PROBABILITY OF DAMAGE TO SIDEWALKS AND CURBS BY STREET TREES IN THE TROPICS

by John K. Francis, Bernard R. Parresol1, and Juana Marín de Patiño2

Abstract. For 75 trees each of 12 species growing along sidewalks in San Juan, Puerto Rico and Mérida, Mexico, diameter at breast height and distance to sidewalk or curb was measured and damage (cracking or raising) was evaluated. Logistic analysis was used to construct a model to predict probability of damage to sidewalk or curb. Distance to the pavement, diameter of the tree, and species were all found to contribute significantly to the probability of damage. Predictive models are presented for each species and numerical trials are used to illustrate the relationship of the independent variables to probability of damage.

One of the major problems of managing trees in metropolitan areas is the damage caused by roots to sidewalks and curbs. Cracking, and subsequent lifting of the broken pieces, proceeds as roots growing under those concrete structures thicken. It is obvious to even casual observers that problems are more severe near large trees. Deserved or not, some species have gained a worse reputation for damage than others. Two quantitative studies, one in San Francisco, California (3) and the other in Manchester, United Kingdom (2), have verified that tree size, species, and proximity to sidewalk or curb are all factors in damage to sidewalks and curbs. However, tree size and rate of growth within a given species seemed to be more important than species, per se.

Street trees are at least as important to quality of life in the tropics as in temperate areas. Tropical trees cause damage to sidewalks and curbs just as their temperate counterparts do. Unfortunately, relatively little is known about the growth and development of urban trees in the tropics, except that they usually grow faster than trees in the temperate zones. This study was conducted to quantify the probability of damage caused by tropical street trees in relation to tree species, size, and distance to sidewalk or curb.

Materials and Methods

The 2 areas chosen for study were San Juan, Puerto Rico, and Mérida, Yucatan, México. San Juan, a city of about 750,000, is situated at 18.5° N latitude and varies in altitude from sea level to 50 m. Various parts of the city receive from 1500 to 1900 mm of rainfall, and mean annual temperature is about 26°C. Mérida has a population of about 400,000 and lies at 21° N latitude. The topography is flat, and the elevation is a few meters above sea level. Mean annual rainfall is about 950 mm, and mean annual temperature is about 25°C. The soils of San Juan are usually deep acid clay Ultisols, often capped with gravelly clay fill. The soils of Mérida are shallow clays over limestone.

In each area, 75 trees each of 12 of the most commonly planted species or genera (Table 1) were assessed. For each tree, diameter at breast height (dbh) was measured in centimeters with a diameter tape. The distance to sidewalk and/or curb from the center (midpoint) of the tree was measured in meters with a cloth tape. It was noted whether the sidewalk or curb was cracked or raised, or if it was undamaged. If there was any suspicion that damage had resulted from another cause—such as settling of the soil base, or reconstruction of the curb or sidewalk during the life of the tree—a new tree was selected.

The resulting data were analyzed using logistic analysis, specifically the categorical data modeling procedure published by the SAS Institute Inc. (1). Damage was entered as a binary dependent variable, tree species as an independent class variable, and dbh and distance to the structure as continuous variables. Data from San Juan and Mérida were analyzed separately, as was

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damage to sidewalks and curbs, making 4 separate analyses in all (Table 2). Initial analyses were conducted using all possible interaction terms. If an interaction proved nonsignificant (α > 0.05), it was dropped from the analyses to produce a simpler model.

Results

First, we developed a general model for the 2 dependent variables (damage to curb and sidewalk) by country. We specified separate intercepts for each species and separate slopes for dbh (Ddbh) and distance to sidewalk (Dissw) or distance to curb (Discb), plus an interaction term between the 2 quantitative independent variables. This resulted in a 48-parameter model (by country). The results of the first iteration showed that this model was overparameterized and, in general, the interactions were redundant. Therefore, we simplified the model, without interaction terms (but keeping separate intercepts and slopes). This yielded a 36-parameter model with species, dbh, and distance to the pavement being significant in the maximum-likelihood analysis of variance test. The model worked well with the San Juan data, on both damage to sidewalk and damage to curb. However, in Mérida, a simpler model was just as efficient. The results seemed to indicate that the effect of distance to sidewalk (or curb) was independent of species. Also, for the dependent variable damage to sidewalk (Dissw), separate intercepts did not seem necessary. Therefore, we modified the model further for Dissw, using a common intercept for each species, separate Ddbh slopes, and a common Dissw slope, for a 14-parameter model. For damage to curb (Discb), we had separate intercepts for each species and separate Ddbh slopes, but a common Discb slope, for a 25-parameter model.

