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PEST MANAGEMENT

Subterranean Termites in Urban Forestry: Tree Preference and Management

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Abstract
Urban tree deterioration is a common problem all over the world. Inappropriate plant species choice and inadequate planting may lead to micro and macro organism attacks, such as pests and diseases. Subterranean termite damage is common and may promote tree falls. In order to help urban forestry planning, this work was carried out for 9 years on 1477 street trees in a neighborhood in the city of São Paulo, Brazil. Plants were identified to species, grouped as native, exotic plants, and palm trees, and their measures of circumference at breast height (CBH) were taken, in order to evaluate if subterranean termite damages are related to tree size and plant group. Four subterranean termite species were identified infesting up to 27% of the plants, with *Coptotermes gestroi* (Wasmann) being the most common. Palm trees were not damaged by subterranean termites, while native plants are the most susceptible, especially *Caesalpinia pluviosa* var. *peltophoroides* (Fabaceae). Among the native plants monitored *C. pluviosa* var. *peltophoroides*, *Caesalpinia ferrea* var. *leiostachya*, *Erythrina speciosa*, *Piptadenia gonoacantha* (Fabaceae), *Gochnatia polymorpha* (Asteraceae), *Tibouchina granulosa* (Melastomataceae), and *Handroanthus* spp. (Bignoniaceae), the latter was the least damaged. Exotic plants were also susceptible with the exception of *Lagerstroemia indica* (Lythraceae) and *Platanus acerifolia* (Platanaceae). Correlation analysis showed that the higher the CBH value, the higher the percentage of internal damage by *C. gestroi.* Infested trees were treated with imidacloprid and thiamethoxam, and subterranean termites were effectively controlled during the 9-year study.

Introduction

Several benefits of urban forestry have been identified, but most are connected with the preservation of human health and well-being. An urban forest is defined as "the inclusive tree canopy across a city or town made up of individual trees, groves, and patch forests located within public or private properties, including streets, parks, open spaces, and residential areas" (Wolf & Krugger 2010). There has been government interest in planning and managing urban forests in Brazil, but cities still suffer with unplanned projects, which may lead to wrong choices for plant species and result in several problems. These problems may range from simple pest problems to whole trees falling on the streets, causing accidents with variable levels of consequences (Zorzenon 2009). Infestations by subterranean termites are common in urban trees, and cause some of the trees to fall.

Faced with this problem and trying to understand the subterranean termite infestations in urban trees in the city of São Paulo, Brazil, this study had four objectives aiming to obtain basic information supporting good urban forestry planning i) to register the diversity of termite species in the studied area, ii) to identify if there is a difference on termite infestation between native or exotic tree species, iii) to determine the influence of tree size and termite damage through correlations of circumference at breast height and

termite internal damage, and, lastly, iv) to test the efficacy of chemical control.

Material and Methods

Subterranean termite diversity in urban trees was recorded from January 2004 to August 2008. A neighborhood in the city of São Paulo, Brazil (23°35′34.72″S, 46°41′57.60″W) was selected for the study. The choice of the area was based on the high concentration of urban trees and the history of complaints from residents about termite infestations.

Plants were identified to species and clustered in four major plant groups, namely native, exotic, palm trees, and "others." The group others was represented by tree species from different families, varying from 1 to 20 individual clustered trees. The palm tree group comprised species of Arecaceae.

The association between termite species and each plant group and species was determined in order to evaluate their infestation in the different groups of plants. The chi-square test was used to compare botanical species, families, and groups (df=3) or the Fisher exact test for samples of less than five.

The measures of circumference at breast height (CBH) were made at 1.30 m above the plant base. Each plant was georeferenced with a GPS (Garmin, model GPSMAP® 60Cx) and the GPS trackmaker program helped with the geographic coordinates (Daniel 2006). Georeferencing was used to easily find trees across the studied years. To analyze the relation between CBH and the percentage of termite damage, the Spearman rank correlation was used (Siegel 1979, Zar 1999). The level of significance was 0.05.

