnoliaceae	BLE	Large	1,087	2.32	75.73
13		*Syzygium grande*	Myrtaceae	BLE	Medium	932	1.99	77.72

(*continued*)

Table 3. Frequency of occurrence of the top 20 common street trees in three south Chinese cities. (*continued*)

Rank		Species[z]	Family	Growth form[y]	Final height[x]	Frequency	Percent	Cumulative percent
14		*Khaya senegalensis*	Meliaceae	BLE	Large	817	1.74	79.46
15		*Cleidiocarpon cavalieri*	Euphorbiaceae	BLE	Large	662	1.41	80.87
16	#	*Ficus altissima*	Moraceae	BLE	Large	595	1.27	82.14
17		*Livistona chinensis*	Arecaceae	Palm	Medium	375	0.80	82.94
18		*Lagerstroemia indica*	Lythraceae	BLD	Small	354	0.75	83.69
19		*Mangifera persiciformis*	Anacardiaceae	BLE	Small	353	0.75	84.44
20		*Cassia surattensis*	Caesalpiniaceae	BLE	Small	352	0.75	85.19
						39,982	85.19	

[z]# = the species is native to the city in question.
[y]Growth form is classified into: BLE = broadleaf evergreen; BLD = broadleaf deciduous and palm; no conifers are found in the top 20 common species.
[x]Final tree height is classified into: small for less than 9 m (29.7 ft), medium for 9 to 18 m (29.7 to 59.4 ft), and large for greater than 18 m (59.4 ft).

2%. Among the less common species, some were cultivated in the past and yet remained rare, and some were only recently used at roadsides in the study area. A small number was inherited from pre-existing woodlands or gardens. Overall, the tree population was mainly represented by a limited range of common species, but the species diversity was notably enriched by many uncommon species. Tree selection for urban planting in the future could explore the large pool of uncommon species.

By growth form, the domination by broad-leaved trees versus other growth forms was evident (Table 5). Evergreen trees contributed 83.4%, and the overall distribution of growth form was consistent with the regional humid subtropical climate and south China flora. By geographic origin, some 82% of the trees and 72.5% of the species were exotic; such a heavy reliance on aliens was not uncommon in other tropical cities (Table 3). Only a few native species managed to become common. Endowment in terms of tree count and species diversity varied notably between districts (Table 6). Tree density also differed a lot among districts. The tree planting plan could bring some redress to the imbalance.

Tree Growth and Environmental Conditions

The stock was dominated by small trees (with less than 15 cm [6 in] diameter at breast height [dbh], less than 5 m [16.5 ft] height, and less than 5 m [16.5 ft] crown spread), which took up two-thirds of the roadside trees (Figure 2). The youthful state reflected the recent spate of assiduous planting efforts. Only approximately 10% of the trees were large (30 to 60 cm [12 to 24 in] dbh) and exceptionally large (greater than 60 cm [24 in] dbh). Such a size bias indicated that many trees failed to reach their biologic maximum dimensions as a result of the inordinately poor roadside environment and widespread mistreatment and that not many species with large potential size were planted in the past.

The study has identified some outstanding specimens, the champion trees, for special care and protection. Many of these previous trees were inherited from the past when the tree growth environment was more conducive to good performance. The survey finds drastic deterioration in their growth site both in the soil and the aboveground conditions. They call for dedicated measures to improve site conditions to ensure that the valuable remnant trees could persist as natural-cum-cultural heritage of the community (Jim 2005). The large specimens in good condition, constituting the champion trees, should be added to the champion tree collection.

By growth space, grass strips situated either adjacent to pavements or at central divider locations were the most common (51.6%). They provided generous above- and belowground growing spaces for tree expansion. Tree pits were the second popular growth space holding 32.8% of the trees; approximately two-thirds had a grille mainly installed in recent years. Some 11.5% of the trees were accommodated in planters with approximately three-fifths fixed and the rest movable. Approximately 2.8% of the trees were restricted in irregular openings or with concrete paved to their trunk base. Many exceptionally large trees were found in limited growth spaces attributable mainly to land-use changes. Large and medium trees were found mainly in tree pits or grassed strips. Small trees were heavily concentrated in grassed strips.

