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Establishment and spread of two invasive subterranean termite species (*Coptotermes formosanus* and *C. gestroi*; Isoptera: Rhinotermitidae) in metropolitan southeastern Florida (1990–2015)

Thomas Chouvenc, Rudolf H. Scheffrahn, and Nan-Yao Su*

Abstract

This study reports the spread of 2 major invasive subterranean termite species (Isoptera: Rhinotermitidae) in metropolitan southeastern Florida: *Coptotermes formosanus* Shiraki and *C. gestroi* (Wasmann). Termite records from 1990 to 2015 were analyzed to determine the expansion of their distribution. Our results suggest that the ranges of their distribution have increased exponentially during this time frame. This observation raises concerns about potential structural damage in this urbanized area, which includes 6 million residents. The risk to structures located in an area with known *Coptotermes* infestation increased from 0.49% in 2000 to 7.3% in 2015, with some species distributional overlap. In addition, several localities that had *Coptotermes* records before 2000 have registered an increased density of termite infestation and swarming activity. We argue that the subterranean termite problem in metropolitan southeastern Florida is still in its early phase of invasion, and we predict that the distribution and structural infestations by *Coptotermes* will continue to increase in the years to come, with an estimated 50% of all structures in southeastern Florida at risk by 2040.

Key Words: species distribution; forecast; economic impact; co-occurrence

Resumen

El estudio se informa de la propagación de 2 especies principales de termitas subterráneas invasoras (Isoptera: Rhinotermitidae) en el sureste de Florida metropolitana: *Coptotermes formosanus* Shiraki y *C. gestroi* (Wasmann). Se analizaron los registros de termitas de 1990 a 2015 para determinar la expansión de su distribución. Nuestros resultados sugieren que el rango de su distribución han aumentado exponencialmente durante este período marco de tiempo. Esta observación plantea preocupaciones sobre el potencial de daño estructural en esta zona urbanizada, que incluye 6 millones de habitantes. El riesgo para las estructuras situadas en una zona con infestaciones conocidas de *Coptotermes* aumentó del 0,49% en 2000 al 7,3% en 2015, con un solapamiento en la distribución de las especies. Además, varias localidades que tenían registros de *Coptotermes* antes de 2000 han registrado un aumento de la densidad de infestación de termitas y la actividad enjambre. Se argumenta que el problema de termitas subterráneas en el área metropolitana el sureste de Florida se encuentra todavía en su fase temprana de la invasión, y predecimos que la distribución e infestación estructural de *Coptotermes* seguirán aumentando en los próximos años, se estima que el 50% de todas las estructuras en el sureste de Florida en situación de riesgo para el año 2040.

Palabras Clave: distribución de las especies; pronóstico; impacto económico; coocurrencia

The introduction of invasive species in Florida has had important ecological and economic impact to both natural and urban landscapes across the state. There is a long list of plants (Gordon 1998), fishes (Shafland et al. 2008), reptiles (Dorcas et al. 2012), birds (Bonter et al. 2010), amphibians (Meshaka 2011), mammals (Perry et al. 2006), and insects (Frank & McCoy 1995) that were introduced (intentionally or not) with several becoming major pests. Six invasive termite species are now established in Florida, and among these, 3 species are of particular concern for residents and for the pest control industry because they cause most of the structural damage (Scheffrahn 2013): *Coptotermes formosanus* Shiraki, *C. gestroi* (Wasmann) (Isoptera: Rhinotermitidae), and *Cryptotermes brevis* (Walker) (Isoptera: Kalotermitidae).

Coptotermes is a subterranean termite genus distributed in much of the tropics and subtropics worldwide and is a major pest to structures and forestry crops (Evans et al. 2013; Krishna et al. 2013). Two species, *C. formosanus* and *C. gestroi*, are particularly invasive (Chouvenc et al. 2015a) and have spread far beyond their native range with the help of human maritime activity (Scheffrahn & Crowe 2011; Rust & Su 2012). They contribute in large part to the annual $40 billion cost associated with termite damage and control around the world (Rust & Su 2012). Whereas *C. formosanus* (Formosan subterranean termite) has a warm temperate/subtropical distribution, *C. gestroi* (Asian subterranean termite) has a tropical distribution (Cao & Su 2015). In the New World, *C. formosanus* has invaded most of the southeastern United States, whereas *C. gestroi* has invaded areas of Brazil, most of the

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Caribbean, and more recently, parts of south Florida (Su et al. 1997; Scheffrahn et al. 2015).

