STRUCTURE OF URBAN STREET TREE POPULATIONS
AND
SAMPLING DESIGNS FOR ESTIMATING THEIR PARAMETERS

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ABSTRACT.--Census data for 7372 street trees in Poughkeepsie, New York have been analyzed to elucidate population structure, species and cultivar composition and their distribution. Only fourteen of the 113 species and cultivars are present in sufficient numbers (29 or more) to permit inferences on dispersion and density. For the eleven most common, more than half occur in clusters. The remaining three species exhibit a widely dispersed pattern, mostly as single specimens. True population variances for stem height and diameter of the five most common species among the older tree populations were used for comparisons with estimates of variance obtained in computer simulation's of various survey sampling methods with these data. Cluster sampling procedures provide an unbiased estimate of variance. Greater precision in the estimates results when a larger number of clusters, i.e. randomly selected streets, are surveyed and when the sampling interval between trees is larger. Fifty to 100 clusters appear to be adequate in number. The sampling interval may vary among species, with its size dependent upon species' incidence, total population size and the desired sample population size. Sample population sizes of 100 and even smaller provided reliable estimates of the true variances for four of the species. Differences obtained for the fifth, red maple, are attributed to the concentration of most of the younger trees along one street. Hence variance estimates would be markedly affected by either the presence or absence of this street in the random sample. A larger sample population size and a greater number of clusters may be advisable for large urban centers with greater environmental

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variability than occurs in Poughkeepsie, a relatively small city in the lower Hudson River valley. The proposed cluster sampling method, however, should be applicable to cities of any size with any species composition as long as the trees of each species or cultivar occur predominantly in clusters. Metro. Tree Impr. Alliance (METRIA:) Proc. 1:28-43, 1978.

## INTRODUCTION

Since the near total elimination of the American elm (Ulmus americana L.) due to Dutch elm disease in Syracuse, New York in the past 15 to 20 years, the mortality rate for sugar maple (Acer saccharum Marsh.) has been estimated to have doubled (Miller, personal communication). Crown dieback of unknown cause has become so widespread, it is difficult to locate healthy trees of this species in Syracuse. These and other problems, some unique to the urban environment, aroused concern at the College of Environmental Science and Forestry for trees in metropolitan areas. Three coordinated projects have resulted, involving detailed studies of street trees in the cities of Rochester and Syracuse, New York. The first is concerned with developing aerial photographic techniques for expeditious dection of stressed trees. The second involves the assessment of environmental and biotic factors associated with declining maples through coordination of aerial photography and intensive ground observations of growth, health, and site conditions. The third project is concerned with the improvement of urban trees through the selection and breeding of trees that have survived one generation in the urban environment. There is some question, however, whether the phenotypic variation among the surviving trees is sufficient to serve as the genetic base for improvement by artificial selection. The purpose of the present study was to devise methods for characterizing the structure of urban tree populations and for estimating the population parameters.

## STRUCTURE OF URBAN STREET TREE POPULATIONS

Results of a 1974 census of street trees in Poughkeepsie, New York conducted by Cary Arboretum of the New York Botanical Garden provided the materials for this study. The data included location, measures of growth and health, and the environmental conditions for each tree. True population parameters were calculated by computer for height and stem diameter at breast height (d.b.h.) for each of the five most common species in the older surviving populations and simulation methods were utilized to determine an efficient, reliable method for estimating these parameters by survey sampling procedures. Additional information provided by these methods includes the species and cultivars present, their incidences and their patterns of dispersion. Though this study is primarily concerned with the older trees, the methods are applicable for all components of street tree populations. Only those aspects of population structure directly related to the aampling procedures that appear to best characterize these populations, however, will be presented.

The population of Poughkeepsie has been stratified in two ways. One is by age, with a species classified as "older" if the average height 115 feet and average d.b.h. > 5 inches and "younger" if the average size is smaller in one or both traits. The eight most common "older" species listed by number of trees and percentage of the total population are given in Table 1. These species are comprised almost wholly of older, established trees except for red maple (A. <u>rubrum</u> L.). About 20% of the trees of this species fall into the "younger" tree class and occur in some of the more recently developed areas of the city as well as areas of urban renewal and redesign. The six species and cultivars comprising the "younger" group (Table 1) reflect a marked change in tree preferences for street plantings. Some of these replaced American elms, but most are present in more recent developments and in areas of urban renewal and redesign.