Trees in high-density urban areas commonly experience the grave shortage of growth space both below and above the ground (Attorre et al. 2000). Tree growth in Hong Kong was widely hampered by various physical and physiological obstacles. Most trees were confined to narrow tree pits or planting strips, and the recently planted ones had more soil rooms. Off-pavement sites were better off with wider grass strips. Some trees were beset by a mismatch between site and final tree dimensions. Because most trees were planted at places without building awnings, the lateral and vertical limitations resulting from this constraint were not common. Physical restrictions to tree growth were common at roadside habitats. It was therefore understandable, if not expected, that the street-tree population is so small. High-quality sites were uncommon, and most trees were planted under suboptimal conditions. The temporary nature of some sites resulting from frequent road and building works imposed additional constraints.

The detailed tree survey data that include species and tree dimensions could be used to assess the environmental and ecologic benefits of the urban forest. The development of the CITYgreen software (American Forests, Washington, DC) expands the GIS capability to the synoptic evaluation of urban tree canopy cover and associated environmental benefits (Dwyer and Miller 1999; American Forests 2004). A similar method was developed to evaluate the spatial pattern of urban tree cover in Munich and to assess its environmental benefits (Pauleit and Duhme 2000).

The survey data could serve as inputs into the Urban Forest Effects (UFORE) model to provide detailed assessment of the environmental benefits (Nowak and Crane 2000; Nowak et al. 2000). Other evaluation and computation methods have also been applied to estimate the environmental benefits of urban forests (e.g., Maco et al. 2004). The ecosystem services could be translated into economic value and monetary units to facilitate

Table 4. Roadside tree composition in Hong Kong according to five frequency groups.

		Number of trees		Number of species	
Frequency group	Frequency range	Count	Percent	Count	Percent
Dominant	Greater than 500	10,674	55.7	10	6.7
Abundant	150 to 500	5,121	26.7	14	9.4
Frequent	50 to 149	2,249	11.7	23	15.4
Occasional	10 to 49	856	4.5	33	22.1
Rare	Less than 10	254	1.3	69	46.3
	Total	19,154	100	149	100

understanding of tree values (McPherson et al. 1997; Tyrväinen and Miettinen 2000; Jim and Chen, in press). Benefit–cost analysis of individual species could provide hints to selection of species to maximize their benefits (McPherson 2003). Such findings could provide strong justifications to preserve tree budgets and to compete with other claims for municipal funding.

Potential Planting Sites

A total of 1,094 potential planting sites with a maximum capacity for 12,063 trees were visually identified in the survey. All plantable locations have been marked on 1:1,000 large-scale maps. The sites were unevenly distributed in districts and regions with Kowloon East taking up 49%, Hong Kong East 22.7%, Hong Kong West 14.8%, and Kowloon West 13.5%. For the study area as a whole with at present 509 streets with trees, a further 389 more could be greened.

Most potential planting sites were small, each with room for less than 13 trees, including many that could accommodate only a few. Only 138 sites could hold more than 20 trees, and only six were large enough for more than 60. On average, each site could encompass 11 trees and each street 31 trees. Thus, the sites were both small and scattered. By dimensions, most sites were shorter than 100 m (330 ft) and narrower than 5 m (16.5 ft). Some 89% of the sites were free from awnings, and the same proportion was situated on pavements. Most off-pavement sites had already been enlisted for planting. The spread of sites among different land uses was very uneven. In addition to using field survey, aerial photographs or satellite imageries could offer an additional tool to identify potential planting sites in cities (Wu et al. 2008). However, ground truths with pertinent bearing on tree growth could not be gleaned; hence, at the implementation stage, field evaluation of the planting site would still be necessary.

The actual number of plantable trees could be significantly reduced as a result of various above- and belowground constraints. In practice, at the most, approximately 70% of the sites could actually be used. It was anticipated that these potential sites would be used up soon. Thereafter, plantable sites would have to come from new development and urban renewal areas. The findings demanded a concerted effort to change the town plan if urban roadside greening were to continue in the future. A joint effort between the government and developers, following clearly defined objectives, would be needed to generate additional planting sites in the long term (Jim 2004b).

