A STATISTICAL METHOD FOR THE ACCURATE AND RAPID SAMPLING OF URBAN STREET TREE POPULATIONS

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Abstract. This paper develops and demonstrates a statistical sampling method that can be used to estimate the species composition of an urban street tree population quickly and accurately, i.e., with an acceptable level of error. The technique is based on stratified random sampling. We first estimate the percentage of street trees in separate zone segments throughout the city, and then distribute a sample of 2,000-2,300 trees across the city. Weighted averaging is used to obtain estimates and confidence limits. We have applied this technique in four cities in New York state and obtained results that agree closely with previously existing complete or partially complete street tree surveys.

Traditionally, street tree management programs have involved creating and manipulating complete inventory databases that include every tree within a city. While this method provides very accurate information it also is very expensive to conduct and complex to manage, and it requires constant updating in order to maintain data accuracy. For example, the full inventory of Ithaca, NY, a small city of 30,000 people and 5,600 street trees (3), required 4 person working 3 months to collect the data, and 2 persons working for another 2 months to computerize and analyze the data. Furthermore, resources must be allocated to future data input for updating and further analysis.

A partial inventory or sample could provide a practical and affordable method for establishing a database of urban street tree information, including species composition, dbh, health, total number of trees, and empty plantable spaces. This kind of sampling could be performed in several days, rather than the months needed for a complete inventory. Sampling could provide a means for a statistically accurate detection of general patterns and trends in street tree populations, such as the overplanting of one or more species, or the prevalence of a particular condition such as insect damage or injury due to environmental stress. With sampling, only a portion of the trees are identified in a structured random fashion, relying on statistical methods to estimate, with an acceptable level of accuracy, the composition of the whole urban street tree population.

Sampling techniques have been developed previously but most, if not all, require some level of pre-existing information, such as knowing the total number of existing street trees in the city, to the spatial planting pattern of the street trees. Mohai et al. developed a sampling technique for Poughkeepsie, NY, based on the hypothesis that species of street trees tended to be planted in "clusters" as well as in widely scattered single specimens (8). The number of trees of any species to be sampled was based upon that species's incidence, so that a sample size of approximately 100 sampling clusters was achieved. In cities without pre-existing complete street tree inventories, the needed information on species incidence is not available. This sampling method also assumed that street trees do, in fact, occur in clusters, which may or may not be an accurate assumption.

In the windshield survey technique used by the Community Forestry Program in Kansas (2), all trees were tallied in communities with fewer than 2,500 people, while every other street was surveyed in communities with populations between 2,500 and 10,000. For these larger cities, sampling 50 percent of the streets would still be a large task. Moreover, no measure of statistical accuracy was given.

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The aim of our research was to develop a practical, statistically accurate street tree sampling procedure. The specific goals established for our sampling methodology were:

1) To estimate accurately the total number of street trees in a city, achieving with 95% probability a relative error of 10% or less (6).

2) To estimate accurately tree species diversity; specifically, with 95% probability:

a) to estimate the percentage of each major species (defined to be any species constituting at least 10% of the trees in the city) within a margin of 10% relative error; the estimate of each major species's percentage should differ from the true species percentage by no more than 10% of the true percentage.

b) to estimate the percentage of each minor species (defined to be any species constituting less than 10% of the trees in the city) within a margin of 1% absolute error; the estimate of each minor species's percentage should differ from the true species percentage by no more than 1% of the total number of street trees.

3) To estimate accurately other variables such as dbh class, tree condition class, height class, maintenance requirements, and number of empty tree planting spaces. The accuracy of these estimates should be at least as good as for species percentages.

Materials and Methods

Our sampling technique reflects the important statistical fact that a high level of accuracy can be achieved by estimates based on a suitably selected random sample constituting only a small fraction of the population of interest (4). For instance, national polls and surveys, such as the Gallup Poll, the Harris Poll, and the Nielsen television rating, typically produce sufficiently accurate estimates using sample sizes of about 1,500 individuals (4, 5, 7). This is possible because the precision of an estimate computed from a sample depends on the sample size, but not on the size of the population being sampled when this population is much larger than the sample.

Zonation. The first step in the sampling and estimation procedure is to stratify, or partition, the city's area into zones. Stratification is useful for two reasons. First, it provides a way of spreading the sample areas appropriately across the city, by dividing the city into regions and then looking at the trees within each region. Second, stratification into relatively small regions allows for the investigation of planting patterns and trends within each region, allowing the tree manager to examine tree populations in discrete sections.

To facilitate the stratification of a city, we now introduce the terminology to be used. A ***zone type*** is a major land use category and may refer to a residential or commercial neighborhood, a physical street layout, or a time of development. The city's area is divided into nonoverlapping regions, each of which is categorized as one of the zone types, except that regions in the city known to contain no street trees (e.g., natural vegetation, parks, etc.) are omitted. The three zone types used in the research reported here are Rectilinear Residential (RR). Curvilinear Residential (CR), and Downtown (DT).

Rectilinear Residential (RR) neighborhoods usually contain the majority of street trees found in the city. These areas, consisting primarily of rectangular blocks, are often the neighborhoods that were first developed around the core of the city (9), and usually contain sidewalks and street tree planting areas.

Curvilinear Residential (CR) zones, on the other hand, were usually developed later within a city, and the layout of these neighborhoods often does not include sidewalks and specified tree pits. The streets in CR zones usually do not form a grid-like pattern.