A second stratification was by "land use," according to city zoning designations, and include: low density residential, medium to high density residential, and commercial industrial. The commercial and industrial zones were combined because of the small areas represented by each in Poughkeepsie and because of the scarcity of street trees in these sections of the city. Even so, the numbers of red and silver maples and basswood (5, 5, and 8, respectively), are too small for meaningful comparisons between the commercial-industrial stratum and the other strata for these species. Comparisons of the true population parameters, $\mu$ and $\sigma^2$ for stem height and diameter between the low density residential and the medium-high density residential strata revealed only small differences except for red maple. The red maple difference is likely attributable to the non-random distribution of younger trees among strata. Twenty-nin of the 36 "younger" trees occur in an area of urban renewal with multiple-dwelling public housing along the riverfront, i.e. the medium-high density residential stratum. They make a large contribution to the larger variances that were obtained for the 82 trees in this stratum compared with that for the 84 red maples in the low density residential stratum. It was concluded, however, that stratification by land use would have little value, and the data were pooled for each species.

The pattern of dispersion of trees could affect the sampling procedures, especially for the less common species and cultivars. Norway Maple (A. platanoides L.) and sugar maple are sufficiently common and widespread throughout the city so that most sampling procedures would provide reliable estimates of incidence, dispersal and population parameters. The trees of both species, however, tend to occur in "clusters" along a street or block, but the clusters are many and widely dispersed, The next three commonest species among the "older" trees, red maple, silver maple (A. saccharinum L.) and basswood (Tilia americana L.), are considerably less frequent, but also tend to occur as clusters with 50% or more of each species present in this pattern of planting. These patterns can be seen in Figure 1 which shows species incidence along residential streets in one of the older sections of the city. The remaining three species in the "older" group each represent less than 1% of the total population and occur mostly as widely scattered single trees. Some of these are shown in Figure 1.

The six species and cultivars in the "younger" group exhibit an even greater tendency of clustering, with 60% of the littleleaf linden (Tilia cordata Mill.) and 80% or more of the other five occurring in this planting pattern. This can be seen in Figure 2, which includes an area of urban renewal in the riverfront section and an area of urban redesign in the vicinity of the downtown mall. High proportions of these species and cultivars occur in these areas, with small numbers in newer developments and replacement plantings.

The results of this analysis of the Poughkeepsie street tree population clearly indicate that a sample survey method for characterizing urban street tree populations must accommodate the practice of planting the trees in "clusters" as well as widely scattered single specimens. Since members of a cluster are likely of common origin, i.e. from the same group of nursery stock, and share a similar environment, one might expect less variation to be exhibited in comparisons of members of the same cluster than between clusters. The sampling procedure herein proposed provides reliable information on the nature of the street population as well as unbiased estimates of true population parameters.

## SAMPLING DESIGNS FOR ESTIMATING VARIABILITY OF URBAN STREET TREE POPULATIONS

The objective of this portion of the study was to devise a workable sampling scheme for estimating the variance, $\sigma^2$ of traits of urban street trees. An estimator which was unbiased and which had a minimal variability was sought. Our approach is based on the fact that the true population parameters for Poughkeepsie street trees are known. The results of various computer simulated sampling surveys, therefore, could be compared with these known values and the schemes evaluated. The true population means and variances for stem height and diameter for each of the five commonest "older" species and the total number of trees comprising the total population of each species are given in Table 2.

Limitations imposed upon the survey methods were that the computer simulated procedure must mimic one that would be feasible for a survey crew walking down a street measuring trees and recording their observations. And secondly, in their design, consideration must be given the actual structure of the Poughkeepsie population since the success of the scheme and the accuracy and precision of the estimates are dependent upon the species' frequencies and distribution.

The proposed sampling scheme is based upon three variables:

- m--the number of streets randomly selected for the' survey from the 275 streets in Poughkeepsie,
- &--the sampling interval for trees of each species, i.e. if $k = 1$, every tree of that species would be sampled:
  if $k = 2$, every second tree would be sampled, etc.
- n--the total number of trees of a given species in the sample population.

In a given sampling scheme, one or more of these variables could be fixed; moreover, the fixed value for a particular variable such as $k$ could differ for the five species.

