A street tree survey for Canadian communities: Protocol and early results

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ABSTRACT
This paper describes early results from a survey that was developed to allow rapid, yet reasonably accurate, estimates of street tree composition in Canadian communities. To carry out surveys, participants walk (or drive) a number of 0.5-km routes, identifying all trees within 10 m of the road edge. The number of survey routes in each community was determined such that tree densities could be estimated within reasonable error bounds: ±5 trees/km for common species and ±1 tree/km for uncommon species. Information from this initiative has already supported invasive species risk assessments and urban forest management activities. Full details are available at http://gmaps.nrcan.gc.ca/uts/index.php.

Keywords: street tree, survey, invasive species, urban forest management, Canada

RÉSUMÉ
Cet article porte sur les résultats préliminaires d'un sondage élaboré afin de permettre des estimés malgré tout raisonnablement précis de la composition des arbres le long des rues des communautés canadiennes. Lors du sondage, les participants se déplacent (en auto ou à pied) sur des sections de rue de 0,5 km, répertoriant tous les arbres situés à moins de 10 m du bord de la rue. Le nombre de sections de rue dans chaque communauté a été déterminé de façon à ce que la densité des arbres pouvait être estimée à l'intérieur d'une marge raisonnable d'erreur : ±5 arbres/km dans le cas d'espèces courantes et ±1 arbre/km pour les espèces exotiques. Les informations tirées de ce projet ont déjà permis de procéder à l'évaluation du risque posé par les espèces envahissantes et des activités d'aménagement des forêts urbaines. Les détails complets de l'étude sont disponibles sur le site : http://gmaps.nrcan.gc.ca/uts/index.php.

Mots clés : arbre de rue, sondage, espèces envahissantes, aménagement des forêts urbaines, Canada

INTRODUCTION

Urban trees are an integral part of towns and cities across Canada, often lending a unique character to streets, neighborhoods, and entire communities. Many benefits have been attributed to urban trees, including shade provision, wind reduction, carbon dioxide sequestration, improved air quality, runoff control, increased property value, wildlife habitat provision, and improvements to various aspects of human health (Dwyer *et al.* 1992). However, urban trees also incur costs, particularly with respect to planting, maintenance, and removal activities. Significant costs also arise when trees come into conflict with urban infrastructure such as hydro and sewage lines (McPherson *et al.* 2007).

Given the substantial benefits and costs associated with urban trees, it is important they are managed carefully. Urban forest surveys are important tools for accomplishing this goal. Such surveys vary widely in the scope and nature of information collected. For example, general information on urban forest cover may be obtained from satellite data (Cumming et al. 2008), while detailed inventories may be used to track the size, age, condition, species composition, and location of trees in a community (Nowak and Crane 2000). The appropriate survey for a given situation is determined largely by available resources and the objectives for which the data are being collected. The state of urban forest data is highly variable in Canada; certain communities have detailed tree inventories (e.g., London, Ontario; http://www.london.ca/d.aspx?s=/ Trees_Lawns_and_Gardens/treeinvnt.htm), but many lack such information entirely.

Knowledge of urban forest composition is particularly important in the context of invasive forest insects and diseases. These species often first become established in urban centers and can incur enormous economic impacts in the urban setting. For example, treatment, removal, and replacement efforts to combat the emerald ash borer (*Agrilus planipennis* Fairmaire 1888) in communities across the eastern United States (Kovacs *et al.* 2010; Sydnor *et al.* 2011, 2007) and Canada (McKenney *et al.* 2012) are expected to cost billions of dollars. Such estimates require at least coarse estimates of urban forest composition across an area of interest.

In order to facilitate rapid assessments of the risk posed by invasive insects to Canadian communities, we have developed a simple survey to collect information on the composition of urban street trees. Street trees (defined here as trees within 10 m of the road edge) were selected because they are relatively easy to survey and—due to their proximity to urban infrastructure—often require a response by stakeholders (property owners, municipalities, utility companies) when attacked. Here we present the survey methodology and selected preliminary results. Our survey is not intended to replace more detailed and exhaustive, spatially referenced inventories as a tool for urban forest management, but it does allow for a rapid, consistent assessment of street tree composition across Canadian communities. In addition, the protocol is simple enough that it may provide municipalities and citizens a reasonable and inexpensive approach to gather street tree data where no such data currently exist.

