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Coptotermes gestroi (Wasmann) (Blattodea [Isoptera]: Rhinotermitidae), a threat to the southeastern Florida urban tree canopy

Thomas Chouvenc[1,*] *and Jeremiah R. Foley IV*[1]

Abstract

In addition to being a structural pest, the Asian subterranean termite, *Coptotermes gestroi* (Wasmann) (Blattodea [Isoptera]: Rhinotermitidae), appears to be a serious pest of the native urban tree canopy of southeastern Florida. Asian subterranean termite colonies have the ability to cause feeding damage to a wide range of trees comprising the urban canopy, some potentially to a lethal level. Slash pine, *Pinus elliottii* Engelm. (Pinaceae), appears to be particularly susceptible to *C. gestroi* feeding damage, as the termites feed primarily on the outer layers of the wood, immediately beneath the bark, wounding live tissues and ultimately girdling the tree. In comparison, hardwood trees such as live oak, *Quercus virginiana* Mill. (Fagaceae), sustain damage to the heartwood at the center of the tree, resulting in a central cavity, but leaving the live tissue intact. Our results suggest that *C. gestroi* has the potential to kill pine trees within the local urban canopy, which may irreversibly alter the urban forest composition. In addition, many large trees in our survey have been consumed partially by mature *C. gestroi* colonies, potentially compromising their structural integrity. Some large oak trees that were extensively hollowed out by *C. gestroi* collapsed in 2017 during hurricane Irma. We discuss different potential approaches for protecting susceptible trees, as a comprehensive IPM strategy is needed for this invasive termite pest species, especially in the complex and extensive urban forest of southeastern Florida.

Key Words: Asian subterranean termite; invasive pest; structural damage; landscape alteration; urban forest

Resumen

Además de ser una plaga estructural, la termita asiática subterránea, *Coptotermes gestroi* (Wasmann) (Blattodea [Isoptera]: Rhinotermitidae), parece ser una plaga seria del dosel de árboles urbanos nativos del sureste de la Florida. Las colonias de termitas subterráneas asiáticas tienen la capacidad de causar daño por alimentación a una amplia gama de árboles que comprenden el dosel urbano, algunos potencialmente a un nivel letal. El pino, *Pinus elliottii* Engelm. (Pinaceae), parece ser particularmente susceptible al daño por alimentación de *C. gestroi*, ya que las termitas se alimentan principalmente de las capas externas de la madera, inmediatamente debajo de la corteza, dañando los tejidos vivos y finalmente ceñen el árbol. En comparación, los árboles de madera dura como el roble vivo, *Quercus virginiana* Mill. (Fagaceae), sostiene el daño al duramen en el centro del árbol, lo que da como resultado una cavidad central, pero deja el tejido vivo intacto. Nuestros resultados sugieren que *C. gestroi* tiene el potencial de matar pinos dentro del dosel urbano local, lo que puede alterar irreversiblemente la composición del bosque urbano. Además, muchos árboles grandes en nuestro sondeo han sido parcialmente consumidos por colonias maduras de *C. gestroi*, lo que podría comprometer su integridad estructural. Algunos robles grandes que fueron ahuecados extensamente por *C. gestroi* cayeron en el 2017 durante el huracán Irma. Discutimos diferentes enfoques posibles para proteger árboles susceptibles, ya que se necesita una estrategia integral de MIP contra esta especie invasiva de plagas de termitas, especialmente en el complejo y extenso bosque urbano del sureste de la Florida.

Palabras Clave: Termita subterránea asiática; plaga invasora; daño estructural; alteración del paisaje; bosque urbano

The Asian subterranean termite, *Coptotermes gestroi* (Wasmann) (Blattodea [Isoptera]: Rhinotermitidae), is an invasive termite pest species occurring in the most southeastern part of the continental USA. It is currently reported from the lower Florida Keys to Palm Beach County, Florida, and is considered a major structural pest throughout metropolitan southeastern Florida (Chouvenc et al. 2016a). This termite pest species originates from Southeast Asia, and has been one of the most successful termite species in spreading throughout the tropics with the help of human maritime activity (Scheffrahn & Crowe 2011; Evans et al. 2013; Chouvenc et al. 2016b). It is similar in its pest status, invasiveness, and damage potential to its close relative, the Formosan subterranean termite *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae), except that its distribution is solely tropical (Scheffrahn & Su 2005; Scheffrahn 2013). *Coptotermes gestroi* was first found in the USA in 1996 in Miami, Florida (Su et al. 1997a), and within 20 years has become a major structural pest throughout this urban region (Chouvenc et al. 2016a).

Although the initial focus on *C. gestroi* primarily has been its potential impact to structures, we want to bring attention to the importance of this pest as a threat to urban forests, and that the current pressure from termites to mature, historical trees may be unprecedented in southeastern Florida. The genus *Coptotermes* is known to infest live trees and to hollow out portions of large trees (Greaves 1962; King & Spink 1969; Becker 1975; Lai et al. 1983), and *C. formosanus* has

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been described as a major threat to mature native trees in Louisiana (Osbrink et al. 1999, 2008). Although *C. formosanus* can have an important impact on the urban tree canopy of the southeastern region of the USA, its impact on living trees in southern Florida is not as readily visible. One of the potential reasons for such a difference in its manifestation of damage to living trees is the tropical climate in this region, which may be too warm for *C. formosanus* to optimally become established in trees. However, *C. gestroi* appears to be fully adapted to tropical climates, and the damage observed on live trees from *C. gestroi* in southeastern Florida may be equivalent to the damage in trees observed with *C. formosanus* in Louisiana (Osbrink et al. 1999).