To illustrate the general scheme, the survey crew would sample every $k_i$ th Norway maple, every $k_j$ thsugar maple, etc. encountered as they proceeded along each of m randomly selected streets. The number of trees sampled-for each species, e.g. $n_i$ Norway maple, $n_j$ sugar maple, etc., would vary because of the different number of trees of each species on these streets and because the sampling interval could vary among species, i.e. $k_i \neq k_j$, etc. Estimates of $\sigma_H^2$ and $\sigma_D^2$ would then be calculated from the sample population for each of the five species.

Each sampling scheme was repeated by computer simulation forty times to yield forty variance of stem height estimates ($s_H^2$) and forty variance of stem diameter estimates ($s_D^2$). The mean and standard deviation of the forty estimates for each of these variance parameters were computed to check for bias and to determine the degree of variability among the estimates. All the schemes investigated will not be presented, only the one that appears most promising.

Computer survey simulations were completed for each combination of m from 30 to 150 at intervals of 10 and values of k of 1,3 and 10. Additional simulations with k values of; 2, 5,7, 15 and 20 were conducted for m values of 50, 100 and 150. Altogether 54 combinations of m and k were used in computer simulated surveys for each of the five species, with 40 interations of each combination. These provide information on the effect of varying m and k on sample size ( n ) and on the variability exhibited by the forty independent estimates of $\sigma_H^2$ and $\sigma_D^2$ for each of the five species.

The results of the computer simulations are presented only in part because of the extensiveness of the data and because the general trends exhibited in all of the results due to varying m and k are exhibited by these data. The results for stem height in Norway maple are presented in Table 3 for illustrative purposes. The results of the computer iterations for a particular sampling scheme are given in the cell formed by the column for m and the row for k, with the upper number the standard deviation of the forty estimates of $\sigma_H^2$ and the lower number the average sample size, $\bar{n}$.

Note the effect on the variability of the estimates (upper numbers) and on the average sample size (lower numbers) as m and k change. If k is held constant, e.g. k = 1, the standard deviation of the $\sigma_H^2$ estimates decreases from 12.51 to 5.09 as m increases from 30 to 150 as shown in Table 3, and the mean sample size increases from 478 to 2396. These results are not unexpected since sample size should increase if the number of streets sampled is increased. Since a larger sample will provide a more precise estimate of the true population variance, less variation in the variance estimates should occur in repeated simulations. Varying k and holding m constant has the converse effect, i.e. as the sampling interval increases, the mean sample size decreases and variability among the variance estimates increases, For example, if m is held constant at 50 and k increases from 1 to 20, the standard deviations of the $\sigma_H^2$ estimates increases from 9.80 to 16.23 and sample size decreases from 758 to 80 as given in Table 3. Again these results are not unexpected as the variability of the estimate should increase as sample size decreases.

The most important trend, however, can be seen if both k and m vary but sample size is held constant. Paired combinations of cells in Table 3 can serve as examples. The first pair of cells is for k = 1 and m = 40 and for k = 3 and m = 110, each with an average sample size ($\bar{n}$) of 643. Note that the variability of the $\sigma_H^2$ estimates is more than halved by sampling every third Norway maple on 110 streets rather than every one encountered on 40 streets. A second pair of cells is for k = 3 and m = 50 and for k = 7 and m = 100, each with $\bar{n}$ = 294. In this example the standard deviation of the $\sigma_H^2$ estimates is decreased by about 35%, i.e. from 11.51 to 7.43 by a larger sampling interval and a greater number of streets. The general effect of increasing both the number of streets (m) and the interval between sample trees (k) but holding the sample size (n) constant is marked reduction in the variability of the variance estimates, The sampling scheme to be proposed is based upon this result. One disadvantage to the improvement of the estimate by this method is of no consequence in a computer simulated survey, but would be of importance to a survey crew on foot. That is the distance to be walked and the total time for the survey will increase as the number of sampled streets (m) increases. Therefore, some compromise must be made between the precision of the estimate and the time and cost factors involved in the actual street surveys.