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Survey Methodology

Preliminary survey design

A geospatial layer of urban centers in Canada was obtained from Statistics Canada. Urban centers were defined as having a minimum population concentration of 1000 persons and a population density of at least 400 persons per square kilometer (Statistics Canada 2010); a total of 895 locations met these criteria (Fig. 1). This layer was intersected with a geospatial layer of the road system of Canada (GeoBase 2007), thus defining the road network for each urban center. The total length of road in each urban centre was calculated. Survey starting points were located at random road intersections; the number of starting points in a given urban centre was determined such that, if a survey of 0.5 km in length was carried out at each starting point, 5% of the total length of roadside in that centre would be surveyed. Note that roadside length is twice road length, since trees are found on both sides of urban roads.

Survey protocol

Surveyors are provided with a list of starting points. At each starting point, surveyors are asked to walk (or drive) a 0.5-km route, recording information on standard datasheets along the way. In order to avoid bias when selecting a route, surveyors are asked to randomly select which direction and which side of the street the route will follow. Survey lengths are measured using a GPS unit or vehicle trip odometer. During the survey, participants are asked to record the following information for any trees found within 10 m of the roadside: species (or genus if species was unknown), height class (1 = 1.5–5 m; 2 = 5–10 m; 3 = >10 m), and whether it is a boulevard tree (i.e., located in the area between the curb and the sidewalk).

Surveyors are instructed to carry out a survey regardless of the number of trees on the route. In the case of heavily treed routes—some of which may have thousands of trees—surveyors are asked to make a best estimate by carefully counting a representative subsample and then multiplying by the length of the route. The survey is intended for trees only; information on shrub species and trimmed hedges is not collected. Finally, surveyors are encouraged to make safety a priority; surveys are not to be carried out at a given location if conditions are deemed unsafe.

Survey improvements

Data collected during the first year of the survey was used to help improve the survey design. The appropriateness of the 0.5-km survey length was explored using the formula of Wiegert (1962), which identifies the optimal trade-off between increased time costs and reduced variability associated with larger sampling units:

[1] $$\text{Optimal Size} = \text{Min}(\text{Cost} \times \text{Variance})$$

where Cost is the amount of time taken to conduct a survey of a given length and the variance associated with a given species and survey length is calculated from the preliminary survey data; both Cost and Variance are expressed in relative terms following Wiegert (1962).

The data used for this aspect of the study were collected in Sault Ste. Marie, Ontario and comprised 10 survey routes that were each 4 km in length. Trees identified during the survey were associated with 100-m segments within each 4-km route, allowing mean and variance estimates to be calculated for a variety of survey lengths. Time costs were estimated based on two

Fig. 1. Canadian urban areas for which street tree data have (black) and have not (gray) been collected using the survey presented here.

participants in a vehicle (one driver and one surveyor) and included both time to carry out the survey and time required to drive between survey routes.

We also used preliminary survey data to examine the appropriate number of survey routes for a given urban centre. Statistical theory suggests that population characteristics can be estimated within a desired degree of accuracy, 95% of the time, using a sample size (n) given by:

$$n = \frac{N\sigma^2}{(N-1)\frac{B^2}{4} + \sigma^2} \quad [2]$$

where N is the population size (in this case the total number of 0.5-km sections of roadway in a given urban centre), σ^2 is the variance (calculated from the preliminary data), and B is the desired bound on the error (Scheaffer *et al.* 1986). Here we examine the sample size required to obtain a bound of five trees per km on density estimates of a common genus (i.e., 25 individuals per km urban roadside), and a bound of one tree per km on density estimates of an uncommon genus (i.e., 2.5 individuals per km urban roadside).

Results

Preliminary survey results

A Web site (http://gmaps.nrcan.gc.ca/uts/index.php) has been developed, which provides: a project description and background, detailed survey protocols, printable maps of survey locations for each urban centre in Canada, printable data forms and lists of species codes, and preliminary data summaries. Registered participants can also enter data at the site. Outreach efforts were undertaken to generate volunteer interest in the survey among naturalist groups and provincial resource stewardship programs. These volunteer groups accounted for approximately one-quarter of the data collected to date, with the remainder collected by staff at the Canadian Forest Service.