Over the course of various termite surveys in the past few years, we noticed that *C. gestroi* was frequently associated with dead or dying slash pine trees, *Pinus elliottii* Engelm. (Pinaceae). However, this association has yet to be fully described and recognized. This study focuses on surveying the impact of *C. gestroi* in slash pine trees for 3 primary reasons: (1) *C. gestroi* can be detected readily in pine trees by scraping off dead, superficial outer bark, while most hardwood trees such as live oaks, *Quercus virginiana* Mill. (Fagaceae), support termite activity primarily deep in the xylem tissues, rendering visual detection difficult; (2) the slash pine is an ecologically valuable native tree species and is a habitat and food source for many wildlife species; and (3) we hypothesized that because of the different nature of wood in *P. elliottii*, the feeding damage caused by *C. gestroi* is different than in hardwood species, and may result in tree decline and death. Therefore, whereas many tree species may be affected by *C. gestroi* in south Florida, we here focused on pine trees because they may be at greatest risk for decline in the near term.

Materials and Methods

PINE TREE SURVEY AREA

The area selected for the survey (Fig. 1) was chosen for its urban forest canopy, with the presence of many old live oaks and slash pines in residential settings. In addition, this area is known for relatively high densities of *C. gestroi* (Chouvenc et al. 2016a, 2017). The survey was initially performed by driving the major streets and visually locating pine trees from a distance, as many of these trees are taller than most of the other trees forming the urban forest canopy.

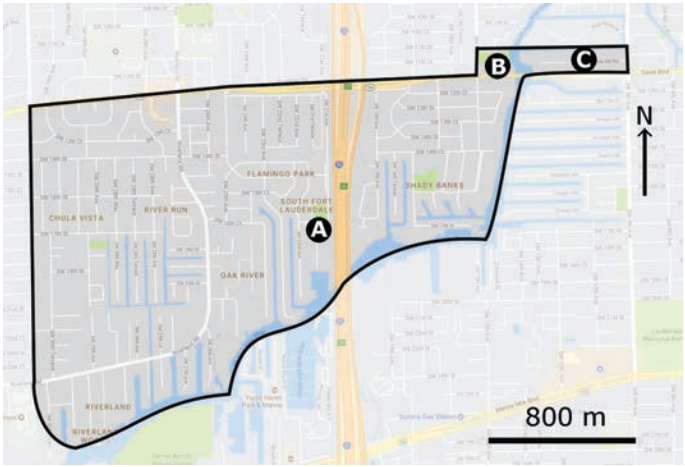


Fig. 1. Residential area surveyed (black outline) for the presence of *Coptotermes gestroi* in slash pines (*Pinus elliottii*) in Fort Lauderdale, Broward County, Florida (ca. 26.1000°N, 80.1800°W). A–C indicates the locations of parks with relatively high densities of pine trees, and which were extensively surveyed. The major road in the center of the image is Interstate I-95.

Two types of locations were surveyed in this study: residential (private properties) and parks. We made this distinction because the relative density of pine trees, the surrounding vegetation, the potential stress levels to trees, and street light intensities are different between the 2 types of locations. Three parks (Fig. 1, locations A-C) with relatively high slash pine densities were selected and fully surveyed. These parks initially were undeveloped areas that were eventually converted into recreational parks, while keeping the initial tree canopy. Parks are regularly maintained and mowed. The residential area (3.4 km^2, highlighted area in Fig. 1) also was extensively surveyed, and pine trees were spotted while driving. Tree inspection was performed only after obtaining permission from residents. Trees were not inspected when a resident could not be contacted, or if permission was denied. Thus, the survey in the residential area represents a subsample of the pine trees.

TREE INSPECTION

Pine trees were visually observed for the presence of *C. gestroi* by inspecting the surface of the trunk from the soil surface to approximately 2 m above-ground. Loose, dry pieces of outer bark were gently peeled off by hand to reveal termite presence or signs of termite activity (termite fecal material, mud tubes, termite damage, or carton material, which is a sponge-like fecal material that fills cavities after wood consumption). Removal of outer bark was kept to a minimum in order to preserve the aesthetics of the trees. Each pine tree was visually inspected for at least 2 minutes by 2 observers. Trees were classified into 4 categories based on the presence of termites and tree status: "live non-infested," wherein no termites or signs of termite activity could be detected; "live infested," wherein *C. gestroi* or obvious signs of *C. gestroi* activity were detected; "dead infested," wherein the inspected pine tree was dead and *C. gestroi* was present; and "dead, non-infested," wherein a dead pine tree had no obvious signs of termite activity or termite feeding damage. All termites collected from pine trees were confirmed to be *C. gestroi* by using soldier morphology.

The distribution of the 4 tree categories was compared among the 3 parks to first determine if all 3 locations (A-C) had similar proportions of trees infested with *C. gestroi*, using a Chi-square test of goodness of fit for multiple groups, with a Yates correction applied (only 3 tree categories were found in parks, 3 groups to compare, df = 4). After confirming that all 3 parks had the same proportions of tree categories, all trees from the parks were combined in a single dataset and the distribution of tree categories between parks (combined, 185 trees) and the residential area (199 trees) were compared with a Chi-square test (4 categories, 2 groups, df = 3).

TERMITE DAMAGE IN TREES

One of the hypotheses for slash pines being differentially susceptible compared to hardwood species is that the location of feeding damage by *C. gestroi* is different. We tested this hypothesis using 2 different means: visual inspection of the cross-section of dead trees, and measuring the wood densities of live trees using a resistograph (IML Wood Testing Systems, LLC, Moultonborough, New Hampshire, USA).