The pattern of distribution of street trees appears to provide tha answer to the question of why the combination of a larger number of sample streets and a greater sampling interval increases the accuracy of the estimate of the true population variance. Recall that trees of a given species tend to occur in clusters. Furthermore, members of the same cluster are likely to exhibit less variation for a trait than members of different clusters. Sampling from groups of phenotypically similar trees will tend to give a more biased estimate of the total variation for a trait among all trees of that species in the entire city. In this case, it will be underestimated. This accords with theories of cluster sampling concerned with the estimation of the population mean, $\mu$, (Mendenhall et al, 1971). It can be demonstrated that samples drawn from clusters[2] with little variation

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[2] In this paper the word "cluster" is used, for the most part, according to the layman's definition, relating to the distribution or dispersion of individuals in groups. In this paragraph, however, it is used according to the definition in sampling statistics, i.e. a cluster is a group in a larger population selected at random so that the sample population is composed of randomly selected groups (Mendenhall et al, 1971). In this study, portions of streets were selected randomly and are the clusters.

tend to lead to estimates of $\mu$, i.e. the $\bar{x}$, with higher variation than samples from clusters with high variation formed from the same population. This principle appears to apply to the streets in this study which act as clusters in estimating the population variance, $\sigma^2$. The larger sampling interval, therefore, minimizes the effect of the within cluster variation by reducing the number of similar phenotypes in the sample.

Another method of comparison of the results in Table 3 suggests how one could decide the most efficient sampling scheme in terms of the actual street survey procedures for a given level of precision in the estimate of the true variance. It can be seen that six combinations of k and m result in about the same standard deviation in the $\sigma^2$ H estimates. These are k = 1 and m = 80 or 90, k = 2 and m = 100, k= 3 and m = 90 or 100, and k = 10 and m = 120. Also note-the differences in the mean sample sizes ($\bar{n}$), with n = 278 for k = 10 and m = 120 the smallest. Since the measurements and the recording of information for sample trees require the most time in a street survey, limiting sample size without sacrificing precision of theestimator would increase the efficiency of the survey. It should be noted, however, that even though time spent walking between sample trees is relatively small, increasing both k and m increases the walking time and must be considered in the-decision of the sizes of these variables. In looking at the six combinations of k and m that exhibit about the same precision in the variance estimate (see above), it would appear that the scheme with k = 10 and m = 120 with the smallest average sample size ($\bar{n}$) = 278) is the best choice. The much smaller number of trees to be measured compared with the other five more than compensates for the larger number of streets to bewalked. For example, in comparison with the k = 1 and m = 80 procedure, the 80% reduction in sample size (278 vs. 1278) obviously offsets the disadvantage of a 50% greater distance to walk (120 vs. 80 streets), especially when these factors are weighted according to their relative-time requirements. The scheme with k = 3 and m = 90 with n = 521, which has exactly the same precision for theestimated variance as the preferred scheme, would appear the next best choice. In fact, it might well be the best if few measurements and ovservations were required for sample trees. The time spent at almost twice as many trees (521 vs. 2'78) would have to be compensated by the fewer streets to be walked (90 bs. 120). These comparisons clearly show that the selection of m, the number of sample streets or clusters, and k, the sampling interval, and their effect on ($\bar{n}$), the sample population size, are critical in designing an efficient but reliable survey sampling scheme. The size of each variable must be weighed in relation to the required precision for the estimated parameter and to the efficiency of the actual street survey.

The amount of variability in the estimate of the true variance, i.e. the precision of the estimate, that can be decided before a sampling scheme can be designed. This has been approached by using a method employed by Namkoong and Roberds (1974) to measure the relative variability in estimated ofgenetic variance ($\sigma_A^2$). They calculated the Coefficient of Variation for the variance estimates and considered estimates with C.V. $< 1/2$ as good. At this level, $\sigma_A^2$ will be larger than twice its standard error of estimate. Applying this to the present study, the values of c. v. for the six variance estimates discussed above would be equal to or less than .06, values much smaller than the value for this statistic suggested by Namkoong and Roberds. This suggests that a much greater variability in the estimate could be permitted. This could easily be achieved by reducing the sample size, which would also greatly increase the efficiency of the sampling scheme.