Data were collected from a total of 53 communities in four different provinces (Fig. 1). These data provide preliminary insights into roadside trees in eastern Canada. For example, the six most common tree genera along urban roadways were *Acer, Betula, Picea, Populus, Thuja*, and *Pinus* (Table 1). In the context of invasive forest insects, the emerald ash borer attacks all species in the genus *Fraxinus*—representing approximately three trees per km of roadside (Table 2). The Asian longhorned beetle (*Anoplophora glabripennis* [Motschulsky, 1853]), another high-profile invasive forest insect, attacks species in at least five different genera, placing nearly 70 trees per km of roadside at risk of attack (Table 2). These data also provide some information on the abundance of non-native tree species along urban streets. For example, our preliminary data indicate that, on average, there are 9.4 Norway maple (*Acer platanoides* L.) trees per km of urban roadway.

Survey improvements

Time costs and variances associated with various survey lengths are provided in Table 3 for a common (*Acer*) and uncommon (*Quercus*) genus. For both genera, low cost-by-variance values were obtained for survey lengths over 250 m.

Table 1. Mean and standard deviation (S.D.) in the frequency of tree genera along roadways in 53 urban centres of eastern Canada.

Genus	Mean (trees/km)	S.D. (trees/km)
Acer	31.52	36.18
Betula	20.31	59.91
Picea	19.61	31.93
Populus	13.68	40.57
Thuja	12.53	30.53
Pinus	9.22	20.53
Other	3.16	6.72
Fraxinus	3.10	9.52
Tilia	2.92	9.78
Abies	2.63	17.80
Prunus	2.50	11.03
Malus	2.31	5.09
Salix	2.15	9.17
Quercus	1.99	5.06
Sorbus	1.96	7.57
Alnus	1.90	13.22
Ulmus	1.30	5.67
Locust	0.98	5.07
Larix	0.88	9.13
Juniperus	0.70	6.19
Fagus	0.49	5.65
Aesculus	0.42	1.83
Tsuga	0.21	1.76
Juglans	0.16	1.07
Chamaecyparis	0.13	1.33
Ostrya	0.05	1.06
Crataegus	0.05	0.54
Liriodendron	0.04	0.52
Carya	0.04	0.47
Magnolia	0.02	0.32
Catalpa	0.02	0.18
Taxus	0.02	0.28
Cornus	0.01	0.18
Ginkgo	0.01	0.15
Syringa	0.01	0.30
Ailanthus	0.01	0.17
Amelanchier	0.01	0.17
Platanus	0.01	0.13
Maackia	0.00	0.07
Taxodium	0.00	0.07

We elected to continue using the 0.5-km route length for future surveys; this length was manageable for surveyors and, by maintaining it, we were able to preserve the data that had already been collected.

Sample sizes required to meet accuracy bounds of five trees per km (for a common genus) and one tree per km (for an

Table 2. Frequency of tree genera along urban roadways in eastern Canada that are at risk by the emerald ash borer (*Agrilus planipennis*) and the Asian longhorned beetle (*Anoplophora glabripennis*).

Invasive insect	Tree genera attacked	Mean (trees/km)	S.D. (trees/km)
Emerald ash borer	*Fraxinus*	3.1	9.5
Asian longhorned beetle	*Acer, Betula, Populus, Salix, Ulmus*	69.0	96.4

uncommon genus) were calculated for a range of road network sizes using eq. 2 above (Fig. 2). For these calculations, we used the preliminary survey data to calculate an "average" common genus (mean = 25 trees/km; SD = 43.8 trees/km) and an "average" uncommon genus (mean = 2.5 trees/km; SD = 9.1 trees/km). The results indicate that substantial changes should be made to the preliminary survey design, which aimed to sample 5% of the roadside in each urban centre (Fig. 2). For a small community with 100 km of road (i.e., 200 km of roadside) and a "population" of 400 0.5-km survey routes, the sample size required to estimate mean density of an uncommon genus with an error of ±1 tree/km is 181; the comparable number for a common genus with an error of ±5 trees/km is 174. These numbers are substantially larger than those of the original survey design, which would have required 20 0.5-km surveys to cover 5% of the total roadside. In contrast, a very large urban center may have 10 000 km of roads and 40 000 0.5-km survey routes. In this case, the calculated sample sizes for the uncommon and common genera would be 327 and 304 respectively, which are much smaller than the 2000 routes that would be required using the 5% approach.