Visual Inspection of Cross-Sections

Three dead pine trees found during the survey were selected and permission was granted from homeowners to have the trees cut down. Cross sections were made using a chainsaw, and were visually assessed for the presence of feeding damage and carton material. In addition, 3 live oak trees where termite presence had been detected also were

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selected, and infested limbs were cross-sectioned, with permission, to identify the location of termite damage and carton material in trees.

Wood Density of Infested Trees

In order to support the hypothesis that *C. gestroi* termites are a major stress to live slash pines, it is necessary to confirm that the heavy damage afflicted to slash pines occurs before the death of the tree and not post-mortem. Therefore, the visualization of feeding damage from cross-sections of dead slash pines that had been cut down also needs to be shown to occur in live trees. However, cutting down these live trees was not possible. Alternatively, slash pine trees that were still alive, but known to be infested with *C. gestroi*, were tested with a resistograph to indirectly locate termite damage within live trees, if any. This tool measures the resistance of the wood as the drill bit penetrates it and provides direct analog readings of the wood's relative density. The trunks of all trees tested in this study with the resistograph measured at least 40 cm in diameter at 1.5 m above-ground for both slash pines and live oaks. During the survey, 3 healthy pine trees with no visible signs of termite infestation (controls), and 3 live pine trees with confirmed termite activity and visible advanced feeding damage were selected. Each tree was tested with the resistograph at 3 heights: 0.5, 1.0, and 1.5 m above the soil. All relative resistance values from the 3 trees were digitally converted and averaged (n = 3 × 3 subsamples). The density measurements were repeated with 3 healthy live oak trees, and 3 *C. gestroi*-infested oak trees using the same protocol.

Results

TREE INFESTATION

Although *C. gestroi* infestations were surveyed principally in association with *P. elliottii*, we also observed the presence of this species of termite in many other tree species in the surveyed area (Fig. 2): live oak (*Q. virginiana*); sabal palm, *Sabal palmetto* (Walt.) (Arecaceae); pindo palm, *Butia capitata* (Mart.) (Arecaceae); gumbo-limbo, *Bursera simaruba* (L.) (Burseraceae); royal Poinciana, *Delonix regia* (Boj.) (Fabaceae); Australian umbrella (*Schefflera actinophylla*), glaucous cassia, *Senna surattensis* (Burm.) (Fabaceae), and other plants that were not identified in this study. This indicates that *C. gestroi* can utilize a number of different trees in Florida, including many of the dominant native and non-native species, though whether or not they were primary or secondary invaders was not determined.

Slash pine trees were the easiest tree species to survey for detection of termites because the activity could readily be detected on the surface of the tree, or immediately underneath the loose outer bark (Fig. 3). In parks, we detected 32, 50, and 104 slash pine trees at locations A, B, and C, respectively. All 3 parks had similar termite infestation proportions, with only 3 of the 4 tree categories detected, as all dead trees were positive for termites (Fig. 4: $\chi^2 = 2.17$; df = 4; $P = 0.71$). During our survey in the residential area, we detected 260 slash pine trees and were able to inspect 199 of them, from 42 separate private properties (Fig. 5A). Among the 199 inspected slash pine trees, 79 were live non-infested, 91 were live infested, 25 were dead infested, and 4 were dead non-infested, resulting in a 58% ($N = 199$) infestation rate (Fig. 6). In comparison, slash pines surveyed in parks (Fig. 5B, $N = 186$) had a lower rate (18%) of *C. gestroi* infestation ($\chi^2 = 73.9$; df = 3; $P < 0.001$).

TERMITE DAMAGE ON TREES

The cross-sections of dead *P. elliottii* revealed that most of the damage was restricted to the outer layer of the wood, and that in no instances was the heartwood affected (Fig. 7A–C). Over time, damage to the dead trees progressively turned the outside layers of wood into carton material, eventually causing the bark to fall from the tree. As the carton material was washed off by the weather, only the heartwood was left standing from the ground, untouched by the termites (Fig. 7D).

Comparative observations of tree cross-sections between pine and oak trees revealed a striking difference in feeding damage patterns. The damage in pine trees was restricted to the outer tissues of the trunk, including the bark, phloem, and cambium, thus effectively girdling the trunk. In sharp contrast, with live oak trees and other hardwood species, the termite damage pattern was primarily restricted to the interior tissues of the tree's trunk (older xylem), forming a central cavity (Fig. 8). This shows that termite feeding damage in *P. elliottii* is directly adjacent to the living tissue of the inner bark, whereas in *Q. virginiana* the damage is much further inside the trunk, away from living tissues. This observation was supported by the resistograph measurements, which showed that for live infested slash pine trees, the damage was located only within the proximity of the bark (outer layers), acting to girdle the tree trunk, whereas in infested live oak trees, the damage was mostly restricted to a central cavity (Fig. 9).