The poor performance of many trees, particularly at roadsides, calls for an overhaul of the tree establishment practice. The survey data provided telltale information on soil characteristics at the existing tree sites and hints at soil qualities at the potential planting sites. It is particularly important to assess soil quality and soil volume available for root growth, because it has been identified as a serious constraint on tree establishment and

Table 5. Distribution of roadside trees by growth form in ten urban districts of Hong Kong.

	Broadleaf evergreen		Broadleaf deciduous		Conifer and related		Palm and palm-like		Total	
District	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent
Hong Kong West										
Central—Western	601	45.5	233	17.6	24	1.8	463	35.0	1,321	100
Southern	717	53.7	350	26.2	34	2.5	233	17.5	1,334	100
Subtotal	1,318	49.6	583	22.0	58	2.2	696	26.2	2,655	100
Hong Kong East										
Eastern	1,162	42.6	566	20.7	15	0.5	987	36.2	2,730	100
Wan Chai	1,372	66.8	288	14.0	31	1.5	363	17.7	2,054	100
Subtotal	2,534	53.0	854	17.9	46	1.0	1,350	28.2	4,784	100
Kowloon West										
Yau-Tsim	1,049	55.3	267	14.1	20	1.1	560	29.5	1,896	100
Mong Kok	161	40.0	53	13.2	6	1.5	183	45.4	403	100
Sham Shui Po	906	52.0	399	22.9	2	0.1	435	25.0	1,742	100
Subtotal	2,116	52.4	719	17.8	28	0.7	1,178	29.2	4,041	100
Kowloon East										
Kowloon City	1,517	58.3	503	19.3	56	2.2	527	20.2	2,603	100
Wong Tai Sin	1,179	69.3	229	13.5	12	0.7	281	16.5	1,701	100
Kwun Tong	1,441	42.8	288	8.5	76	2.3	1,565	46.4	3,370	100
Subtotal	4,137	53.9	1,020	13.3	144	1.9	2,373	30.9	7,674	100
Total	10,105	52.8	3,176	16.6	276	1.4	5,597	29.2	19,154	100

Table 6. Frequency, diversity, and density characteristics of roadside trees in ten urban districts of Hong Kong.

	Tree frequency		Species richness		Species diversity		Tree density	Street with trees
District	Count	Percent	Count	Percent[z]	Index[y]	Rank	trees/km^2	No.
Hong Kong West								
Central—Western	1321	6.9	76	51.0	5.8	2	107	52
Southern	1334	7.0	66	44.3	4.9	3	34	55
Hong Kong East								
Eastern	2730	14.3	63	42.3	2.3	9	147	59
Wan Chai	2054	10.7	77	51.7	3.7	4	207	62
Kowloon West								
Yau-Tsim	1896	9.9	57	38.3	3.0	5	487	44
Mong Kok	403	2.1	39	26.2	9.7	1	255	24
Sham Shui Po	1742	9.1	52	34.9	3.0	6	204	41
Kowloon East								
Kowloon City	2603	13.6	67	45.0	2.6	8	268	86
Wong Tai Sin	1701	8.9	48	32.2	2.8	7	182	39
Kwun Tong	3370	17.6	52	34.9	1.5	10	305	47

[z]Species richness (%) = (species count/149) × 100%; total number of species equals 149.
[y]Species diversity index = (species count/tree count) × 100.

growth in compact cities (Jim 1998c; Pauleit et al. 2002). The need to ameliorate impervious soil sealing and soil compaction problems before tree planting cannot be more emphatically stressed (Jim 1998b; Herz et al. 2003). The potential planting site survey found some locations that could accommodate large tree pits, tree strips, or soil corridors to improve long-term tree growth (Bühler et al. 2007). The need for soil replacement and soil improvement by amendments could also be assessed with the help of the survey data. Instead of sticking to the standard and anachronistic tree pit design that traps newly planted trees in a tiny soil volume of 1 m^3 (35 ft^3), it is necessary to provide custom-designed solutions to individual planting sites to tackle a chronic problem in local tree growth.