Termite damage

At first, trees were observed for termite tunnels on the trunks or termite traces on or under the bark and for cracks, cavities, or damage caused by termite activity. For internal assessment and damage dimension, we used a new technique proposed by Zorzenon & Campos (2014). Briefly, this technique consists of making holes on the trunk with drills and taking the measurement of the depth of the perforations. Further, through trigonometric formulae, we estimated the percentage of damage caused by subterranean termites. To determine the size and the exact location of the termite damage in the inner region of the trunk, three holes (n) are drilled at a 45° angle into the base of the trees to establish triangulation points. The diameters of the steel drills vary according to the tree CBH. The intention is to reach the deepest regions of the heartwood for inner exploration to confirm termite infestations that are not externally visible and to estimate the percentage of damage. This approach does not promote any damage to the plants.

Termite soldiers and workers were collected and preserved in 80% ethanol. Specimens were identified at the Adolph Hempel Entomology Collection (CEAH), Instituto Biológico. A conservative taxonomic approach was used throughout with species being assigned to existing names whenever possible. Termites with soldiers were identified to genus level with the aid of a key to the genera of Neotropical termite (Constantino 2002) and to the species level with the aid of several keys (Emerson 1952, Krishna & Araújo 1968, Constantino 2000) and specimens deposited in the CEAH. The specimens are deposited in the CEAH, Instituto Biológico, São Paulo, Brazil.

Termite control

The control of termites was conducted in 2004 through the injection of imidacloprid (0.25 mL/L) into the trunk. Those plants with CBH <40 cm were injected with 10 L while those larger than 40 cm were injected with 20 L per tree when active termites were found. Insecticide was injected by a pressurized spray or by watering cans and plastic funnels. All trees were annually inspected for new infestations or resurgence. From 2008 to 2013 Thiamethoxam (2 g/L) was used when infestations were found instead of imidacloprid.

Results and Discussion

We identified 1477 botanical specimens to the species level in 8 km of streets and avenues with a mean of one tree or palm tree every 5 m. Fabaceae and Arecaceae were the most relevant families, presenting the largest number of species (Table 1).

Native trees were the most abundant, representing 42.0% (n=620) of the identified specimens. Exotic trees represented 35.6% (n=526), others 13.1% (n=193), and palm trees 9.3% (n=138). This result disagrees with the recommendation of Grey & Deneke (1978) that each species planted in urban areas should not constitute more than 18% of the total plant population due to the risk of pests and diseases. But tree species density was not high, and only *Caesalpinia pluviosa* var. *peltophoroides* exceeded the Grey & Deneke (1978) recommendation (Table 1).

Most of the trees exhibited healthy external appearance (72.9%); however, more than 25% of them were infested by termites (Table 2), as termite tunnels, cracks on the trunk, and generalized laceration were observed. All plants infested by termites showed some kind of mechanical injury, such as root constriction due to inadequate planting, high trees in small sidewalks, or presence of decomposing fungi. The poor

Table 1 Absolute and relative (%) frequencies of the most common trees and palm trees recorded in a neighborhood studied in the city of São Paulo, Brazil.

Plant group	Family	Tree species	Absolute frequency (*n*)	Relative frequency %
Native	Fabaceae	*Caesalpinia pluviosa* var. *peltophoroides*	267	18.08
		Caesalpinia ferrea var. *leiostachya*	54	3.66
		Erythrina speciosa (Fabaceae)	38	2.57
		Piptadenia gonacantha	39	2.64
	Asteraceae	*Gochnatia polymorpha*	26	1.76
	Melastomataceae	*Tibouchina granulosa*	116	7.85
	Bignoniaceae	*Handroanthus* spp.	80	5.42
Exotic	Bignoniaceae	*Jacaranda mimosifolia*	80	5.42
		Spathodea campanulata	44	2.98
	Lythraceae	*Lagerstroemia indica*	71	4.81
	Platanaceae	*Platanus acerifolia*	52	3.52
	Pinaceae	*Pinus elliottii*	98	6.64
	Oleaceae	*Ligustrum lucidum*	24	1.62
	Fabaceae	*Tipuana tipu*	36	2.44
		Delonix regia	84	5.69
		Bauhinia variegata	37	2.51
Palm trees (native and exotic)	Arecaceae	Several	138	9.34
Others (native and exotic)	Several	Several	193	13.07
Total			1477	100

maintenance of trees in public streets, with strangulation of the bases of the branches due to close and inadequate pavement, cutting of surface roots, drastic pruning, or trees with hollows and cemented roots, greatly facilitate future termite infestations (Amaral 2002). The stress induced by these inadequate practices leads to a general state of low resistance, undermining the vigor of the plant.