Discussion

IMPACT OF SUBTERRANEAN TERMITES TO LIVE TREES

In addition to being a major structural pest (Chouvenc et al. 2016a), this study shows that *C. gestroi* has the potential to become a major threat to live trees in southeastern Florida. Some of the native trees may be naïve hosts without sufficient adaptations to survive such termite pressure. Although some tree species may be able to sustain the damage from termites, our observation suggests that *C. gestroi* infestation in *P. elliottii* may ultimately be fatal. The resistograph data confirmed that live slash pines infested with *C. gestroi* sustained heavy damage corresponding to the girdling observed in cross sections of dead slash pines. Therefore, the damage that could potentially result in the death of slash pines can occur pre-mortem when termites are present. This observation and the high association rate of *C. gestroi* with declining slash pines suggest that *C. gestroi* is a major stress factor to slash pine in urban southeastern Florida. This may be partially because wounding of live tissues puts too much stress on the trees, which are relatively slow-growing by nature, and the trees may not be able to sustain the pressure of a large *C. gestroi* colony.

When comparing feeding damage in different tree species, the feeding damage in slash pines is located adjacent to the live tissue underneath the bark, which differs from hardwood trees, wherein the damage is located in a central cavity far from the live tissue. It is possible that the heartwood of pines is resistant to termite attack because of its density and concentration of allelochemicals (Scheffrahn et al. 1988; Scheffrahn 1991). Ultimately, this may serve to restrict *C. gestroi* to the outer layers of the tree trunk. One key observation we made is that termite-infested pine trees did not produce resin secretions to flush insects out of their trunk, like pines would do with some beetle infestations (Phillips & Croteau 1999). One of the possibilities for the absence of defensive secretion is that *C. gestroi* deposits fecal material in direct contact to the wood chamber that was excavated. We suggest that such fecal deposition may be analogous to a bandage to the wound, inhibiting subsequent secretions from the pine tree, keeping termites safe from the tree's defense. However, a chemical analysis is necessary to confirm if the fecal deposit in direct contact with the wood is saturated with resin. Alternatively, slash pine trees that are

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Fig. 2. Feeding damage from *Coptotermes gestroi* on various tree species. (A) Carton material extracted from (B) a dead gumbo-limbo tree (*Bursera simaruba*); this tree was still alive less than 1 yr before the picture was taken. (C) Termite feeding damage on a *Senna surattensis*, still alive, but having lost most of its branches. (D) Old scars from feeding damage of *C. gestroi* on a live sabal palm (*Sabal palmetto*). (E) Active infestation and carton material in the trunk of a live sabal palm. (F) Carton material in the heart of a dead pindo palm (*Butia capitata*).

heavily infested with *C. gestroi* may have been stressed previously by other factors, weakening the tree and preventing it from producing the resin.

Some may argue that it is unknown if the termite damage is the cause or a consequence of the initial stress to *P. elliottii*, as other stress sources may ultimately be responsible for slash pine decline. Because

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Fig. 3. Active infestation of *Coptotermes gestroi* in slash pines. (A) Visible termite mud covering the surface of the bark of a pine tree. (B) Fecal deposition and carton material visible after peeling the dead scale of the bark from a pine tree. In this case, the activity was only noticeable after scraping the bark.

of the long life cycle of this termite species (> 5 yr), and the challenge to infest slash pines with *C. gestroi* colonies and wait for feeding damage (it may take up to 10 additional yr) while preventing any other stress sources, it is logistically difficult to test for the Koch's postulate in this system. It is possible that *P. elliottii* in urban setups are already stressed by a wide range of factors, and that *C. gestroi* is taking advantage only of weakened trees. We noticed that many trees had what appeared to be numerous cerambycid (Coleoptera) exit holes, in absence of sap

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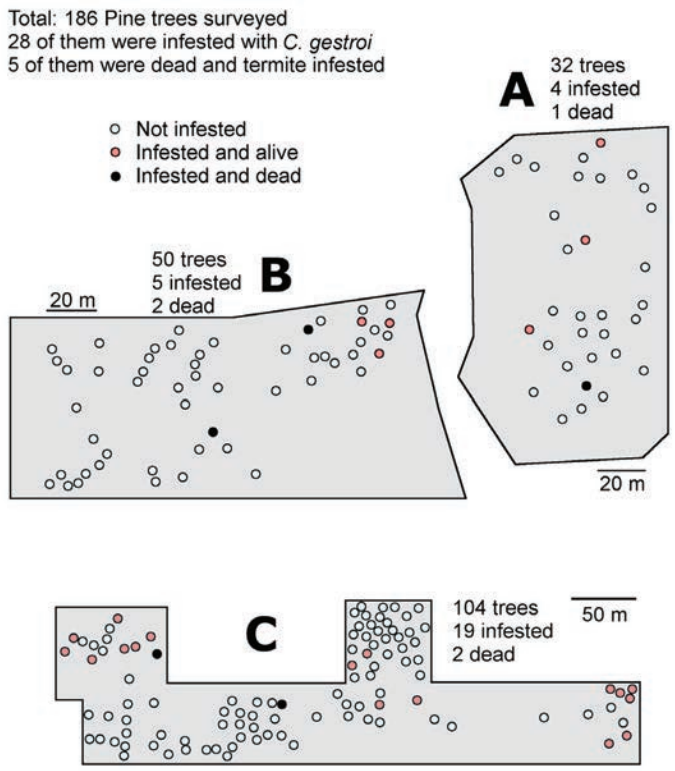


Fig. 4. Details of slash pines infested by *Coptotermes gestroi* in three parks (A–C). The 3 locations are referred to in Figure 1. The prevalence of each tree category within each location was not different among locations (χ^2 = 2.17; df = 4; P = 0.71).