These 2 termite species occupy distinct climatic envelopes and historically did not have any geographic distribution overlap (Li et al. 2010). However, both species have spread extensively and, with the help of human activity, have established sympatrically within non-native climatic boundaries (Chouvenc et al. 2015a) including southern Taiwan, Hainan (China), Oahu (Hawaii), and the metropolitan area of southeastern Florida (Chouvenc et al. 2015a; Fig. 1). It is notable that *C. gestroi* is found extensively in the Florida Keys, where *C. formosanus* is absent, and conversely, *C. formosanus* is established northward from Miami-Dade County, whereas *C. gestroi* has not been detected north of Palm Beach County (Scheffrahn 2013). Therefore, the Miami-Fort Lauderdale-West Palm Beach metropolitan area, which is one of the 10 most densely urbanized clusters in the United States (Anonymous 2010), represents the only location in the continental United States where both species overlap in their distribution.

Coptotermes formosanus probably became established in Florida in the early 1970s, remained undetected until the first reported record (Koehler 1980) in Hallandale (Broward County), and has since been found in most urban localities throughout Florida (Scheffrahn & Su 2005; Scheffrahn 2013). The first *C. gestroi* infestation was found in 1996 in Miami (Miami-Dade County) and has since remained restricted to tropical Florida (Su et al. 1997; Scheffrahn & Su 2005; Scheffrahn 2013). The expansion rate and distribution forecast of both species were estimated at the Florida state level (Tonini et al. 2014). However, looking at the current pest status of *C. formosanus* in New Orleans, Louisiana, it took more than 40 yr for the species to reach maximum carrying capacity in some areas of the city, causing considerable damage (Mullins et al. 2011). We therefore stress the need of a high-resolution understanding of the *Coptotermes* distribution and spread at the local scale in metropolitan southeastern Florida, owing to the potential structural damage in this densely urbanized area. In this study, we estimated the overall geographical spread of both termite invaders in metropolitan southeastern Florida over a 25 yr time frame by using collection records of specimens contained in the University of Florida Termite Collection at the Fort Lauderdale Research and Education Center. In addition, we updated the current distribution of *C. formosanus* and *C. gestroi* throughout the area.

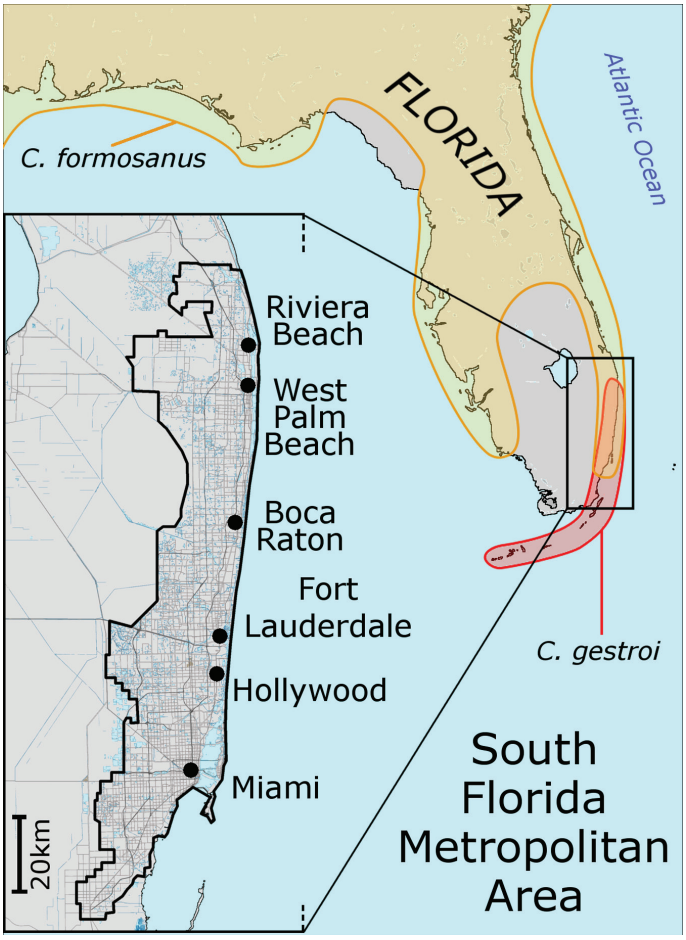


Fig. 1. Putative distribution of *Coptotermes formosanus* and *Coptotermes gestroi* in the southeastern United States. Both species have a distribution overlap in metropolitan southeastern Florida.