The third zone type is the Downtown (DT) or central business district. Because of high tree mortality rates, the prevalence of new construction, and the general clustering of trees in downtown urban areas, downtown areas are substantially different from residential areas, thus warranting a separate zone type classification. The streets in DT zones usually form a grid-like pattern.

These three zone type classifications are sufficient for the analysis of many cities. The general attributes of a particular city's composition may, however, suggest different categories. If a city contains areas that do not fall within the above descriptions, new zone types can and should be defined.

A ***zone segment*** is a contiguous region of a single zone type containing between 20 and 500 sampling units (city blocks in RR or DT regions). To the greatest extent possible, zone segments should be constructed to have areas as nearly equal as possible. A contiguous region of a single zone type should be subdivided into two or more adjacent zone segments if it contains potentially important natural or political boundaries or if it is too large to constitute a single zone segment. This process is illustrated in Figures 1 and 2. It is within the individual zone segments that the random sampling is performed.

In the stratified random sampling procedure described here, each zone segment is sampled. Within each zone segment, a simple random sample is drawn, ensuring that every block has an equal probability of being selected. Stratification allows us to combine the results of the simple random samples from all zone segments to obtain the final composite result (4). Estimates from a stratified sample of blocks selected within zone segments will be more precise than those from a simple random sample of blocks taken from the city as a whole, since the stratified sample will give improved coverage of the entire city. If stratification is not used, then there is an increased probability that the random sampling process could miss, underrepresent, or overrepresent large sections of the city.

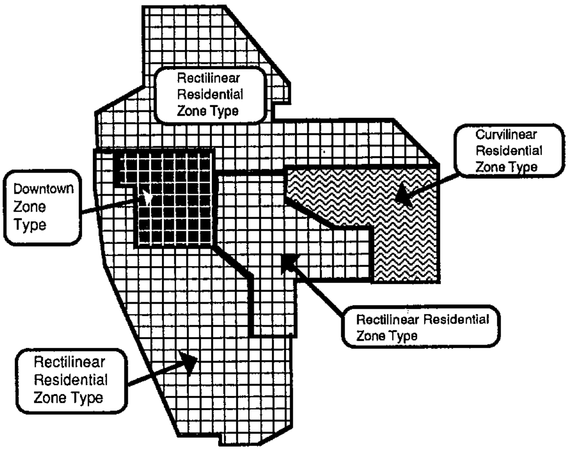

Figure 1. Example of a city partitioned into three different zone types

Establishment of a uniform sampling entity. The elements that are chosen during the random sampling process to form the sample are called ***sampling units***. In our approach, each zone segment is divided into sampling units called ***street units***. These are the elements that will be randomly sampled throughout the city. A street unit in a Rectilinear Residential or Downtown zone segment is defined to be the inside perimeter of a block; for convenience, we will usually refer to this simply as a block. A block is the preferred sampling unit in RR and DT zone segments for two reasons. First, it is easy to drive completely around a single block, sampling trees from only the inside perimeter of the block, thus eliminating the chance of observing the same individual tree twice as part of two separate street units (Fig. 3). Second, neighborhoods tend to be developed as several contiguous blocks at the same time. Street trees on a single block have a higher chance of having come from the same nursery or of being planted in soil of the same general type than trees on different blocks. This aspect of heterogeneity between blocks and homogeneity within blocks is often referred to as clustering (8).

It is usually difficult, or impossible, to drive around a block in a Curvilinear Residential neighborhood, because the streets do not form blocks. Therefore, a different kind of basic sampling unit

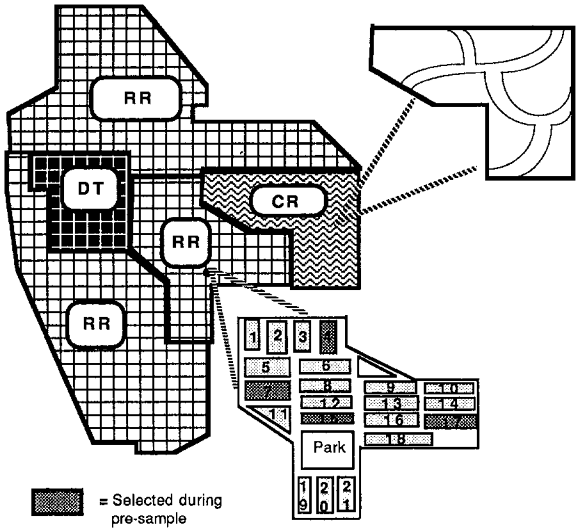

Figure 2. Example of zone segments and street units.

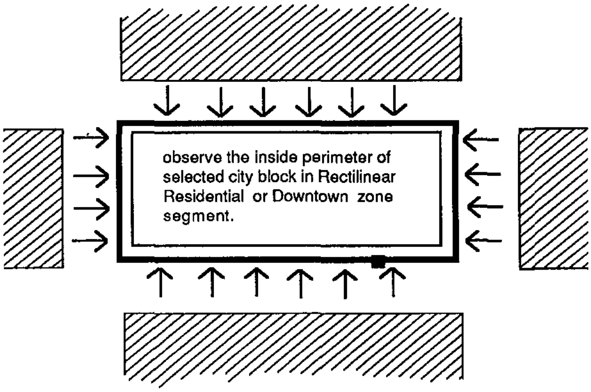

Figure 3. Example of one street unit or block, selected to be observed (one side only) within a Rectilinear Residential or Downtown zone segment.