The final models follow a similar generalized form. For example, the logistic model for damage
to sidewalks in San Juan appears as follows:

$$
\text{logit} = (\mu + \alpha_i + \epsilon + \beta_i) \text{Dbh} + (\tau + \gamma_i) \text{Disw} + \epsilon
$$

where

- \text{logit} is the logistically transformed (see later) value for the ith species
- \epsilon is residual error
- \mu is a general intercept
- \alpha_i is the effect of the ith species
- x is a general Dbh slope
- \beta_i is the effect of the ith species on the Dbh slope
- \gamma_i is the effect of the ith species on the Disw slope
- \tau is from 1 to 11 (Table 3)

Table 3. Listing of the parameters and estimates for the 4 final models for probability of damage to sidewalks and curbs by street trees.

<table>
<thead>
<tr>
<th>Effect Parameter</th>
<th>Estimate</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-1.6330</td>
<td>-1.6664</td>
</tr>
<tr>
<td>Species</td>
<td>-1.8222</td>
<td>-0.8923</td>
</tr>
<tr>
<td>Dbh</td>
<td>-0.4649</td>
<td>-0.9893</td>
</tr>
<tr>
<td>Disw</td>
<td>2.1181</td>
<td>1.9654</td>
</tr>
<tr>
<td>x</td>
<td>0.0014</td>
<td>0.0194</td>
</tr>
<tr>
<td>\alpha_i</td>
<td>-0.7030</td>
<td>-0.7030</td>
</tr>
<tr>
<td>\beta_i</td>
<td>0.0008</td>
<td>0.0008</td>
</tr>
<tr>
<td>\tau</td>
<td>0.0008</td>
<td>0.0008</td>
</tr>
<tr>
<td>\gamma_i</td>
<td>0.0008</td>
<td>0.0008</td>
</tr>
<tr>
<td>\epsilon_i</td>
<td>0.0008</td>
<td>0.0008</td>
</tr>
</tbody>
</table>

The proper parameters for the 12th species are given differently:

$$
\text{logit}_{12} = (\mu - \frac{\gamma_i}{\delta_i}) \text{Dbh} + (\tau - \frac{\gamma_i}{\delta_i}) \text{Disw} + \epsilon
$$

To predict the logit for species 1 (caoba) in San Juan, for example, use:

$$
\text{E(logit)} = (\mu + \alpha_1 + \epsilon + \beta_1) \text{Dbh} + (\tau + \gamma_1) \text{Disw}
$$

E(logit) = (-1.6330 - 1.8222 + 0.1200 + 0.1243)Dbh + (-2.3839 - 2.5705)Disw

Assuming Dbh = 50 cm and Disw = 0.5 m, we have:

$$
\text{E(logit)} = -3.4402 + 0.2443(50) - 4.9589(0.5) = 6.2954
$$

Since the probability of damage to sidewalk can be calculated, we obtain:

$$
\text{logit} = \text{natural log} \left[ \hat{P} / (1 - \hat{P}) \right]
$$

Then:

$$
\hat{P}_{\text{damage}1} = e^{0.3954} / (1 + e^{0.3954}) = 0.9982
$$

As another example, consider species 12 (almendra) in San Juan. For Dbh = 36.6 and Disw = 1.65 we have:

$$
\text{E(logit)} = -2.2071 + 1.1297(36.6) - 1.3863(1.65) = 0.2525
$$

$$
\hat{P}_{\text{damage}12} = e^{0.2525} / (1 + e^{0.2525}) = 0.5628
$$

These particular results support the intuitive conclusion that the smaller the tree and the farther away it is situated from sidewalk or curb, the lower the probability of damage.

Each species displayed different probability trends that overlap one another in the range of diameters and distances from sidewalks or curbs. Therefore, we ran simulations to compare the various species in their potential to cause damage to sidewalk and curb, selecting a 75% probability (an arbitrary level) of damage and a distance of 0.5 m as test parameters (Table 4). In San Juan the least
Table 4. Dbh at which probability of damage reaches 75% for trees planted 0.5 m from sidewalks and curbs.