The Coefficient of Variation has also been employed to assist in making decisions on the sizes of the three variables, m--number of randomly selected streets or clusters. &--the sampling interval, and n--sample population size. Comparisons were made of the Coefficient of Variation for the various computer simulated sampling schemes for both stem height and diameter for each of the five species. It was found that a minimum value of $\underline{m} = 50$ would provide variance estimates with a C.V. $\leq .50$ for both traits in all five species. The larger values of C.V. occurred for the less common species, which is to be expected because of the smaller sample sizes. For Norway and sugar maple with $\underline{m} = 50$, increasing the sampling interval ($\underline{k}$) to 10 and 3, respectively, to reduce sample sizes to 113 and 70, respectively, still resulted in a C.V. $\cong .20$. The C.V. values increased sharply in most cases for values of $\underline{m}$ less than 50, and of course, sample size was markedly reduced. Increasing $\underline{m}$ above 50 results in a greater precision, C.V. decreases and sample size increases, but a point of diminishing return is generally evident when $\underline{m}$ is approximately 100. Certain exceptions to this were obtained for less common species. Nevertheless, in this study reasonably reliable variance estimates were obtained for stem height and diameter for both silver maple and basswood with $\underline{m} = 50$ and k = 1 even though they are relatively rare (incidence approximately 2%) and the sample sizes were small, 27 and 31, respectively. It would appear that the number of streets or clusters ($\underline{m}$) should be at least 50 but not more than 100. A total sample size of about 100 appears sufficiently large for precise estimates of population variances, although much smaller sizes provided reasonably precise estimates. Finally k can be determined for each species on the basis of the total population size and species' incidence so that a sample population of 100 is obtained for the more common species.

For less common species and cultivars, every tree should be sampled, i.e. k = 1. If considerable environmental variation occurs, it would be advisable to increase the number of clusters (m) as well as sample size (n). If sample size must be limited or held constant, both k and m could be increased.

To illustrate how thissampling scheme works, results that might be obtained by a survey crew using this scheme are given in Table 4. The true population variances are also given for easy comparisons. The number of streets (m) selected at random for each species was 100. The sampling intervals (k) is different for each species because of different species densities and for red maple, because of the peculiarity in its distribution previously discussed. If the estimates of the variance for each trait ($s_H^2$ and $s_D^2$) are compared with true variances ($\sigma_H^2$ and $\sigma_D^2$) for each species, striking similarities are evident except for both traits for red maple and the variance of diameter for basswood. None of the remaining differences are statistically significant. In fact, it can be shown that these estimated variance values are within one standard deviation of their respective true population variances.

The results of this simulated survey clearly show that the proposed sampling scheme can be used to provide precise estimates of population variances, based upon a relatively small sample population. Though Poughkeepsie is a rather small city (approximately 32,000 population and area of four square miles) with a reasonably homogeneous environment in the lower Hudson River Valley, the proposed sample survey method should be equally applicable to other urban centers, even large ones,, as long as tree species occur as clusters along the city streets.