Materials and Methods

LOCATION

The densely populated Miami-Fort Lauderdale-West Palm Beach area is a metropolitan statistical unit defined and used by the U.S. Census Bureau (Anonymous 2010), as it represents a large contiguous urban area (15,980 km^2) located in southeastern Florida (between latitudes 27.0 and 21.4, with a maximum elevation of 16 m asl). The area includes land development of urban and suburban landscapes and encompasses 6 million residents as of 2014, which represents approximately a third of all Florida residents located on less than 10% of the state's area. Urban development is nearing its limits in a swath of land 180 km long by 10 to 30 km wide, bounded to the east by the Atlantic Ocean and to the west by the seasonally inundated Everglades.

TERMITE SAMPLES

Termite samples used in this study are housed at the Fort Lauderdale Research and Education Center in Davie, Florida. Termite samples were obtained between 1985 and 2015. Samples were predominantly collected in or near human structures by pest control professionals, residents, and the authors. Termites were identified by the authors, using soldier and alate morphology as in depicted in Scheffrahn et al. (2015). All samples were stored in 85% alcohol and inventoried electronically with the following information: sample location (GPS coordinates), date of collection, collector identification, and type of sample (soldier, alate, dealate, nymph, worker). In total, 496 *C. formosanus* samples and 327 *C. gestroi* samples collected in the metropolitan area of southeastern Florida were used in this study.

COPTOTERMES DISTRIBUTION REPRESENTATION

An animated distribution of both termite species in the metropolitan area of southeastern Florida was generated for the 1990–2015 period (Supplementary Material S1, available online at http://purl.fcla.edu/fcla/entomologist/browse). For each termite record, a data point was added to the map for the year it was collected. In addition, snapshots of the distribution for the years 2000, 2005, 2010, and 2015 were provided in Fig. 2. For both the generated animation and Fig. 2, a single dot on the map representing a termite record corresponds to a circle of 2.15 km radius, for visual representation purpose.

AREAS AT RISK

Within the metropolitan area of southeastern Florida, the surface area in the region that is at risk of being infested with *Coptotermes* over time was estimated. For each year, we estimated that any struc-

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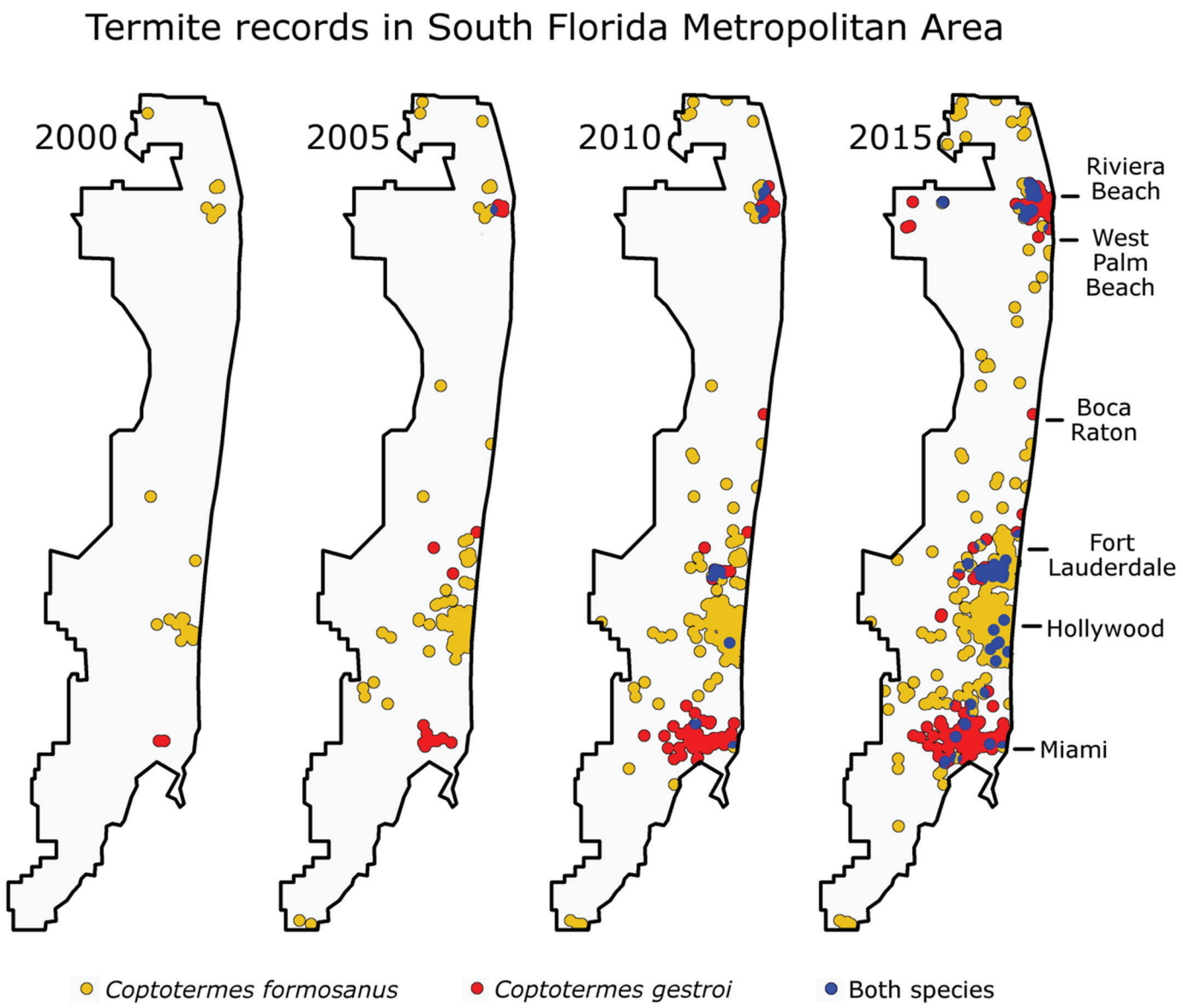