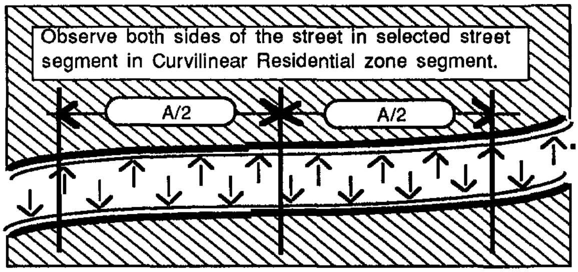

Figure 4. Example of the street segments that comprise street units within a Curvilinear Residential area. Trees are recorded on both sides of the street.

is needed in CR zone segments. To define a CR sampling unit called a ***street segment***, we began by estimating the average rectilinear block perimeter length from all Rectilinear Residential zone segments. This length was called A. Using A as the size of the sampling unit, we subdivided the curvilinear streets into sections of that size. It was convenient in sampling CR zone segments to observe the trees on both sides of the street, so a CR street segment consisted of both sides of a section of street having a length of A/2 (Fig. 4). This method established an equivalent length of street observed between RR and CR zone segments. Small sections of street remaining at intersections, and at the edges of the CR zone segments, could be included in any adjoining street segment.

Finally, within a block or street segment, each individual street tree was observed. A street tree was defined as any tree under the control of the city, and bounded on one side by a curb or street edge and on the other by a sidewalk. Trees in median strips were also included with the adjacent block. If a sidewalk was not present, then a distance of approximately 8 feet in from the street edge, comprising the public right-of-way, may be used as the criterion defining a street tree. Certain trees on private property can act as street trees but are not generally considered in an inventory, since the city often has no control over them. Areas of natural vegetation along street edges are not generally part of an inventory. In downtown areas, street trees are often planted in special isolated planters or pits. These plantings have to be within the right-of-way to qualify as street trees.

Sampling at the block level instead of randomly selecting individual street trees out of the total population offers advantages when sampling in large, widespread zone segments. Typically we find that in cluster (block) sampling:

1) the cost per tree is much lower, due to the lower cost of locating and observing each tree within a block;

2) the variance between blocks is higher than the variance within blocks, due to the usual, though irregular, heterogeneity of trees between clusters; and

3) the complexity of statistical analysis is greater. Cluster sampling is preferred over individual selection when the lower cost per tree more than compensates for the more complex structure (7).

The pre-sample. A preliminary sample, or pre-sample, was used to estimate two important quantities: a) the average block perimeter length over all Rectilinear Residential zone segments, and b) the number of street trees in every zone segment. A random sample of block perimeters was measured in each zone segment, and the average perimeter length for each of the random samples was calculated. The average perimeter lengths were combined, using weighted averaging, to give A, the estimated average block perimeter length over all blocks in all RR zone segments. As described earlier, this estimated average length was then used to divide the streets in CR zone segments into *street segments of length A/2*. In all zone segments, random samples of these street segments were then drawn for pre-sampling and sampling of street trees.

Pre-sampling also helped in estimating the number of street trees in each zone segment, and throughout the entire city. For each zone segment, we estimated the tree density, or average number of trees per street unit, from the street units (blocks for RR or DT, street segments for CR) in the pre-sample. We estimated the total number of street trees in each zone segment as the product of the estimated number of trees per street unit in a given zone segment and the total number of street units in that zone segment. These estimated total numbers of street trees for all zone segments were than summed to provide an estimate for the total number of street trees within the city. This pre-sampling technique also allowed estimation of the percentage of the city's trees that are in each zone segment. This had an important role in the distribution of the sample of 2,000-2,300 trees across the city.

The rationale for 2,000 - 2,300 trees. Statistical sampling theory shows that a suitably selected random sample consisting of only a small fraction of the population can often be used to estimate the characteristics of the entire population with an acceptably high level of accuracy, i.e., an acceptably low degree of error (4). The sample selection procedure may be complex, as in the multistage sampling method described fully below, in which the city is divided into zone segments, a sample of street units is drawn from each zone segment, and the trees in each of these street units are inspected. This is done in a way that gives all individual trees in the population approximately the same probability of being selected. In this situation, a sample of 2,000 - 2,300 trees is sufficient to attain the stated goals of accurate estimation of the city (population) total number of street trees, tree species diversity, and other variables. The degree of error in these estimates can also be estimated, and is an important criterion for judging and comparing estimates.

Increasing the sample size used in a sampling and estimation procedure will increase the level of accuracy of the estimates. However, the improvement may not be substantial. The extra cost of conducting a survey with a sample of more than 2,000 - 2,300 trees, in time, personnel, and data analysis, generally seems not to be justified by the limited increase in accuracy and information available. Note that selecting a sample of known size, e.g., 2,300 trees, is much easier than sampling a known percentage of the total population for two reasons: 1) it is often impossible to know the population size, even approximately, before conducting the survey, and 2) percentage sampling of a very large population requires a very large sample.