Species Recommendation and Planting Plan

Information on the recommended species was compiled to assist tree selection. The most important consideration was finding an optimal match between site characteristics and final tree dimensions. The width of the plantable site was the primary criterion in species selection. Other site attributes included building setback, awning, roadside location, and land use. For the species, attainable height (exceptionally large, greater than 15 m [49.5

Table 7. An extract of the 5-year roadside tree planting plan showing the assignment of suitable number of trees and species to individual potential planting sites identified in the course of the tree census.

Serial number	Map reference	District	Street	Site code	Land use	Roadside location	Plantable width (m)	Building setback	Plantable tree (no.)	Species
1	11NE01A	WTS	Tsz Wan Shan Rd	1	3	1	4.5	2	6	*Callistemon rigidus*
2	11NE01B	WTS	Tsz Wan Shan Rd	1	2	1	3.8	2	30	*Callistemon rigidus*
3	11NE01B	WTS	Tsz Wan Shan Rd	2	10	1	4.8	3	2	*Spathodea campanulata*
4	11NE01C	WTS	Chuk Yuen Rd	1	3	1	3.0	2	16	*Syzygium hancei*
5	11NE01C	WTS	Chuk Yuen Rd	2	10	1	2.9	3	18	*Jacaranda mimosifolia*
6	11NE01C	WTS	Chuk Yuen Rd	3	2	1	3.2	2	13	*Syzygium hancei*
7	11NE01C	WTS	Chuk Yuen Rd	4	10	1	3.1	3	19	*Jacaranda mimosifolia*
8	11NE01C	WTS	Choi Chuk St	5	10	1	3.0	3	14	*Podocarpus nagi*
9	11NE01C	WTS	Choi Chuk St	6	2	1	3.0	1	12	*Brachychiton acerifolius*
10	11NE01C	WTS	Wing Chuk St	7	10	1	2.8	3	13	*Albizia lebbeck*
11	11NE01C	WTS	Wing Chuk St	8	10	1	3.2	3	13	*Pterocarya stenoptera*
12	11NE01C	WTS	Chui Chuk Lane	9	10	1	2.8	3	16	*Khaya senegalensis*
13	11NE01C	WTS	Chui Chuk Lane	10	10	1	2.8	3	14	*Koelreuteria bipinnata*
14	11NE01C	WTS	Chui Chuk Lane	11	10	1	2.8	3	23	*Khaya senegalensis*
15	11NE01C	WTS	Chuk Yuen Rd	12	10	1	3.3	3	14	*Jacaranda mimosifolia*
16	11NE01C	WTS	Chuk Yuen Rd	13	10	1	3.3	3	9	*Bischofia javanica*
17	11NE01C	WTS	Chuk Yuen Rd	14	10	1	3.2	3	16	*Jacaranda mimosifolia*
18	11NE01C	WTS	Shatin Pass Rd	15	10	1	4.0	1	14	*Sapium sebiferum*
19	11NE01C	WTS	Shatin Pass Rd	16	6	1	4.8	1	8	*Oroxylum indicum*
20	11NE01C	WTS	Chuk Yuen Rd	17	10	1	2.9	3	1	*Bischofia javanica*
21	11NE01C	WTS	Nga Chuk St	18	9	1	3.6	3	7	*Brachychiton acerifolius*
22	11NE01C	WTS	Shatin Pass Rd	19	10	1	3.0	3	25	*Sapium sebiferum*
23	11NE01C	WTS	Tsz Wan Shan Rd	20	2	1	3.8	1	6	*Michelia champaca*
24	11NE01C	WTS	Tsz Wan Shan Rd	21	2	1	3.8	1	10	*Michelia champaca*
25	11NE01D	WTS	Tsz Wan Shan Rd	1	10	1	3.2	3	2	*Spathodea campanulata*

ft]; large, 10 to 15 m [33 to 49.5 ft]; medium, 5 to 10 m [16.5 to 33 ft]; small, less than 5 m [16.5 ft]) and crown spread of the exceptionally large and large trees (less than 15 m [49.5 ft] and greater than 15 m [49.5 ft] crown diameter) were used to match sites with species. Additional botanical attributes were assessed such as growth form, attractive flowers, native versus exotic origin, and hardiness.