## LITERATURE CITED

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Namkoong, G., and J. H. Roberds.
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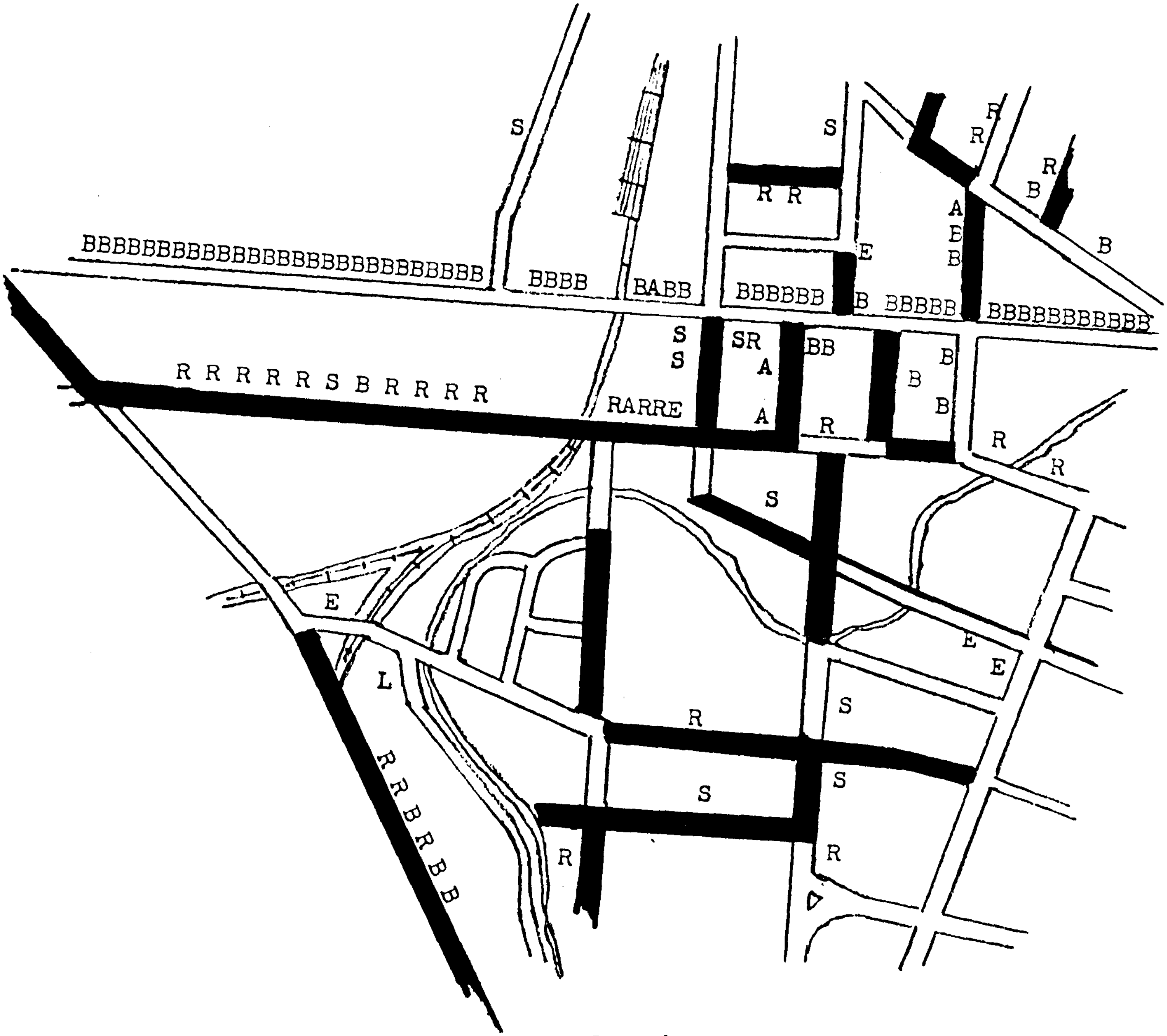
Figure 1

Distribution of common older street trees.