The sample. The actual sampling used in our procedure was performed by observers in an automobile. We found that each observer could usually handle two different kinds of observations. For example, one observer could be responsible for species identification and dbh class, while a second observer could assess tree condition and tree planting opportunities. To expedite the sampling procedure, it was helpful to have a person in addition to the driver whose sole responsibility was navigation. Data were recorded onto tape using a microphone, or could be entered directly into a handheld laptop computer. Every data entry had to be identified with a specified street unit at the time of observation. This was necessary because the data from each observed street unit were weighted by the zone segment they were in when estimates were calculated.

Weighting of results. The results of the pre-sampling phase of this procedure allowed us to estimate not only the total number of street trees in the city, but also the percentage of those trees located in each zone segment. After estimating the proportions of all the individual species in each zone segment from the counts observed during the actual sample, the values were multiplied by the estimated percentage of the city's street trees located in each zone segment. This weighting procedure adjusted the estimated proportions to reflect the number of street trees expected in a given zone segment. For example, if a zone segment were estimated to contain 20% of the total street trees in the city, then the species proportions estimated from counts observed in that zone segment were weighted (multiplied) by 0.20. For each species, summing these weighted values over all zone segments provided an accurate estimate of the number of street trees of that species within the city.

The Method

This section provides a step by step discussion of how to implement the sampling technique presented in this paper. The chart in Appendix A shows the data to be used in the illustrative calculations.

The data in Appendix A show that the city is divided into four separate zone segments, two of which are of the same type, RR. The numbers given are for illustrative purposes only. The steps in the analysis are:

1) Obtain an accurate street map with a scale ranging between 1"= 400' and 1"= 900', depending on the size of the community.

2) Stratify the city, in preparation for random sampling, by dividing it into relatively homogeneous zone segments of the three zone types: RR, CR, and DT. Every RR and DT zone segment should be between 20 and 500 blocks in size.

3) In each RR and DT zone segment, give every block a number. If B_i denotes the number of blocks in a particular zone segment (i), then number these blocks from 1 to B_i (Fig. 2). As noted earlier, parks and areas of natural vegetation are omitted from this numbering process.

4) Start the pre-sampling phase. The pre-sample has two functions: to estimate the number of street trees in each zone segment, and to estimate the average block perimeter length of all the RR and DT blocks in the city. This average block perimeter value only needs be calculated if the city contains any Curvilinear Residential zone segments (see Step 5).

a) Randomly select 4 - 10 numbered blocks in each RR and DT zone segment, based on the following chart.

Number of blocks in zone segment i (B_i)	**Number of blocks in pre-sample i (b_i)**
20 - 50 blocks	20% of B_i (rounded to nearest integer)
50 - 500 blocks	10 blocks

b) To select a simple random sample of b_i blocks from the B_i blocks in zone segment i, label the B_i blocks with the integers from 1 to B_i; see the expanded RR zone segment in Figure 2, where $B_i = 21$ and $b_i = 4$.

c) Then generate b_i different random integers between 1 and B_i, using either published random number tables or a computer program that generates discrete random numbers between 1 and B_i. Mark the randomly selected blocks on the street map (Fig. 2).

5) If the city has CR zone segments, follow steps 5 a-g; otherwise, go to step 6. The purpose of step 5 is to calculate a *street segment* length for all CR zone segments, which is equal to the estimated average block perimeter length for all RR and DT zone segments.

a) measure the perimeter of each RR and DT block that was selected in Step 4

b) For each RR and DT zone segment, sum the measured block perimeters and divide by the number of blocks measured in this zone segment.

Illustrative example: For RR zone segment number 1

Random block number	**Measured perimeter**
1	1460'
2	1600'
3	1240'
4	1400'
5	1375'
6	1540'

$$(\text{average block perimeter})_1 = 8615'/6 = 1436'$$

Repeat for each RR and DT zone segment.

c) Estimate the average block perimeter length over all RR and DT zone segments in the entire city, using a weighted average A. The estimated average block perimeter length for each zone segment is weighted by the number of blocks contained in the zone segment:

$$A = \frac{\Sigma_{i=1} \text{(block count)}_i \times \text{(average block perimeter)}_i}{\Sigma_{i=1} \text{(block count)}_i}$$

Illustrative example (see Appendix A, columns A and C):

$$A = \frac{30(1436') + 87(1300') + 95(1538')}{30+87+95} = 1426'$$

d) To obtain a street segment length for use in all zone segments, divide the estimated average block perimeter length obtained in step 5c by 2.

Illustrative example (see Appendix A, column C, CR zone segment):

1426'/2 = 713' = street segment length for all CR zone segments.

e) using a scale that matches the street map, mark off street segment lengths in all CR zone segments (Fig. 4).

f) Number each street segment in each CR zone segment.

g) Apply the method in steps 4 a-ç to street segments (instead of blocks) in each CR zone segment. This selects a simple random sample of street segments, which are marked on the street map of the CR zone segment.

6) Using the pre-sample blocks selected in step 4 and the CR street segments selected in 5g, drive to each selected random site and count each street tree. Count from one side of the block only in RR and DT zone segments, but from both sides of the street segment in CR zone segments. Refer to Figures 3 and 4.