<table>
<thead>
<tr>
<th>Species</th>
<th>San Juan</th>
<th>Mérida</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>sidewalk(cm)</td>
<td>curb(cm)</td>
</tr>
<tr>
<td>1</td>
<td>28.7</td>
<td>54.2</td>
</tr>
<tr>
<td>2</td>
<td>125.3</td>
<td>157.7</td>
</tr>
<tr>
<td>3</td>
<td>36.0</td>
<td>44.3</td>
</tr>
<tr>
<td>4</td>
<td>28.0</td>
<td>48.1</td>
</tr>
<tr>
<td>5</td>
<td>35.7</td>
<td>51.4</td>
</tr>
<tr>
<td>6</td>
<td>42.4</td>
<td>70.6</td>
</tr>
<tr>
<td>7</td>
<td>31.9</td>
<td>69.0</td>
</tr>
<tr>
<td>8</td>
<td>10.0</td>
<td>52.3</td>
</tr>
<tr>
<td>9</td>
<td>37.0</td>
<td>50.9</td>
</tr>
<tr>
<td>10</td>
<td>36.3</td>
<td>52.0</td>
</tr>
<tr>
<td>11</td>
<td>32.2</td>
<td>85.1</td>
</tr>
<tr>
<td>12</td>
<td>30.8</td>
<td>49.7</td>
</tr>
</tbody>
</table>

*Number is the species identification used during analysis. See Table 1 for scientific and common names. Species differ between San Juan and Mérida.

Damage to sidewalks and curbs is caused by the impact of falling branches or the presence of large trunks. In San Juan, the species with the greatest potential for causing damage is Jacaranda mimosifolia, followed by Pithecellobium dulce and Syzygium jambos. In Mérida, the species with the greatest potential for causing damage is Pterocarpus macrocarpus, followed by Jacaranda mimosifolia and Syzygium jambos. The size and weight of the branches and trunks are important factors in determining the potential for damage. The use of smaller and lighter species, such as Ficus spp., is recommended to reduce the potential for damage.

Discussion
For Swietenia in San Juan, the probability of damage to sidewalk is projected under various diameters and distances (Figure 1). At small diameters, probability of damage is 0 or nearly so until some threshold dbh is reached. Probability of damage increases slowly at small diameters, then very rapidly as diameters increase, and again more slowly as 100% probability is approached. The slow approach to 100% probability results from a fortuitous lack of large roots under certain sections of sidewalk or from soil conditions, such as extraordinary compaction, that inhibit roots from growing under particular sidewalk sections. In positions close to the structure, only trees with small dbh’s result in little probability of damage, but with increasing distance from the sidewalk, larger and larger dbh’s are possible without a high probability of damage.

A price must be paid in terms of tolerated dbh or minimum distance to curb in order to assume a lower degree of certainty of damage. Although greater precision at the lower probabilities of damage could be obtained if it were possible to completely eliminate Type II experimental error (attributing damage to sources other than tree roots), it is not practical to reduce predicted probability of damage to very low levels.
The most obvious way to avoid damage to sidewalks and curbs is to plant far enough away from them that damage will not occur. For some species that grow large, such as terocarpus and samán, this can be 5 m or more away—practical in parks and large estates, but hardly useful in the space between the sidewalk and curb along city streets. Even those large-growing species are sometimes planted in constricted spaces with the intention of removing them in 10 to 15 years, before they have cracked or raised the nearby pavement.

The alternate approach is to plant trees that do not become large enough to be a threat to structures or that, because of their growth patterns, do little or no damage. A number of ornamentals, such as the Bauhinia group included in this study, usually do not exceed 15 to 20 cm in diameter and consequently cause few problems for sidewalks or curbs. Another group that very rarely causes problems in even constricted rooting space, presumably because their roots do not thicken beyond a few mm, are the palms. A maintenance treatment used occasionally in San Juan is to periodically cut narrow trenches 30 cm deep along sidewalks and curbs to sever young roots beginning to extend under them. This treatment may have dangerous consequences in the long run. A large tree with a constricted root system is very prone to tipping in high winds.

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Literature Cited

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Résumé. Douze espèces (75 arbres par espèce) poussant le long des rues de San Juan, Puerto Rico et Mérida au Mexique ont été évaluées en mesurant leur diamètre à hauteur de poitrine, leur distance par rapport au trottoir ou à la bordure de rue et les dommages (fissures ou soulevements) causés dans le voisinage sur ces structures. Une analyse logistique a été utilisée afin de construire un modèle pour prédire la probabilité de dommages au trottoir ou à la bordure de rue. La distance de l'infrastructure, le diamètre de l'arbre et l'espèce ont tous été jugés comme des facteurs significatifs en regard de la probabilité de dommages. Des modèles de prédiction sont présentés pour chaque espèce et des essais numériques sont employés pour illustrer la relation des variables indépendantes face à la probabilité de dommages.