The tree survey data confirm the conservative species selection in both government and private projects with overreliance on popular species (Table 3) and implications on disease resistance and landscape quality (Raupp et al. 2006). The species homogenization phenomenon (Attorre et al. 2000) has spread from old to new neighborhoods. The species frequency profile could pinpoint the candidates to be weaned, including some excessively planted palms. The strong preference for exotics and the lack of species with attractive blooms could be consciously rectified. The tendency to plant trees with small final dimensions in large planting sites would need some attention. The obstacles to the wider use of natives such as the lack of supply by the landscape trade, inadequate practical experience on their suitability for urban use, and meager scientific information could be overcome by relevant policies and actions. An official species palette and guideline on species selection and matching with site conditions could be established by a coalition of landscape professionals and researchers.

The existing species composition and choice highlights the supply-led situation by local tree nurseries, which could gradually be adapted to a demand-led scenario. The seed collection and propagation techniques of local nurseries could be upgraded by training and demonstration schemes to meet the changing demands (Sæbø et al. 2005). Uncommon, rare natives with good performance as registered by the tree survey could be targeted for suitability testing. The choice of species in future planting programs could aim at adjusting the present imbalance in species composition and to enhance urban floristic biodiversity (Santamour 1990; Frank et al. 2006), which could bring collateral benefits to urban wildlife. Native species with the potential to supply suitable shelter and forage to indigenous wildlife could be targeted. In view of the frequent typhoon attack, the empiric tree performance data could recognize species that are tolerant or susceptible to wind damage. Overall, the results hint that future species choice could extend from aesthetic to ecologic and social considerations (Banks and Brack 2003).

The results also yield information on the type and magnitude of construction damages on trees and provide hints to minimize such impacts (Ames and Dewald 2003; Jim 2003). The old trees that grow spontaneously on old stone walls, a unique urban ecologic feature of the city, deserve special conservation efforts (Jim 1998a). The results identify some old or haphazard trees that are approaching their useful and safe lifespan, that demand a well-planned removal and replacement program. The findings on the cracked and raised pavement of sidewalks pinpoint the species with vigorous roots that could be avoided in confined paved areas.

A 5-year planting plan was designed to cover the ten urban districts (Table 7). The total number of plantable trees was divided into five approximately equal portions to be spread over 5 years. Rather than following strictly objective criteria in using the potential sites, some general principles were adopted in assigning priority in the planting program. Sites situated in neighborhoods with little or no existing trees, and sites that were more readily available, were targeted first. In addition, localities with high development density and poor environmental condition, that could benefit more from early introduction of greenery, were tackled as soon as possible. The plan should not be regarded as rigid and definitive. Instead, it could be appropriately modified to match the changing opportunities and constraints encountered in the course of implementation.

CONCLUSIONS

The methods developed for the detailed field evaluation of roadside trees provided useful data to study the intimate relationship between tree growth and the tight urban fabric in a dense city environment. The unique features of the field technique are the microscale assessment and measurement of the planting site and tree dimensions to highlight the intense conflicts between trees and urban structures. The inclusion of a survey of potential planting sites expanded the study. The proposed framework for the systematic identification, characterization, and use of potential planting sites in crowded streetside environs could be applied to other cities. Interpretation of the results permitted understanding of the arboricultural problems that commonly beset roadside trees in a cramped and stressful habitat and offered hints to design planting site, select species, and adjust tree planting and maintenance practices to enhance growth. The experience could be shared with Asian, African, and South American cities, which are commonly densely packed, and with the core commercial heart of Western cities, which have a similar tight town plan and tree growth confinements.