7) Estimate from the pre-sample the average number of street trees per street unit in each zone segment; for zone segment i,

$$\frac{\text{(total trees counted in pre-sample of street units in zone segment)}_i}{\text{(total number of street units pre-sampled in zone segment)}_i}$$

Illustrative example:

Zone segment	Total # trees counted		# street units pre-sampled		Estd. avg. # trees per street unit
1	132	/	6	=	22
2	270	/	10	=	27
3	144	/	10	=	14.4
4	120	/	9	=	13.3

Now estimate the total number of street trees in the city as $N = \Sigma_i N_i$ where N_i = (Estd. no. trees)$_i$ = (Estd. avg. no. trees/street unit)$_i$ x (no. street units)$_i$

Illustrative example:

Zone segment	Estd. avg.#. of trees per street unit		Actual #. of street units in zone segment		Estd. #. of trees
1	22	x	30	=	660
2	27	x	87	=	2349
3	14.4	x	95	=	1368
4	13.3	x	47	=	626
					5003

N =estimated total number of street trees in city =5003

8) Estimate the percentage (w_i) of the total city street tree population that is located in each zone segment; for zone segment i,

w_i= (Estd. # trees)$_i$ / (Estd. total # trees in city) = N_i/N

Illustrative example (see Appendix A, columns F and G, zone segment 1):

w_i = 660/5003 = 13.2% of all street trees are estimated to be in zone segment 1

(9) Determine how many trees and street units should be sampled within each zone segment. The number of trees we wish to sample in zone

segment i is 2300 x w_i. To obtain the desired number of street units, divide 2300 x w_i by the estimated average number of trees per street unit from step 7.

Illustrative example (see Appendix A, columns G and H, zone segment 1)

2300 x w_1 = 2300 x 13.2% = 303 trees are to be sampled from zone segment 1

Since zone segment 1 has an estimated average of 22 trees per block, we will need to sample 303/22 ≈ 14 blocks in order to sample approximately 303 street trees.

10) Apply the method of steps 4 a-c to street units in each zone segment. This selects a simple random sample of street units from each zone segment; mark the selected street units on the map.

11) Survey each randomly chosen block (RR and DT) or street segment (CR) from an automobile. Record species, dbh classes, tree maintenance priorities, insect damage, plantable spaces, etc. The data can be recorded directly to tape and transcribed after the sampling, or can be entered directly into a small handheld computer.

12) To estimate p, the percentage of a particular species in the a city street tree population, let p_i denote the percentage of the species among trees in zone segment i. Then, using w_i from step 8 as a weight for p_i, the overall p is given by

$$p = \Sigma_i w_i p_i + w_1 p_1 + w_2 p_2 + w_3 p_3 = \ldots.$$

For each zone segment i, estimate p_i by

$$p_i = \frac{(\text{no. of the particular species observed})_i}{(\text{total no. of trees observed})_i}$$

The overall p is estimated by

$$p = \Sigma_i w_i p_i$$

This can be repeated for any number of desired species, as well as condition classes, etc.

Illustrative example: In zone segment 1, we observed 106 *Acer platanoides* out of 220 trees, so p_1 = 106/220 = .482; in zone segment 2, 327 *Acer platanoides* out of 1010 trees, so p_2 = 327/1010 =.324; in zone segments 3 and 4, 185 out of 620 and 93 out of 270, respectively, so p_3 = .298 and p_4 = .344. Multiply each of these percentages by the percentage of total street tree population located in the corresponding segment, e.g., for zone segment 1, $w_1 p_1$ = (.132)(.482). Then the estimated percentage of *Acer platanoides* among the street trees in the entire city is

$$p = (.132)(.482) + (.469)(.324) + (.273)(.298) + (.125)(.344)$$
$$= .0635 + .1520 + .0815 + .0431 = .3403 = 34.03\%$$

Results

Total Number of Trees. Four cities in New York State were surveyed between the fall of 1989 and summer of 1990 to evaluate the accuracy of this technique. The four cities, Ithaca, Syracuse, Rochester, and Brooklyn, NY, were chosen because they represented areas ranging from 5.6 square miles (Ithaca) to 78.5 spare miles (Brooklyn). Brooklyn, although only a part of New York City, would be the fifth largest city in the U.S. if considered on its own. The three smaller cities had either complete or partially existing inventories against which we could check the accuracy of our sample-based estimates; Brooklyn had only a total count of street trees to compare to our data.

The four cities had street tree populations ranging from 5,571 for Ithaca to 113,000 for Brooklyn (Table 1). Rochester had only a partial inventory of one area of the city, completed in 1988. At that time, a gross estimate of 60,000 trees was given by the partial inventory, but was not supported by any methodology or data. The other three cities had data against which to compare our sample-based results. For these cities, for total number of street trees, we were well within the ± 10% accuracy desired for the method (Table 1).

Species Composition. During the 1990 sample conducted in Ithaca, NY, we observed a total of 56 species, compared to 103 species during the 1988 full inventory. As can be seen from Table 2, the top four species, three of which are maples, comprise 66.9% of all street trees in the city of Ithaca. The accuracy of the sample was well within our statistical objectives (Table 2). However, between 1988 and 1990, there were 82 *Acer saccharum* removed from Ithaca, NY, and none has been replanted. Therefore, the percentage of total existing *Acer saccharum* changed from 19.1% to 17.5%, so the estimate of 17.0% is within our goal of ±10% of the actual fraction of existing trees of that species.

In Syracuse, NY, four species comprised 58.6% of the total street trees in the city (Table 3). Syracuse Parks and Recreation records showed that between 1978 and 1988, approximately 1000 silver maples were removed. This would adjust the 1978 inventory percentage for *Acer saccharinum* to approximately 13.4%, keeping it within the desired bounds of statistical accuracy.