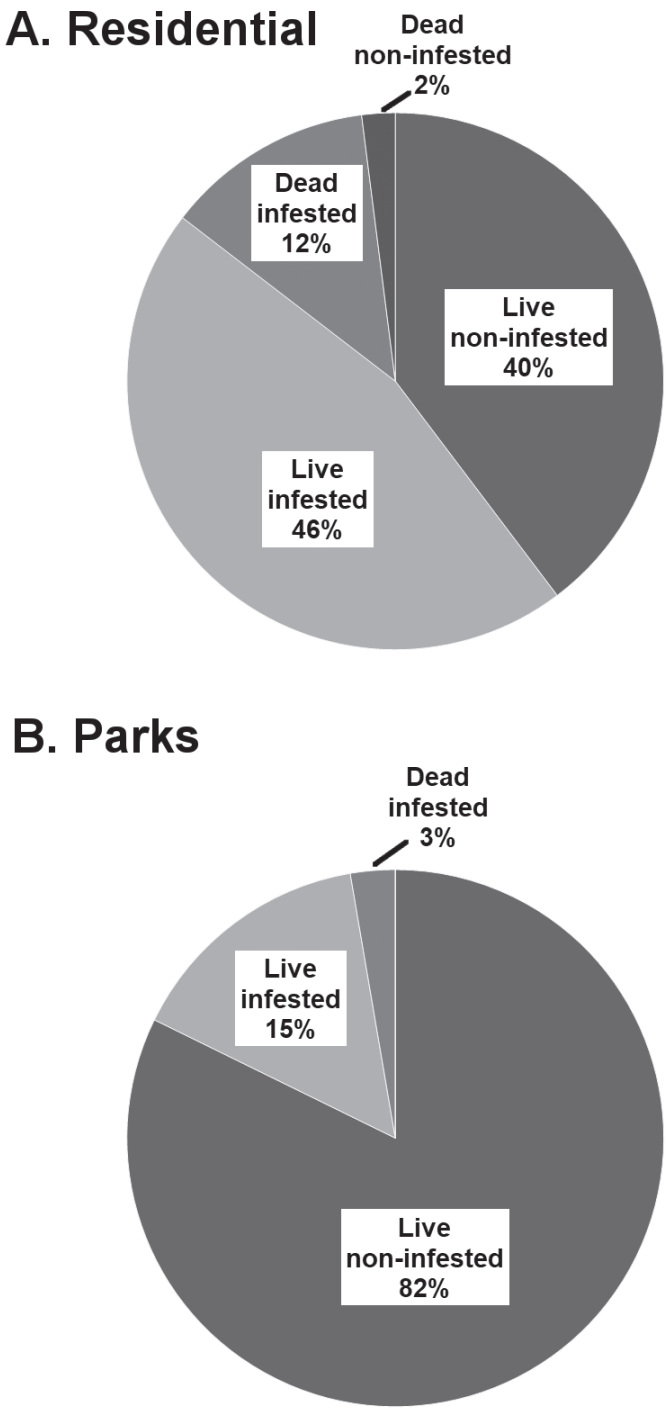


Fig. 5. Proportion of slash pine trees (*Pinus elliottii*) infested by *Coptotermes gestroi* in the surveyed area presented in Figure 1. (A) Residential areas, (B) Cumulative data from all 3 parks. The distribution among tree categories was different between the 2 types of area (χ^2 = 73.9; df = 3; P < 0.001).

secretion. These trees were therefore stressed, but it is unknown if termites where the initial stress factor and if beetles came before or after the stress from termite damage. Urban stresses from additional sources contributing to *P. elliottii* decline cannot be ignored. Grade changes due to construction, soil compaction due to reoccurring landscape maintenance operations (frequent mowing), excessive irrigation and fertilization, potential diseases, and other insects all may take their toll. Urbanization, therefore, may be a confounding stress factor that can exacerbate the susceptibility of slash pines to wood destroying insects, including *C. gestroi*.

It is remarkable that *C. gestroi* was detected more often in *P. elliottii* around residential areas (58%) than in the 3 parks (18% of the trees we surveyed). The difference in surrounding vegetation and urbanization composition, and in relative densities of slash pines, may be an important factor influencing the rate of *C. gestroi* infestation. One additional factor may be the relative absence of city lights in the direct proximity of pine trees in parks, as Chouvenc et al. (2017) showed that *C. gestroi* alates were attracted to light during dispersal flights at dusk in early Mar. As the city lights automatically turned on, alates are directly attracted to them. Therefore, the presence of city lights in the residential area may be responsible for a higher incidence of *C. gestroi* in the landscape around structures, in addition to other factors.

The Asian subterranean termite was first detected in 1996 in South Florida (Su et al. 1997a), and has been spreading since at an alarming rate, building high-density populations throughout urban southeastern Florida (Chouvenc et al. 2016a). With termite densities increasing over the past few years (Chouvenc et al. 2017), slash pine and other susceptible trees are at risk. More problematic, our survey suggests that in residential areas, 10% of the surveyed slash pines already were dead, potentially as a result of termite damage, but this figure may be overly conservative for 2 primary reasons. First, termite infestation in pine trees could be detected only if the damage was heavy enough and located at the base of the tree, where the inspection occurred. If the damage was relatively minor because the tree had become infested only recently, or if the damage was located higher in the canopy, then it might not have been detected. This means that our observed rate of infestation (58%) may be an underestimation. Second, we noticed that some of the dead trees that we surveyed, both in parks and in the

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Fig. 6. (A) Dead pine tree with (B) active *Coptotermes gestroi* infestation revealed after peeling the superficial scales of the bark.

residential areas, were cut down after we surveyed them. A common theme echoed by homeowners was that they used to have more pine trees on their property, but had to have them removed after they died within the past few years, before we had a chance to detect and survey them. Therefore, because the survey in the residential area relied on visually locating the pine trees within the urban canopy, it is possible that many of the trees killed by *C. gestroi* may have been removed prior our survey. Given this scenario, it is possible that our 10% death rate for pine trees in residential areas over the past few years may understate the actual impact of *C. gestroi* on the pine tree population.