Fig. 2. Distribution of *Coptotermes formosanus* and *Coptotermes gestroi* in metropolitan southeastern Florida 2000–2015.

ture within a 500 m radius from any recorded *Coptotermes* is potentially at risk of infestation. The rationale behind this risk-distance is that during the swarming event that originated the colony on record, there is a chance that other colonies were able to establish within proximity, especially with repeated swarms in the following years. In addition, not only can a mature colony forage beyond 100 m underground and attack any structure within this range (Su & Scheffrahn1988), but also flights from a mature colony can disperse alates that can fly in a range of 200 to 600 m (Mullins et al. 2015). We are therefore confident that a 500 m radius around a recorded *Coptotermes* location is representative of an area at risk of infestation. We calculated the cumulative area encompassed with such risks for the whole metropolitan region between 1990 and 2015, which indirectly represents the increased risk for structures of being infested by a *Coptotermes* colony over time (Fig. 3). Keeping in mind the statement formulated by Tonini et al. (2014) that distribution of *Coptotermes* in Florida is more influenced by urban development than climate alone, a projection on the future cumulative area at risk was done using a logistic population growth model (maximum carrying capacity being 15,980 km^2 and the initial exponential growth being the data provided in Fig. 3).

Results and Discussion

Coptotermes records in the metropolitan area of Miami, Fort Lauderdale, and West Palm Beach have steadily increased between 1990 and 2015 (Supplementary Material S1; Fig. 2). Structural infestation by either one of the species was relatively rare before 2000, owing to the low colony density in the area. For invasive species, it may take many years after introduction before they expand their distribution (Su 2013). Because of the relatively long life cycle of *Coptotermes* colonies, it can take up to 8 yr for a mature colony to commence its first dispersal flight (Chouvenc & Su 2014) and even longer if the growth rate of the colony is impeded by resource limitation (Osbrink et al. 2015). In addition, new incipient colonies may only successfully establish within flight distances (Mullins et al. 2015). However, since 1990, the activ-