Based on the survey times presented in Table 3, it is possible to estimate the amount of time required to survey a given community. For the small community described above, which required approximately 180 surveys, total survey time would be roughly 60 hours; the comparable estimate for a large community (requiring ~ 300 surveys) would be 100 hours. These time requirements appear quite reasonable in comparison to a full urban forest inventory; most communities could be surveyed in one to two weeks, particularly if multiple surveyors were involved. These time estimates are based on two participants in a vehicle (one driver and one surveyor); other approaches, such as walking, could involve considerably longer survey times.

Improvements to the survey protocol were also made based on early findings and feedback. First, a field was added to the survey form to collect information on the confidence (low, medium, high) associated with each tree identified. This addition recognizes the challenges involved in urban tree identification and allows database users to work with quality-related subsets of the data, which may be desirable for certain applications. Clearly, there is a degree of subjectivity involved in assessing confidence levels; however, we provide guidance in the survey protocol to help standardize this entry across surveyors. Second, surveyors are encouraged to train themselves in distance estimation prior to carrying out the survey by using a tape measure to calibrate their ocular estimates of tree heights and distances from curb edge. We also note in the updated survey protocols that a common height of utility poles in many Canadian communities is approximately 10 m and telecommunication lines are often strung at a height of approximately 5 m—offering excellent guidance for placing trees into height classes. Surveyors can contact local PUC authorities regarding pole and line heights in their community.

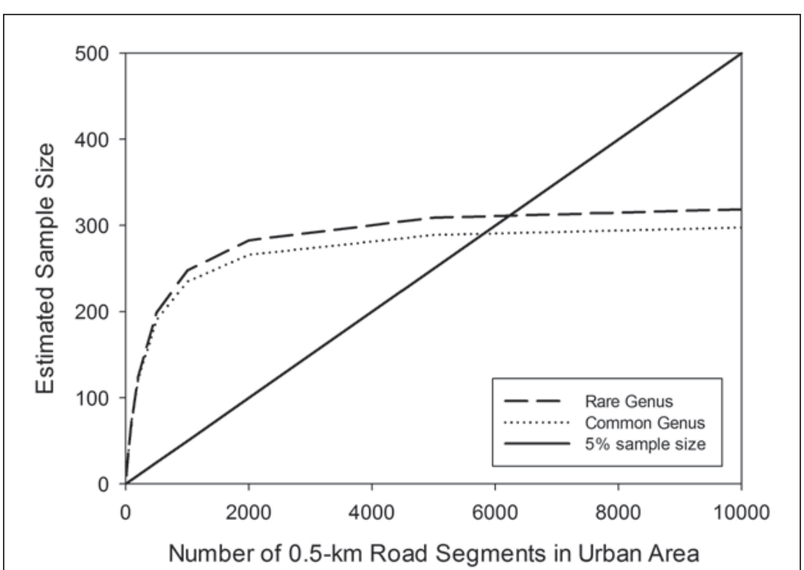

Fig. 2. Sample size required to estimate density of a common tree genus (±5 trees/km) and an uncommon tree genus (±1 tree/km) for a range of road network sizes. Also shown is the sample size required to cover 5% of the road network.

Discussion

The survey described here is designed to allow rapid acquisition of data on the composition of street trees in urban centers across Canada. By incorporating the survey improvements described above, particular species and/or genus densities can be estimated within acceptable error bounds for a range of community sizes. Such information is well-suited to national-level assessments of the risks posed by invasive forest insects and diseases in the urban setting, and has already been used to help estimate emerald ash borer economic impacts on Canadian communities (McKenney *et al.* 2012). Preliminary survey results were also used to estimate the incidence of Norway maple along urban roadways in eastern Canada (Bullas-Appleton *et al.* 2013).

There are a number of limitations to the survey that warrant discussion and clarification. First, it considers only trees within 10 m of urban roadsides, which clearly underestimates the full forest resources of a community. However, given that a full inventory is beyond

Table 3. Sampling cost associated with various street tree survey route lengths for a common (*Acer*) and uncommon (*Quercus*) tree genus.