EXCHANGES WITH RESIDENTS

During the survey of pine trees in the residential area, 61 trees from 18 properties were not inspected, as we were not able to contact the owners or obtain their permission to access the property. Fortunately,

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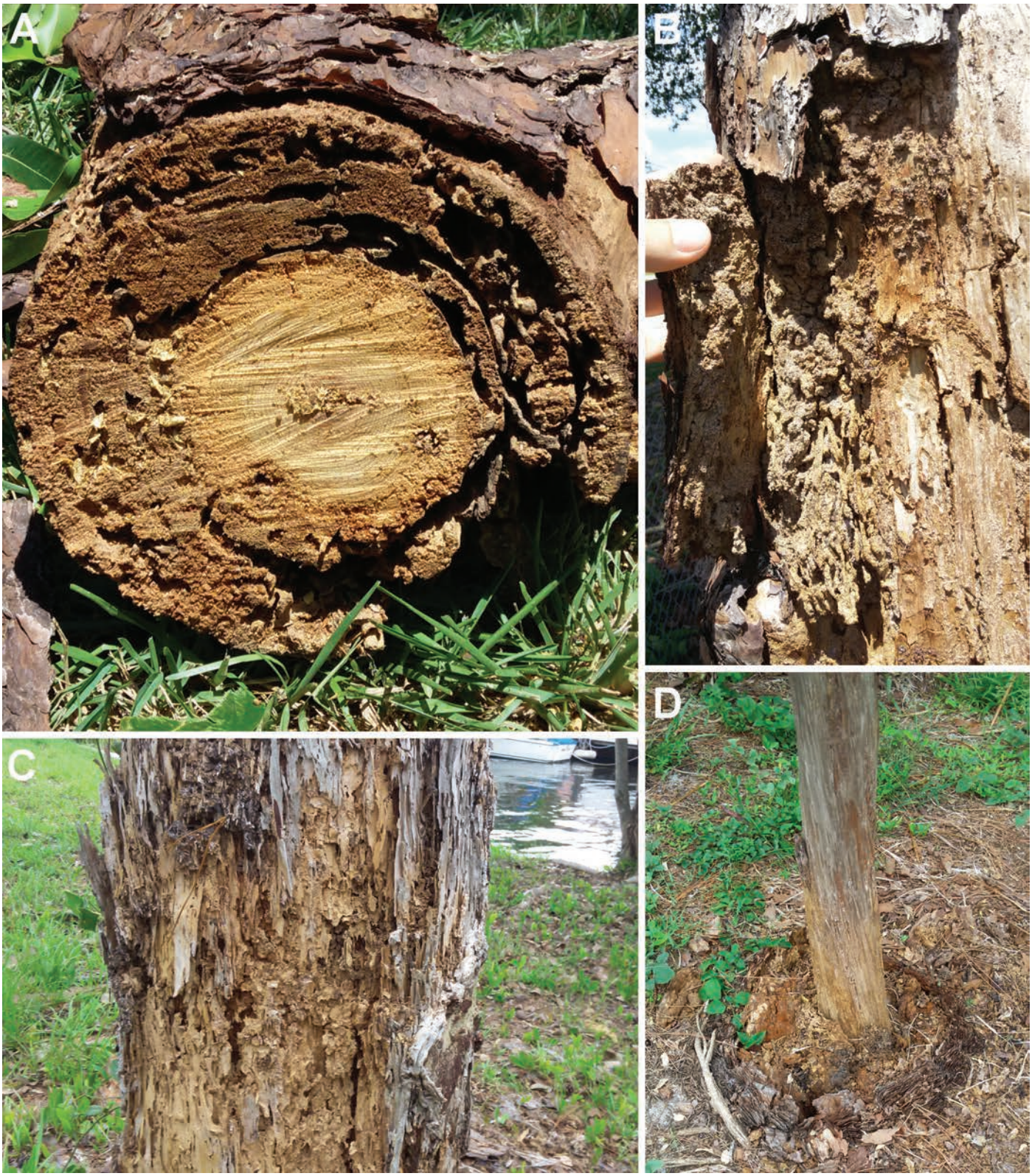


Fig. 7. Feeding damage from *Coptotermes gestroi* on dead pine trees. (A) Cross section of a dead pine tree, revealing the feeding occurred from the outside-in, leaving the heartwood intact. (B) All the space between the bark and the tree was replaced with carton material, effectively resulting in the detachment of the bark. (C) Advanced feeding damage, where the bark has fallen off and revealing extensive "shredding" of the wood with deposition of carton material 10–15 cm deep. (D) Final damage on a pine tree, where all the wood, except the heartwood was consumed, leaving a "pole" sticking out from the ground. Notice the bark ring at the base, showing the size of the tree before death, and all the in-ground space between the bark and the heartwood is exclusively carton material.

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Fig. 8. Cross section of tree trunks with *Coptotermes gestroi* feeding damage. (A) Pine tree (*Pinus elliottii*), dead, with damage from the outside-in, destroying all the wood material adjacent to the live tissue underneath the bark (bark absent here). (B) Oak tree (*Quercus virginiana*), still alive, with damage from the inside-out, leaving a central cavity, but sparing most of the material adjacent to the live tissue.

we encountered direct refusal to perform tree inspection only twice during the course of the survey. The vast majority of the residents were welcoming and interested. Therefore, throughout the survey process, we engaged homeowners in discussions about termite problems in southeastern Florida. We report here some of the exchanges that reflect some of the opinions and questions that the local residents had concerning termite issues. Comments presented here are subjective and solely reflect the authors' opinion.