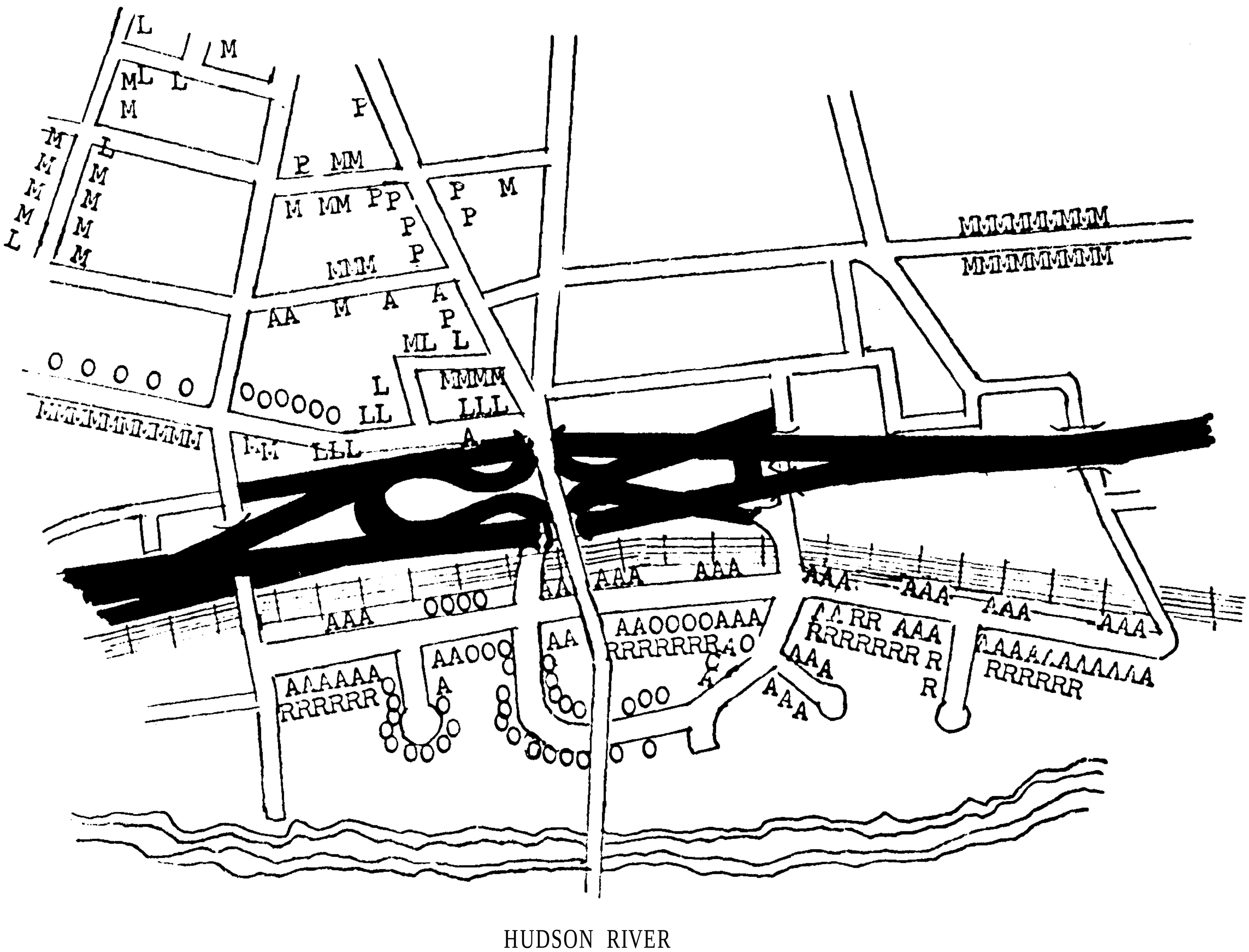

Legend

Each letter represents one tree; a shaded street indicates one or more sugar maple per block; Norway maple not shown but is cosmopolitan

| | | | |
|---|---|---|---|
| White ash | A | Black locust | L |
| Basswood | B | Red maple | R |
| American elm | E | Silver maple | S |
| Sugar maple | | | |

Figure 2

Distribution of recent street tree plantings.




Legend

Each letter. represents one tree except near the riverfront where space limitations prevented showing all trees.

| | | | |
|---|---|---|---|
| Marshall's seedless green ash | A | Pin oak | 0 |
| Littleleaf linden | L | *Prunus* spp. | P |
| *Malus* spp. | M | Red maple | R |

TABLE 1

Common street trees of Poughkeepsie, New York

| Name<br>Older Trees | Number | Per-<br>cent | Distribution |
|---|---|---|---|
| Norway maple<br>(Acer platanoides I,.) | 4334 | 59 | Ubiquitous |
| Sugar maple<br>(A. saccharum Marsh.) | 834 | 11 | Clusters |
| Red maple<br>(A. rubrum L.) | 193 | 3 | " |
| Silver maple<br>(A. saccharinurn L.) | 149 | 2 | " |
| Basswood<br>(Tilia americana L.) | 156 | 2 | " |
| White ash<br>(Fraxinus americana L.) | 52 | 0.7 | Scattered |
| American elm<br>(Ulmus americana L.) | 44 | 0.6 | " |
| Black locust<br>(Robinia pseudoacacia L.) | 32 | 0.4 | " |
| Young Trees | | | |
| Malus spp. | 813 | 11 | Clusters |
| Pin oak<br>(Quercus palustris Muenchh.) | 97 | 1 | " |
| Littleleaf linden<br>(T. cordata Mill.) | 88 | 1 | " |
| Marshall's eedless green ash<br>(F. subintegerrima var. lanceolata 'Marshall') | 85 | 1 | " |
| Cherry<br>(Prunus spp.) | 40 | 0.5 | " |
| Goldenraintree<br>(Koelreuteria paniculata Laxm.) | 35 | 0.5 | " |
| Other Trees | 420 | 5.7 | |
| Total Population | 7372 | | |