Over 50% of the trees inventoried in the Downtown zone segment were *Gleditsia triacanthos*. This species has been heavily planted within the last 10 years. Also, within the last 10 years *Tilia cordata, Fraxinus* sp., and *Acer rubrum* have become very popular street trees, and their numbers have increased dramatically. Taking into consideration these changes related to us by the Syracuse City Forester, our sample provides acceptable levels of accuracy.

During the 1989 sample conducted in Syracuse, NY, we doubled the size of our sample from 2,300 to 4,600 sampled street trees in order to calculate the effect of increased sample size (Table 3). While our goal was 2,000-2,300 sampled trees, we actually observed 1,922 trees from one side of the street, 2,080 from the opposite side of the street, and a total of 980 street trees from the Downtown zone segment. As can be seen from Table 3, doubling the sample size did not change the results appreciably.

The 1988 inventory results for Rochester, NY, shown in Table 4, are from a partial inventory conducted in one section of the city during the summer of 1988 (1). Our 1990 results reflect a sample drawn from the entire city. In Rochester, four species make up over 65% of the street tree population, with *Acer platanoides* again, as in Ithaca and Syracuse, making up about one-third of the population. *Gleditsia triacanthos, Acer saccharum* and *A. saccharinum* also played important roles in all three cities.

Brooklyn, New York was the first city we sampled where there was no known existing street tree inventory. The same sample size of 2,000 - 2.300 trees that was used in the three previous cities was also used for Brooklyn. The pre-sample for Brooklyn took 1 day, the actual sample took 2 days, and the analysis of the data took approximately another week. Table 5 shows that two species were the major street trees in the city, and the top four species comprised approximately 75% of the street trees within the city.

Table 1. Estimated number of trees in 4 New York Cities

City	Based on sample	Actual (inventory)
Ithaca	5,700 (1990)	5,571 (1988)z
Syracuse	34,886 (1989)	37,668 (1978)y
Rochester	47,375 (1990)	60,000 (1988)est
Brooklyn	110,937 (1990)	113,000 (1988)x

z From complete survey (3).
y In conversations with the Syracuse City Forester, it was his opinion that there has been an approximate 3-4% loss of street trees over the last 10 year period. Richards (10) inventoried a total of 39,030 street trees in Syracuse in 1978.
x From conversation with City Forester of New York City.

Table 2. Comparison of 13 species comprising > 1% of total street tree population in Ithaca, New York.

Species	1990 sample estimates (%)	1988 (3) inventory (%)
Acer platanoides	33.8	33.1
Acer saccharum	17.0	19.1
Gleditsia triacanthos	9.0	8.7
Acer saccharinum	6.1	6.0
Acer rubrum	5.6	5.2
Quercus sp.	3.1	2.7
Picea sp	3.1	0.7
Ginkgo biloba	2.7	2.2
Malus sp	2.5	2.5
Pyrus sp	1.9	1.6
Fraxinus sp.	1.8	1.9
Platanus x acerifolia	1.3	2.3
Robinia sp	1.2	0.3
Other	(43 species) 10.8	(90 species) 13.7

Table 3. Comparison of 13 species comprising > 1% of total street tree population in Syracuse, New York.

Species	1989 sample estimate(%)	2X sample estimate(%)	1978 (10) inventory(%)
Acer platanoides	31.7	32.3	31.2
Acer saccharium	11.8	12.1	16.1
Acer saccharum	6.9	5.9	7.9
Gleditsia triacanthos	8.2	7.3	5.1
Malus sp.	5.5	6.0	4.9
Tilia cordata	7.3	6.7	3.0
Platanus x acerifolia	2.8	2.6	2.8
Fraxinus sp.	5.0	4.9	3.5
Acer rubrum	5.5	4.3	2.3
Acer negundo	1.3	1.4	2.2
Zelkova serrata	1.0	1.4	1.7
Ginkgo biloba	1.0	1.0	0.7
Sophora japonica	1.3	1.0	0.5
Other (54 species)	10.7	13.1	18.1

For all four cities, four or fewer species made up the majority of street trees, Maples figured heavily in all cities, but in Brooklyn, *Platanus x acerifolia* (London plane) comprised the largest proportion. The overplanting of a few species leaves that city vulnerable to attack by insect or disease. These results suggest that greater diversity is necessary when planting street trees in these cities.

DBH Class. For Ithaca, Rochester, and Brooklyn, we also took data on dbh size class, by species. This is a good indicator of the age of any population of trees within the city. Table 6 shows the distribution of dbh size classes for all species making up >1% of the street tree population in Ithaca, NY. For example, *Acer platanoides* comprised 33.8% of the city's street trees. Of these Acer *platanoides,* 20.4% were in dbh class 1"- 5", 51.3% were in dbh class 6"- 12", etc. The dbh proportions were calculated by exactly the same method as species composition, i.e., the number of a particular species observed in each dbh class was weighted by the percentage of trees expected in the zone segment within which they were observed. Values from all zone segments were then totaled for the city.

Of the four main species comprising 57.8% of the street trees in Rochester, three were distributed

Table 4. Comparison of 16 species comprising > 1% of total street tree population in Rochester, New York.