"*Termites? It's okay, I tented last year.*" One of the problems is the confusion about termite treatments in Florida because most termite infestations relate to drywood termites, *Cryptotermes brevis* (Walker) (Isoptera: Kalotermitidae), for which structural fumigation is the most common remedial treatment. Such treatment is useless against subterranean termites and we repeatedly had to explain that subterranean termites are a different problem all-together.

"*Termites in my tree? I'll just cut it down.*" This statement was probably the most disconcerting, and unfortunately far too common among residents, as it bypasses the rationale behind termite biology and the legality of tree removal. First, as colonies of Asian subterranean termites are connected to the ground, a large part of a colony may not be contained within the infested tree. If the tree is removed, the next available item for the remaining termite population to consume would be the house itself (or other trees), increasing the chance for structural damage. Second, Broward County has strict rules about tree removal, and most Broward jurisdictions require a permit and mitigation. Steep fines can be given for illegal tree removals. Finally, some of the trees are decades old, and simply cannot be replaced. Let us reiterate that the initial goal of this study was to provide data in order to set-up a long-term strategy to protect and save these trees in the first place.

"*I lost three pine trees this year, what can I do to save the other two?*" Alternatively, some concerned homeowners shared their distress about witnessing the death of sometimes centennial trees on their properties. Many homeowners had strong motivation to do anything possible to prevent the death of their trees. We discuss potential remedial treatments to protect pine trees below.

"*Is this because of climate change? I've been here for 35 years and I see things now that I have never seen before.*" Although *C. gestroi* became established in southeastern Florida because of human maritime activity and favorable environmental conditions (Chouvenc et al. 2016a), the peculiar damage on pine trees by this termite species may be inherent to the biology of the pine tree and the behavior of this termite species interacting with it. However, given the hypothesis that temperatures will rise in the foreseeable future, it is possible that this termite species will expand its distribution northward (Su et al. 2017) and that the problem may not be restricted to just southeastern Florida.

"*Termites? I'll just pour some chlordane. I still have some.*" No comment, in light of the ban of this pesticide for all uses in the USA since 1988.

PROTECTING PINE TREES FROM TERMITE DAMAGE

Preventive Treatments

There are at least 2 different approaches that can be considered, and that reflect current protocols for preventative structural treat-

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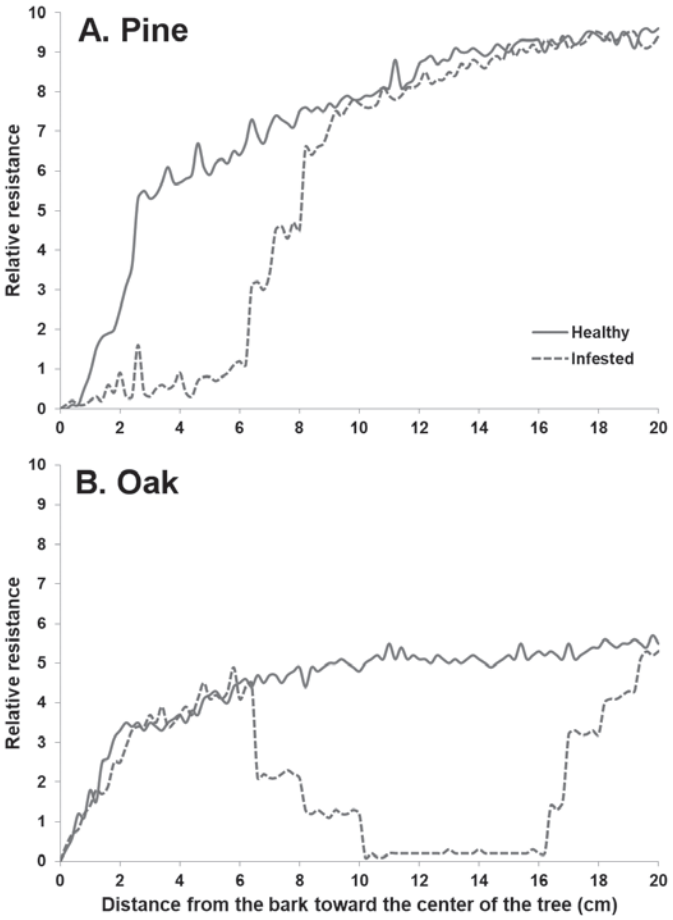


Fig. 9. Relative resistance (density) of the wood on different live trees, categorized as healthy or infested with *Coptotermes gestroi*. Each line represents the average resistance value obtained from the resistograph, from 3 trees per category, with 3 subsamples per tree (n = 3). (A) Pine trees, (B) oak trees. Infested pine trees reveal damage right underneath the bark, while infested oak trees reveal a cavity at the center of the trunk. The "step" effect on the lines resulted from the average of 3 different trees, with different level of termite damage.

ments against subterranean termites. The first would be the use of a chemical barrier using liquid termiticides, so that a foraging colony of *C. gestroi* in the soil would be denied access to the tree in the first place. However, the surviving termite population (Su 2005) may still affect nearby untreated areas (trees and structures). Second would be the use of termite baits, placed in the soil around the tree. Such termite baits would be fed upon by foraging termites, and result in colony elimination over time (Su 2005; Eger et al. 2012). Loose, shaggy pine tree bark appears to be a good entry point for alates during their dispersal flight (Chouvenc et al. 2017). Most pine trees that we surveyed within a few weeks after major dispersal flight events had *C. gestroi* wings present underneath the outer layer of the bark, suggesting that alates may have the opportunity to establish colonies directly in live trees. Although there are no research data to support trunk treatments with persistent insecticides to prevent termites from attacking live trees, this approach is commonly used to prevent attack by bark beetles in the urban forest, so it also might be an effective method to reduce the risk of infestation by these termites.