TABLE 2

True population parameters for stem height in feet and diameter in inches for the five most common "older" street tree populations in Poughkeepsie.

| | | | Population parameter | | | |
|---|---|---|---|---|---|---|
| | | | Height | | Diameter | |
| Species | Number | Incidence | $\mu_H$ | $\sigma_H^2$ | $\mu_D$ | $\sigma_D^2$ |
| Norway maple | 4334 | 59 | 32.2 | 121.0 | 13.8 | 34.9 |
| Sugar maple | 834 | 11 | 43.7 | 158.6 | 17.3 | 49.6 |
| Red maple | 193 | 3 | 37.5 | 238.2 | 16.4 | 86.0 |
| Silver maple | 149 | 2 | 52.5 | 153.7 | 26.7 | 92.8 |
| Basswood | 156 | 2 | 45.7 | 136.7 | 19.3 | 25.6 |
| Others | 1706 | 23 | – | – | – | – |
| Total Population | 7372 | 100% | | | | |

TABLE 3

Standard deviations of $\sigma_H^2$ - estimates (upper number) and average sample population, $\bar{n}$, (lower number) for Norway maple based upon forty computer simulations of each sampling procedure.

| Sampling interval (k) | Number of streets (m) 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 12.51 | 13.20 | 9.80 | 7.00 | 8.11 | 6.75 | 6.81 | 6.03 | 5.36 | 5.13 | 4.65 | 4.27 | 5.09 |
| | 478 | 643 | 758 | 945 | 1130 | 1278 | 1417 | 1591 | 1750 | 1927 | 2076 | 2246 | 2396 |
| 2 | | | 10.64 | | | | | 6.72 | | | | | 3.87 |
| | | | 436 | | | | | 841 | | | | | 1231 |
| 3 | 15.47 | 12.10 | 11.51 | 10.09 | 8.84 | 8.61 | 6.79 | 6.78 | 6.21 | 6.42 | 6.21 | 5.03 | 4.91 |
| | 180 | 235 | 294 | 343 | 417 | 457 | 521 | 582 | 643 | 691 | 757 | 827 | 870 |
| 5 | | | 11.42 | | | | | 7.36 | | | | | 3.85 |
| | | | 190 | | | | | 378 | | | | | 562 |
| 7 | | | 14.57 | | | | | 7.43 | | | | | 3.96 |
| | | | 147 | | | | | 294 | | | | | 443 |
| 10 | 1527 | 14.02 | 14.53 | 10.52 | 9.32 | 8.88 | 9.30 | 9.61 | 7.16 | 6.79 | 7.00 | 6.12 | 4.01 |
| | 71 | 94 | 113 | 136 | 166 | 184 | 208 | 279 | 253 | 278 | 299 | 323 | 347 |
| 15 | | | 21.75 | | | | | 10.17 | | | | | 6.12 |
| | | | 90 | | | | | 183 | | | | | 273 |
| 20 | | | 16.23 | | | | | 10.23 | | | | | 5.92 |
| | | | 80 | | | | | 160 | | | | | 240 |

TABLE 4

Estimated variances of stem height (ft.) and diameter (in.) from a computer simulated sample survey of Poughkeepsie street trees.

$m$ = number of streets, $k$ = sampling interval, and $n$ = sample population size

| | | | | Population parameter | | | |
|---|---|---|---|---|---|---|---|
| | | | | Variance of height | | Variance of diameter | |
| | Sampling variables | | | (Estimate) | (True) | (Estimate) | (True) |
| Species | $m$ | $k$ | $n$ | $s_H^2$ | $\sigma_H^2$ | $s_D^2$ | $\sigma_D^2$ |
| Norway maple | 100 | 10 | 244 | 114.8 | 121.0 | 34.1 | 34.9 |
| Sugar maple | 100 | 3 | 127 | 167.7 | 158.6 | 51.7 | 49.6 |
| Red maple | 100 | 10 | 34 | 117.8 | 238.2 | 40.3 | 86.0 |
| Silver maple | 100 | 1 | 58 | 120.8 | 153.7 | 106.1 | 92.8 |
| Basswood | 100 | 1 | 40 | 150.5 | 136.7 | 43.2 | 25.7 |