Four subterranean termite species were identified: *Coptotermes gestroi* (Wasmann) (Rhinotermitidae), *Heterotermes tenuis* (Hagen) (Rhinotermitidae), *Nasutitermes corniger* (Motschulsky) (Termitidae), and *Neocapritermes opacus* (Hagen) (Termitidae). The frequency of infestation caused by these subterranean termites on each of the main groups of plants varied (Fig 1).

Heterotermes tenuis, *N. corniger*, and *N. opacus* showed low infestation rates with 1, 3, and 3%, respectively. Despite its low frequency, *N. opacus* showed significant infestation in the exotic species to Brazil, *Spathodea campanulata* (Bignoniaceae) (Fisher exact test, $p=0.015$, $n=10$ trees). Injuries and tunnels were always superficial, and no internal intrusions were observed. This species nests in the soil and infests grass roots, tree seedlings, and bushes, as well as decaying wood. Significant damage on growing trees has not been reported yet, and termites were found only between the bark and the trunk of the trees. However, this termite species does make galleries in the plant root system hampering the water absorption and translocation of the nutrients to the tree. The presence of dead tree seedlings among healthy plants is a good indicator of its presence (Zorzenon 2009).

Table 2 Number of plant specimens showing subterranean termite infestation according to the four major plant groups.

Group	Infested specimens	Percentage of infestation	Total of plants in the group
Native	230	37.1	620
Exotic	132	25.1	526
Palm trees	0	0	138
Others	37	19.2	193
Total	399	27.0	1477

The termite *N. corniger* infested the plants grouped as others (Fisher exact test, $p=0.008$, $n=4$ trees), while *H. tenuis* was recorded in only five trees: three natives and two exotics. Due to the low frequency, no significant difference was found for *H. tenuis* infestations to different groups of plants (Fisher exact test, $p=1.000$).

The most common species, *C. gestroi*, was found infesting 371 trees (93%) out of the 399 trees attacked by subterranean termites. It was present in all botanical families, except Platanaceae (exotic), and in palm trees (Fig 1). The high frequency of *C. gestroi* might be related with the size the colony can reach (more than 1 million individuals) and with the large foraging area this termite is able to cover (linear distances over 100 m). A single colony may be feeding on several trees

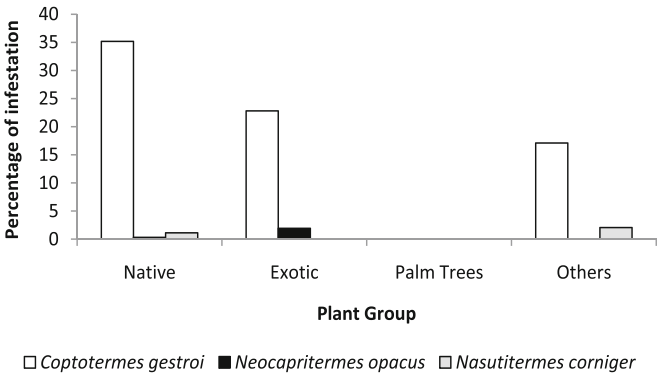

Fig 1 Percentage of infestation by subterranean termites in a neighborhood in the city of São Paulo, according to the plant group. *Coptotermes gestroi* (χ^2= 87.62; *df*=3; *p*<0.001), *Neocapritermes opacus* (Fisher exact test, *p*=0.015), and *Nasutitermes corniger* (Fisher exact test, *p*=0.008).

or households at the same time (Costa-Leonardo 2002). It is a species found only in urban areas in the south, southeast, and northeast regions of Brazil.

Among native plants, *C. pluviosa peltophoroides* was the most commonly attacked by *C. gestroi*, while *Handroanthus* spp. (Bignoniaceae) (2.5%) was seldom infested (Fig 2a). The tree *C. pluviosa peltophoroides* is one of the preferred urban trees in Brazil. It may reach 16 m in height, with moderately dense (0.85 g/cm^3) and durable wood. The tree canopy may reach 15 m in diameter (Lorenzi 2002), and tree falling is common especially during the rainy season (November to March) in the studied area. Many of *C. pluviosa peltophoroides* trees in the studied site were planted on straight sidewalks with little space for the adequate growth of the trees.