Species	1990 sample estimates (%)	1988 (1) inventory (%)
Acer platanoides	27.5	26.6
Fraxinus pennsylvanica	11.1	11.3
Gleditsia triacanthos	11.0	10.8
Tilia cordata	8.2	7.9
Acer saccharum	4.6	4.1
Acer saccharinum	4.1	6.2
Acer platanoides Columnare	2.2	0.9
Acer platanoides Crimson King	3.9	4.5
Acer platanoides Schwedleri	1.7	1.0
Acer rubrum	1.7	2.0
Liquidambar styraciflua	2.4	1.9
Malus spp.	2.2	0.6
Platanus x acerifolia	3.2	3.9
Pyrus calleryana	2.3	1.2
Sophora japonica	1.4	2.6
Tilia americana	1.4	0.1
other	(43 sp)10.9	(69)12.9

Table 5. Species comprising > 1% of total street tree population in Brooklyn, New York.

Species	1990 sample estimates (%)
Platanus x acerifolia	33.9
Acer platanoides	27.0
Quercus palustris	7.3
Tilia cordata	7.1
Gleditsia triacanthos	3.8
Fraxinus pennsylvanica	3.2
Acer saccharinum	2.9
Ginkgo biloba	2.2
Acer pseudoplatanus	1.7
Pyrus calleryana	1.2
Sophora japonica	1.1
Other (32 species)	8.6

Table 6. DBH distribution by class, in the 1990 sample, Ithaca, New York.

Species	1"-5"	6"-12"	13"-24"	25"+
		%		
Acer platanoides	20.4	51.3	24.4	3.8
Acer rubrum	13.3	75.1	6.2	5.4
Acer saccharinum	0.0	3.2	23.6	73.2
Acer saccharum	2.3	29.2	49.1	19.4
Gleditsia triacanthos	13.7	57.9	26.9	1.5
Fraxinus sp	28.7	43.0	13.8	14.5
Ginkgo biloba	27.9	64.1	8.0	0.0
Malus sp	23.1	75.4	1.5	0.0
Picea sp.	29.9	43.0	24.5	2.6
Platanus x acerifolia	7.8	54.2	25.3	12.6
Pyrus sp.	16.1	72.8	11.1	0.0
Quercus sp.	21.4	45.5	23.1	10.0
Robinia sp	9.5	73.9	13.6	3.9

nicely throughout the lower dbh classes (Table 7), whereas only one, *Acer platanoides* was showing signs of aging.

The two most common species observed in Brooklyn both had more than 50% of their trees in the 13"-24" dbh range (Table 8). This suggests that the top two species, which together are estimated to comprise 60.9% of the street trees in Brooklyn, are beginning to reach maturity.

Table 7. DBH distribution by class, in the 1990 sample, Rochester, New York.

Species	1"-5"	6"-12"	13"-24"	25"+
		%		
Acer platanoides	7.6	31.7	52.2	8.4
Fraxinus pennsylvanica	18.2	54.9	27.0	0.0
Gleditsia triacanthos	12.2	68.0	19.9	0.0
Tilia cordata	17.8	44.8	37.3	0.0
Acer saccharum	6.5	59.9	26.0	7.5
Acer saccharinum	0.0	7.0	37.3	55.7
Acer platanoides Columnare	24.2	73.4	2.5	0.0
Acer platanoides-Crim. King	26.1	70.6	3.3	0.0
Acer platanoides Schwedleri	7.2	63.0	29.7	0.0
Acer rubrum	47.5	46.2	6.2	0.0
Liquidambar styraciflua	5.0	62.9	32.1	0.0
Malus sp.	53.1	46.9	0.0	0.0
Platanus x acerifolia	7.2	36.6	49.9	6.3
Pyrus calleryana	70.3	29.7	0.0	0.0
Sophora japonica	0.0	82.3	17.7	0.0
Tilia americana	6.5	63.2	30.2	0.0

Table 8. DBH distribution by class, in the 1990 sample, Brooklyn, New York.

Species	1"-5"	6"-12"	13"-24"	25"+
		%		
Platanus x acerifolia	0.6	14.9	63.8	20.7
Acer platanoides	10.4	34.5	50.1	5.0
Quercus plaustris	19.3	47.6	32.0	1.2
Tilia cordata	40.3	37.9	17.2	4.6
Gleditsia triacanthos	42.5	54.8	2.8	0.0
Fraxinus pennsylvanica	37.1	59.2	2.6	1.1
Acer saccharinum	6.1	28.2	34.0	31.6
Ginkgo biloba	24.2	53.2	18.9	3.7
Acer pseudoplatanus	31.3	61.8	6.9	0.0
Pyrus calleryana	75.4	21.4	3.2	0.0
Sophora japonica	21.0	66.9	12.1	0.0

For all cities, *Acer saccharinum* clearly comprised the oldest tree population, followed by *Acer saccharum* and, in Brooklyn, *Platanus* x *acerifolia*. Although *Acer saccharinum* is not planted today because of its defect-prone nature, it must be admired for its adaptability and longevity in the urban environment.

Tree Condition. During the observation of the Brooklyn sample, one observer also noted the condition of each sampled tree, a subjective rating of the overall health, soundness, and shape of the Tree (Table 9). *Acer platanoides* and *Quercus palustris* stood out as being in poorer condition than the other species. Of the trees observed that fell into the categories of Good and Poor, *Acer platanoides* had the largest number of trees showing crown dieback and foliage scorch (Table 10).