Survey length (m)	Number of samples	Survey time (min)[a]	Common Genus Mean (trees/km)	Common Genus Variance (trees/km)	Common Genus Cost[b]	Uncommon Genus Mean (trees/km)	Uncommon Genus Variance (trees/km)	Uncommon Genus Cost[b]
100	400	11.6	26.0	2974.1	28.0	2.2	86.4	57.2
250	160	15.4	26.0	1770.7	22.1	2.2	32.4	28.5
500	80	19.8	26.0	575.8	9.2	2.2	10.1	11.4
1000	40	30.5	26.0	377.8	9.3	2.2	6.0	10.5
2000	20	72.3	26.0	184.9	10.8	2.2	2.7	11.0
4000	10	148.7	26.0	106.3	12.8	2.2	1.5	12.8

[a] Includes time required to travel to subsequent survey route.

[b] Cost is unitless and is calculated as relative survey time multiplied by relative variance following Wiegert (1962).

the scope of a volunteer-based survey, a reasonable cutoff was required. We selected 10 m because it is a common front-yard depth in Canadian communities and it allows relatively easy viewing of survey trees without requiring access to private property. Furthermore, trees in this zone would likely require a prompt (and often costly) response from stakeholders in the event of an invasive insect attack. We have explored approaches for extrapolating our roadside results to other components of the urban forest (e.g., backyards; McKenney *et al.* 2012), but the lack of information on urban parks and green spaces remains problematic. Second, the survey is only "semi-spatial" in nature; estimates of forest composition are associated with survey start points (i.e., specific intersections), but the location of individual trees is not recorded. This, along with the lack of information collected on tree condition, makes the survey of limited use for urban forest management; nonetheless, "semi-spatial" information on tree species composition could be quite valuable in communities where detailed inventory data do not exist. Finally, due to the rapid nature of the survey and the involvement of volunteers with variable tree identification skills, the taxonomic accuracy of the survey is limited. While we feel confident that volunteers can accurately identify trees to the genus level, species-level information may need to be used with care. Our incorporation of a confidence rating for each tree identified in the database allows users to employ higher quality subsets of the data as required.

Relatively few studies have explored rapid survey techniques for urban street trees. Jaenson *et al.* (1992) outlined an approach to obtain rapid and accurate estimates of street tree populations using stratified random sampling. Their approach yielded accurate estimates of tree species composition for several test communities in the United States; however, it required detailed information regarding the spatial delineation of different zones within the city (e.g., older residential, modern residential, and downtown) and a preliminary survey in order to distribute samples throughout the community. Obtaining such information and carrying out a preliminary survey for each urban center in Canada was not feasible, thus we developed the simple random approach described here. In support of this approach, Alvarez *et al.* (2005) reported that simple random surveys were easier to establish and provided more accurate estimates of street tree density than stratified surveys for a test community in São Paolo, Brazil.

Preliminary data collection allowed us to modify and improve our survey design. In particular, we used calculated variances and an established sample size formula to estimate the appropriate number of surveys for a range of community sizes. In comparison to our original design, which aimed to survey 5% of urban roadways, the modified design incorporates more surveys in smaller communities and far fewer in large communities. These changes have been incorporated into the survey maps that are available for each community at the Web site provided above. When adding or removing survey routes for a community, we attempted to retain survey routes for which data had already been collected if at all possible.

As noted, a variety of approaches have been used to quantify different aspects of urban forests for a range of objectives (e.g., Nowak and Crane 2000, Cumming *et al.* 2008, Nowak and Greenfield 2012). In a perfect world, detailed urban forest inventories would be carried out on an annual basis in all Canadian communities, but limits to fiscal and human resources make this impractical. Given our objective of generating reasonably accurate estimates of urban forest composition for use in national-level invasive species risk assessments and basic urban forest management (particularly in communities where detailed inventories are lacking), we feel that the survey presented here strikes a reasonable balance between survey effort and quality of the resulting data. We hope that, over time, it will join other citizen science efforts, such as the Christmas Bird Count (National Audubon Society 2013), the plant hardiness Web site (McKenney et al. 2007), and various phenology monitoring networks (Nature Canada 2013, USA-NPN 2013), in encouraging citizen participation in a national-scale effort and providing valuable information on broad-scale biological phenomena.

Surveys carried out to date provide an early picture of street tree composition across eastern Canada; however, additional surveys would clearly add veracity to the effort. At our Web site, interested participants can read about the project and download all materials required to carry out a survey in their community. Further outreach efforts will continue to target community-based naturalist groups and resource stewardship organizations as potential volunteers; particularly in Québec and western Canada where little data currently exists. We encourage any interested readers to contact the senior author for further information on how to participate.

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