Coptotermes gestroi also infested the native trees *Tibouchina granulosa* (Melastomataceae) and *Piptadenia gonacantha* (Fabaceae), which can reach up to 12 and 20 m in height, respectively. In order to avoid serious accidents in the event of a tree fall, shorter trees should be chosen instead. Further, *Handroanthus* spp. is represented by several tropical species that can reach up to 35 m in height and are considered dense wood trees with high durability and resistance (wood density between 0.80 and 1.08 g/cm^3). They are recommended for urban forestry, especially the shorter species such as *Handroanthus chrysotrichus*, that show large and

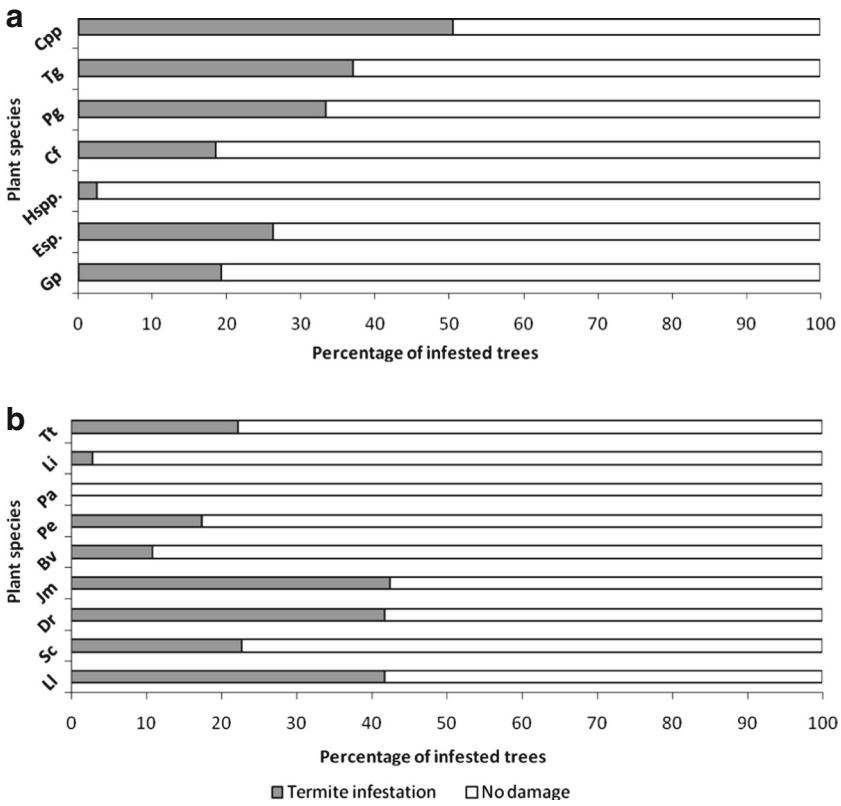

Fig 2 Percentage of plants infested by *Coptotermes gestroi* in a neighborhood in the city of São Paulo, Brazil. **a** Native plants (χ^2=76.21; *df*=6; *p*<0.001); **b** Exotic plants (χ^2=75.60; *df*=8; *p*<0.001). Legend: Cpp—*Caesalpinia* var. *peltophoroides*, Tg—*Tibouchina granulosa*, Pg—*Pitptadenia gonoacantha*, Cf—*Caesalpinia ferrea*, Hspp.—*Handroanthus* spp., Esp.—*Erithrina* sp., Gp—*Gochnatia polymorpha*, Tt—*Tipuana tipu*, Li—*Lagerstroemia indica*, Pa—*Platanus acerifolia*, Pe—*Pinnus elliottii*, Bv—*Bauhinia variegata*, Jm—*Jacaranda mimosifolia*, Dr—*Delonix regia*, Sc—*Spathodea campanulata*, and Ll—*Ligustrum lucidum*.

showy flowers and are resistant to urban pollution and require a low intensity of pruning, or *Handroanthus heptaphyllus* (Mori *et al* 2012).