Remedial Treatments

While the use of a liquid termiticide in the ground surrounding a tree may prevent the flow of termites in and out of an infested tree, it may not prevent damage to the tree. Non water-soluble termiticides such as fipronil would not be picked up by the tree, and soluble termiticides such as imidacloprid may partially become systemic to the trees in very high dosage, but effectiveness is unlikely (MacDonald & Meyer 1998; Grosman & Upton 2006). In addition, if the termite population is restricted to the tree because of their inability to forage out in the soil owing to the presence of pesticides in the soil, it might intensify the damage to the tree itself, and speed up its potential death. Because of the type of damage to pine trees by *C. gestroi*, there is no central cavity that could be used to inject a foam formulation throughout the tree, as can be done with hardwood trees with central cavities (Osbrink & Lax 2003; Osbrink & Cornelius 2013). Insecticide injections and implants are sometimes used to protect trees or kill wood-boring insects. Although there are no data on this application for termites, it also should be considered.

Alternatively, termite baits could be used in the ground around the tree, but the time required for colony elimination might rely on the ability of the colony to detect the baits. One possible way to reduce this time would be to use above-ground bait stations (Su et al. 1997b). Such a product could be placed directly on the surface of the tree where termite activity was detected. This would allow direct access and feeding of the colony on the bait, reducing the overall time needed for colony elimination (Chouvenc & Su 2017), thereby increasing the tree's chance for survival. A full field study is needed to confirm the efficacy or lack thereof for each protocol to provide protection to pine trees, but given the biology of this termite species and the type of damage it does to pine trees, above-ground baits might currently be the favored option. Ultimately, an injectable fluid bait formulation (Su 2015) could be used and applied directly in active termite galleries of infested pine trees, but no commercial product is currently available.

CONCLUSION

If *C. gestroi* termite colonies increase their population density in trees, it is possible for mature colonies to move to nearby structures from their underground foraging galleries and cause structural damage after they have fed upon the tree. This underscores the fact that IPM strategies to protect structures should not rely solely on temporarily keeping termites outside of structures (Su 2005), but rather, they should involve colony elimination within the surrounding environment to prevent future potential damage. Aside from structural damage, *C. gestroi* may have a strong negative effect on the current urban forest canopy of southeastern Florida. Many live trees seem to be directly affected by the feeding damage of this termite species, and the rate of infestation in pine trees and other trees may be critical in the near future for the overall survival of a diverse urban tree canopy. Many of the pine trees currently present in the urban landscape were part of the original environment when urban development occurred more than half a century ago and represent a legacy of the native southeastern Florida landscape. The rapid loss of such trees due to termite feeding activity may, therefore, have irreversible negative consequences for the health and sustainability of affected urban forest canopy.

The continuous feeding damage to live trees also may have an important indirect effect. Trees weakened by Formosan subterranean termite colonies may break or be uprooted during storms (Osbrink et al. 1999; Cornelius et al. 2007; Osbrink et al. 2008). As we advocate that the effects of *C. gestroi* on live trees in southeastern Florida are analogous to the impacts of *C. formosanus* on live trees in Louisiana, we raise major concerns about the fate of these weakened trees in the event of a major hurricane landfall in southeastern Florida. In

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Fig. 10. Large oak tree hollowed out by *Coptotermes gestroi*, with presence of carton at the center of the tree (arrow), and property damage resulting from the tree structural collapse during hurricane Irma (Sep 2017

2005, hurricane Wilma was the last named storm to bring major damage to southeastern Florida, and all the while, many trees have been severely compromised by *C. gestroi* feeding damage over a span of 12 years. As hurricane Irma struck Florida in Sep 2017, the center of the storm spared Broward County and most oak trees lost only a few branches, at most. However, we monitored several large oak trees that completely collapsed during the storm. Out of 3 collapsed oak trees found, all were hollowed out by *C. gestroi*, confirming that the tree structures were compromised. Such falling and breaking trees resulted in property damage (Fig. 10). Therefore, in addition to potentially killing slash pines, *C. gestroi* also can affect other tree species indirectly and negatively affect the south Florida tree canopy as a whole, as previously observed in Louisiana with *C. formosanus* (Osbrink et al. 1999), and be a hazard to people and properties in urban landscapes.

Therefore, we here suggest that the presence of *C. gestroi* in trees is a time-sensitive issue because in addition to its potential ability to directly kill trees, it also indirectly can increase the destructive power of major storms by weakening the structural integrity of the trees. There is an incentive to save large trees, including many native trees such as gumbo-limbo, live oak, sabal palm, slash pine and others, which comprise a large proportion of the native urban forest canopy of southeastern Florida. The loss of such urban forest would have direct negative effects on the local ecosystem, and a long term economic impact, as high densities of *C. gestroi* colonies will ultimately result in structural damage. Managing populations of *C. gestroi* in urban southeastern Florida through a comprehensive IPM program is very much needed.

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