Dieback of tree crowns was clearly the most common symptom of tree decline, followed by the presence of trunk wounds. The prevalence of trunk wounds generally followed the age or size of the tree population, with the youngest group, *Pyrus calleryana* showing no wounds, and the oldest, *Acer saccharinum,* showing the most. Chlorosis was most prevalent in *Quercus palustris,*

Table 9. Visual assessment of tree condition in the 1990 sample, Brooklyn, New York.

Species	Excellent	Good	Poor	Dead
		Condition		
		%		
Platanus x acerifolia	82.8	16.0	0.7	0.5
Acer platanoides	56.9	30.5	10.3	2.3
Quercus plaustris	59.8	30.3	8.4	1.5
Tilia cordata	77.9	15.0	6.4	0.7
Gleditsia triacanthos	76.8	22.2	0.0	0.9
Fraxinus pennsylvanica	80.2	19.8	0.0	0.0
Acer saccharinum	75.2	18.6	4.7	1.6
Ginkgo biloba	84.9	10.0	3.3	1.8
Acer pseudoplatanus	73.8	26.2	0.0	0.0
Pyrus calleryana	82.4	17.6	0.0	0.0
Sophora japonica	76.1	16.3	3.1	4.5

Table 10. Visual assessment of tree damage in the 1990 sample, Brooklyn, New York.

Species	Crown dieback	Trunk wounds	Chlorosis	Leaf scorch
		%		
Platanus x acerifolia	91.7	6.1	0.0	2.3
Acer platanoides	67.8	12.3	1.1	18.8
Quercus plaustris	59.3	8.4	30.9	1.4
Tilia cordata	70.5	18.6	1.2	9.7
Gleditsia triacanthos	88.6	11.4	0.0	0.0
Fraxinus pennsylvanica	82.7	17.3	0.0	0.0
Acer saccharinum	65.7	29.4	0.0	5.0
Ginkgo biloba	87.7	12.3	0.0	0.0
Acer pseudoplatanus	77.5	14.0	0.0	8.5
Pyrus calleryana	84.5	0.0	15.5	0.0
Sophora japonica	75.7	12.1	12.1	0.0

a species known to be intolerant of alkaline urban soils. The percentage of 30% is not as great as has been noted for this species in Ithaca, NY, where 70% has been recorded (3).

Conclusions

This new methodology provides a rapid, easily implemented way of gathering accurate information about street tree populations. The central feature of the method is that approximately 2,000 trees must be randomly sampled, regardless of the size of the total tree population. The technique, including pre-sample, sample, and data analysis, generally took about one week, rendering this method much faster than traditional inventory techniques.

The data collected for four sample cities confirmed the long-held assumption that a very few species make up the largest proportion of street trees in the urban environment. This information can help city foresters reassess their recommended species lists, to achieve a 5%-10% ceiling on any one tree species.

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Appendix A

ZONE SEG.	Column A	Column B	Column C	Column D	Column E	Column F	Column G	Column H	Column I	Column J
(RR) #1	30	6	1436'	132	22	660	13.2%	303.3	220	106
(DT) #2	87	10	1300'	270	27	2349	46.9%	1079.6	1010	327
(RR) #3	95	10	1538'	144	14.4	1368	27.3%	628.8	620	185
(CR) #4	47	9	713'	120	13.3	626.7	12.5%	287.9	270	93
			See 5d							
Totals						5003.7	100%		2120	

Notes:
Column A = # of Blocks (RR), or # of street segments (CR).
Column B = # of Street units to pre-sample.
Column C = Average block perimeter or street segment length.
Column D = Total # of trees observed in pre-sample.
Column E = Average # of street trees per block or street segment.
Column F = Estimated number of street trees.
Column G = Percentage (w) of trees estimated in each zone segment.
Column H = # of street trees to sample.
Column I = # of street trees observed.
Column J = # of *Acer platanoides* observed.

Résumé. Cet article développe et fait la démonstration d'une méthode statistique d'échantillonnage qui peut être employée pour estimer rapidement et avec précision, c'est-à-dire avec un degré acceptable d'erreur, la composition en espèces d'une population urbaine d'arbres de rues. Basé sur la technique d'échantillonnage stratifié, on estime tout d'abord le pourcentage d'arbres de rues dans les segments de zone séparés au sein de la ville et, ensuite, on distribue un échantillonnage de 2000 à 2300 arbres au travers de la ville. Une moyenne pondérée est utilisée pour obtenir les limites de confiance et d'estimation. Nous avons appliqué cette technique dans quatre villes de l'état de New York, obtenant d'excellents résultats en accord intime avec l'information complète ou partielle déjà existante sur l'arbre de rue.

Zusammenfassung. Dieser Beitrag zeigt eine statistische Methode für eine schnelle und präzise Abschätzung der Artenzusammensetzung einer Stadtbaumpopulation mit einer akzeptablen Fehlerquote. Basierend auf der Technik der schichtenweisen Erhebung (statified sampling) wird zunächst der prozentuale Anteil an Straßenbäumen in einzelnen Abschnitten der Stadt ermittelt und anschließend eine Probe von 2000 bis 2300 Bäumen auf die ganze Stadt ausgedehnt. Um die Abschätzungen und die Vertrauensgrenze zu erlangen, wird gewichtend gemittelt. Wir haben diese Methode in vier Städten im Staat New York angewandt und gute Resultate damit erzielt, die annähernd mit den bestehenden Erhebungen über den Straßenbaumbestand übereinstimmen.