Among the exotic tree species, *C. gestroi* was most common on *Jacaranda mimosifolia* (Bignoniaceae) (42.5%) followed by *Ligustrum lucidum* (Oleaceae) and *Delonix regia* (Fabaceae), both with 41.5% of trees infested. Such results concur with Amaral (2002) who found similar results for *L. lucidum*. This plant species was not the most abundant in our study but had high levels of termite infestation. The least infested plant species by *C. gestroi* were *Lagerstroemia indica* (Lythraceae) (2.8%), followed by *Platanus acerifolia* (Platanaceae) that showed no infestation at all by *C. gestroi* (Fig 2b).

Some infestations by dry-wood termites, *Rugitermes* sp. and *Incisitermes* sp. (Kalotermitidae) were also found. Dry-wood termites commonly found in stumps and dead trees may also be observed infesting dry parts of live trees, but they do not cause any injury to the trees (Cowie *et al* 1989). Thus, both dry-wood termite genera found in this study were observed in few live trees within the experimental area and were numerically insignificant.

Termite damage

The analysis was restricted to *C. gestroi*, the most common subterranean termite species found in this study. The higher the value of the CBH, the higher is the percentage of internal damage, except for *Handroanthus* spp. (Bignoniaceae) and *Bauhinia variegata* (Fabaceae) (Table 3). Studies have demonstrated the presence of naphthoquinones in Bignoniaceae, some of which represent a first defensive line as they deter feeding, but even if termites overcome this deterrence, the quinones are toxic to them after consumption (Castillo & Rossini 2010). This may explain the reduced number of *Handroanthus* infested by *C. gestroi.* Damage to *B. variegata* with a CBH below average may have interfered with the correlation.

Table 3 Correlation between percentage of damage by *Coptotermes gestroi* and values of circumference at breast height (CBH) in native and exotic urban trees.

Plant group species	Number of specimens	Spearman rank correlation (*r*)	*p* value
Native			
Gochnatia polymorpha	26	0.3907	*0.0485*
Erythrina sp.	38	0.3271	*0.0450*
Handroanthus sp.	80	0.1203	0.2880
Caesalpinia ferrea var. *leiostachya*	54	0.4919	*0.0002*
Piptadenia gonoacantha	39	0.6689	*<0.0001*
Tibouchina granulosa	116	0.5763	*<0.0001*
Caesalpinia pluviosa var. *peltophoroides*	267	0.5652	*<0.0001*
Exotic			
Bauhinia variegata	37	0.1234	0.4667
Spathodea campanulata	44	0.4075	*0.6000*
Delonix regia	84	0.6321	*<0.0001*
Jacaranda mimosifolia	80	0.6488	*<0.0001*
Ligustrum lucidum	24	0.5623	*<0.0042*
Pinus elliottii	98	0.5473	*<0.0001*
Lagerstroemia indica	71	0.2579	*0.0299*
Tipuana tipu	36	0.7169	*<0.0001*

Numbers in italics are statistically significant.

Termite control

Control of termites by imidacloprid injection was 100% efficient against *C. gestroi* and the other three termite species infesting the evaluated trees. The occurrence of new infestations was only 2.5% and only on trees initially identified as noninfested by termites. Treatment with thiamethoxam on these new infestations also showed 100% efficacy.

Both imidacloprid and thiamethoxam are neonicotinoids, a class of insecticides with a common mode of action that affects the central nervous system of insects, causing paralysis and death (EPA 2014). Results on soil treatment provide strong evidence that the field application of imidacloprid can have severe effects on subterranean termite colonies (Haagsma & Rust 2007, Parma & Vargo 2010), but few studies evaluated its efficacy when applied in trees. Osbrink & Lax (2003) reported observing symptomatic termites of *Coptotermes formosanus* (Shiraki) 46 m from treated trees with imidacloprid, suggesting that toxic doses can be transferred over long distances. Thiamethoxam showed efficacy against subterranean termites but only under laboratory conditions (Remmen & Su 2005). Thus, this is the first report on the efficacy of thiamethoxam and imidacloprid in urban trees subjected to intensive monitoring of subterranean termites in the field that showed a strong control response for many years.

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