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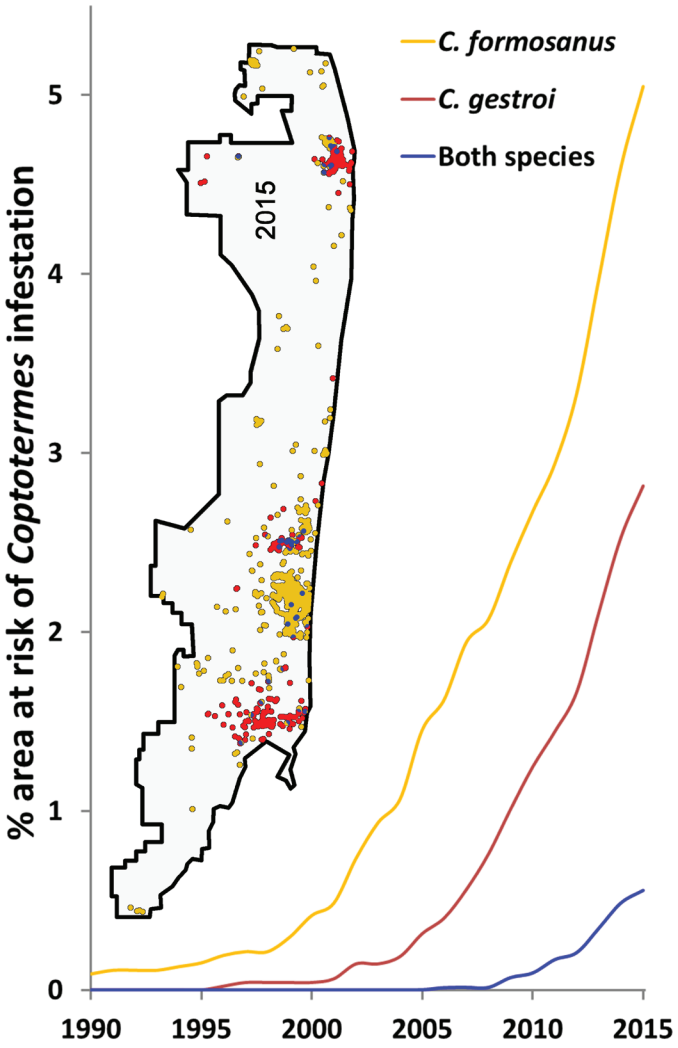


Fig. 3. Cumulative area within metropolitan southeastern Florida that is at risk of infestation by *Coptotermes* species over time. An area at risk was determined by the zone within a 500 m radius from a termite record (at scale on the figure).

ity and distribution of these 2 invasive species have expanded their range considerably in Florida (Tonini et al. 2014), implying that the movement of the species was enhanced by human activity (Scheffrahn et al. 2015). As a direct result of the spread of the 2 termite pests, the number of structures that are at risk of being infested has also increased over time (Fig. 3). In addition, the spread of *Coptotermes*, as documented herein, is presumably an underestimation of the situation because it represents only the termite distribution that was reported to us in the past 25 yr. With the presence of *Coptotermes* species being overwhelmingly undetected owing to their cryptic life style, we expect the current distribution of both species to be more widespread than actually reported.

Nevertheless, both *Coptotermes* species are still in their invasion phase within the area, and the populations remain in the early phase of a logistical growth (Fig. 3). In 2000, only localized areas in southeastern Florida were at risk of being infested by either species (0.06% for *C. gestroi*, 0.42% for *C. formosanus*), but by 2015, this risk has risen to 2.8% for *C. gestroi* and 5.1% for *C. formosanus*. By taking into account the overlapping distribution of both species, the combined area in the region at risk of infestation by either one species was 0.46% in 2000 and reached 7.3% by 2015. If this rate of expansion is maintained, using a logistic growth model, by 2040, *Coptotermes* is expected to reach a distribution that would place 50 to 60% of structures in the area at risk of infestation, with large areas of species distribution overlap. With an expected growth of the southeastern Florida human population in this time frame (7.5 million residents projected for 2040), it is inevitable that more termite damage will be associated with the spread of both termite species and the increase of human activity.

To conclude, the use of long-term records of termite activity throughout the metropolitan area of southeastern Florida has shed light on the invasiveness of *C. formosanus* and *C. gestroi* by providing data enabling us to calculate the pace of their spread at a regional scale and documenting their increasing status as structural pests. We argue that, facing the increasing pressure of these invasive subterranean termite species in southeastern Florida, area-wide termite management programs (Su & Scheffrahn 1998; Mullins et al. 2011) should be implemented, as they may provide a long-term, sustainable solution for communities to a long-term, increasing problem. Finally, several locations in Riviera Beach, Fort Lauderdale, Hollywood, and Miami have had overlapping distributions of both *C. formosanus* and *C. gestroi* since 2005. This overlapping area has also increased over time and may be cause for concern, because it has been reported that the 2 species have the opportunity to hybridize during simultaneous swarming events (Chouvenc et al. 2015b).

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