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Résumé. Les inventaires des forêts urbaines de la cité à l'environnement dense de Hong Kong ont été initiés en 1985 et régulièrement mis à jour par la suite. Les arbres de rues ont été évalués en premier dans le recensement des arbres suivis ensuite par ceux dans les parcs urbains, les propriétés publiques et les habitats particuliers tels les vieilles enceintes de pierre ou les spécimens spéciaux comme les arbres historiques. La méthodologie d'inventaire visait à collecter des données détaillées afin de connaître à la fois la condition des arbres ainsi que les interactions entre les arbres et leur environnement. De l'information détaillée a été glanée, avec l'aide d'assistants bien entrainés, sur le site de l'arbre, l'espace de développement, la structure de l'arbre ainsi que les défauts structuraux et les désordres de santé. Une fiche d'inventaire a été mise au point, testée et raffinée pour obtenir des réponses à partir de choix multiples ou de mesures directes afin de minimiser la subjectivité et les erreurs dans l'entrée et l'enregistrement des données. L'étude a aussi identifié les sites potentiels de plantation, en enregistrant des données sur les conditions potentielles de développement, les caractéristiques de site et les dimensions. Les données de terrain ont été déterminées de telle manière à être quantitatives ou convertibles en rangs ordinaux dans le but de faciliter l'analyse statistique. La localisation des arbres ainsi que les sites de plantation ont été marqués sur une carte à grande échelle pour permettre une analyse spatiale. En plus de l'analyse statistique, des attributs de communauté écologique et des indices de design sur mesure ont été utilisés pour évaluer la structure de la forêt urbaine. Cette méthode multi-usage pourrait être ajustable de manière appropriée au sein d'autres villes denses.

Zusammenfassung. 1985 wurden in dem dichten Stadtgebiet von Hong Kong Aufnahmen des urbanen Waldbestands durchgeführt und hinterher regelmäßig aktualisiert. Die Straßenbäume und anschließend die Stadtparkanlagen, öffentliche Anlagen, spezielle Standorte wie alte Steinmauern oder Naturdenkmale wurden mittels eines Wertermittlungsverfahrens erfasst und in diesem Bericht dargestellt. Die Erhebungsmethode zielte darauf ab, umfassende Daten zum Zustand der Bäume und der Interaktionen am Standort zu sammeln. Mit der Hilfe von gut ausgebildeten Assistenten wurden detaillierte Informationen zum Standort, Baumscheibe, Baumstruktur, Defekte und Krankheiten erfasst. Es wurde ein Erfassungsprotokoll entwickelt, getestet und überarbeitet, um überlappende Antwortmöglichkeiten zu vereinzeln und die Fehler in der Datenaufnahme zu minimieren. Die Studie identifizierte auch potentielle Pflanzstandorte, indem sie die Wachstumsbedingungen, Standortcharakteristika und Dimensionen registrierte. Die Daten waren entweder quantitativ auszuwerten oder konvertierbar für Methoden der statistischen Analyse. Die Baumstandorte und Pflanzflächen wurden auf großen Plänen vermerkt, um eine räumliche Analyse zu ermöglichen. Neben der statistischen Analyse wurden auch der ökologische Nutzen und kundenspezifische Aspekte erfasst, um die urbane Forststruktur zu untersuchen. Diese multifunktionale Methode kann möglicherweise auch für andere, ähnliche Regionen verwendet werden.

Resumen. Se iniciaron estudios de bosques en ambientes urbanos compactos de Hong Kong en 1985 y regularmente actualizados desde entonces. Los árboles de alineación fueron evaluados primero en un censo y reportados en este artículo, seguidos por parques urbanos, parques públicos estatales y hábitats especiales tales como paredes de piedra antigua o especímenes especiales tales como árboles patrimoniales. El método de levantamiento intenta colectar datos tanto de las condiciones del árbol como las de las interacciones ambientales. Se distribuyó información detallada en tres sitios con la ayuda de asistentes bien entrenados, espacio de crecimiento de los árboles, estructura del árbol, defectos y desórdenes de los árboles. Se diseño un formato de registro de campo, así como una prueba piloto, y se refinó para solicitar respuestas a múltiples posibilidades o mediciones directas, para minimizar la subjetividad y errores en la entrada y el registro de los datos. El estudio también identificó sitios potenciales de plantación, registrando condiciones apropiadas para el crecimiento de los árboles, características del sitio y dimensiones. Los datos de campo fueron designados en rangos ordinales o cuantitativos para facilitar el análisis estadístico. Las localidades de los árboles y los sitios de plantación fueron marcados en mapas a escala grande para permitir el análisis espacial. Además del análisis estadístico, los atributos ecológicos de la comunidad y los índices fueron usados para evaluar la estructura del bosque urbano. El método multipropósito podría ser ajustado apropiadamente para usarse en otras áreas urbanas compactas.