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RESEARCH

# *Cryptotermes brevis* (Isoptera: Kalotermitidae) in the Azores: Lessons After 2 yr of Monitoring in the Archipelago

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**ABSTRACT.** The dispersal flights of West Indian drywood termite, *Cryptotermes brevis* (Walker) (Isoptera: Kalotermitidae) were surveyed in the major cities of Azores. The sampling device used to estimate termite density consisted of a yellow adhesive trap (size 45 by 24 cm), placed with an artificial or natural light source in a dark attic environment. In addition, data from two other projects were used to improve the knowledge about the geographical distribution of the species. The level of infestation in the two main Azorean towns differed, with high levels in the houses of Angra do Heroísmo, whereas in Ponta Delgada, there are fewer houses with high levels of infestation. The infestation in Ponta Delgada shows a pattern of spreading from the center outward to the city's periphery, whereas in Angra do Heroísmo, there was a pattern of spreading outward from several foci. The heavy infestation observed in Angra do Heroísmo and the clear increase of infestation levels observed from 2010 to 2011 is a reason for concern and calls for an urgent application of an Integrated Pest Management (IPM) control strategy.

**Key Words**: urban pest management, Macaronesia, invasive species, Blattodea, Isoptera

Four species of termites are currently known from the archipelago: the European drywood termite, *Kalotermes flavicollis* (F.), the West Indian drywood termite, *Cryptotermes brevis* (Walker), the Iberian subterranean termite *Reticulitermes grassei* Clément, and the American eastern subterranean termite *Reticulitermes flavipes* (Kollar) (Borges and Myles 2007, Austin et al. 2012; Fig. 1). All these species are "lower termites," i.e., more primitive taxa, do not have sterile adult workers, generally eat only wood, and have a diverse population of prokaryotes and flagellated protists (single-cell eukaryotes) in their gut, which are essential for the digestion of wood (Watanabe et al. 1998, Lo et al. 2000). With exception of *C. brevis*, these termites tend to occur in more temperate latitudes.

The knowledge on Azorean termites has only been recently reported (Borges and Myles 2007). Currently, the subterranean species have a restricted distribution in the Azores, *R. grassei* (Fig. 1c) occurring only in Horta (Faial Island; Nunes and Nobre 2007) and *R. flavipes* (Fig. 1d) is restricted to a small site near the Lajes Air Force Base at Praia da Vitória ("Bairro de Santa Rita," Terceira Island; Austin et al. 2012; Fig. 2). Concerning the other two species, *K. flavicollis* (Fig. 1b) has a larger distribution occurring in most of the southeast coast of Terceira, Ponta Delgada (S. Miguel), and Horta (Faial; Myles et al. 2007); *C. brevis* (Fig. 1a) has been recorded on these same three islands plus Santa Maria, São Jorge, and Pico (Myles et al. 2007, Guerreiro et al. 2010; Fig. 2).

Because of human-aided transport, *C. brevis* has a widespread distribution in the tropical and subtropical regions of the world, the Azores being the northern boundary where this species is established, although the occurrence of *C. brevis* was also registered in cities such as Lisbon and Barcelona (Nunes et al. 2010). However, because of the more temperate climate of the Iberian Peninsula, this termite is not likely to flourish as it has in the Azores. Originally from the deserts of Peru and Chile (Scheffrahn et al. 2009), this species was first described in Jamaica (Walker 1853) and recorded in the Azores in 2000 (Borges et al. 2004, Borges and Myles 2007). *C. brevis* is currently the most damaging

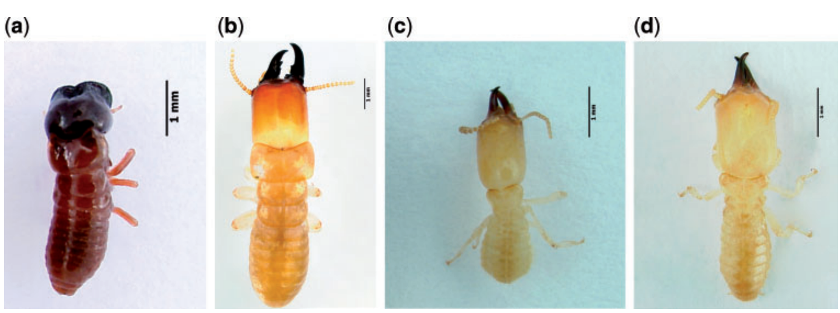

**Fig. 1.** Soldiers from the different species occurring in the Azores: (a) *C. brevis*, (b) *K. flavicollis*; (c) *R. grassei*; and (d) *R. flavipes* (photos: Enésima Mendonça).


**Fig. 2.** Distribution of the four species currently known from the archipelago: the European drywood termite, *K. flavicollis* (green circle), the West Indies drywood termite, *C. brevis* (yellow circle), the Iberian subterranean termite *R. grassei* (dark brown circle), and the eastern subterranean termite *R. flavipes* (light brown circle).

drywood termite of human dwellings worldwide, as it is in the Azores (Nunes et al. 2005, Borges et al. 2007).

It is now recognized as most probably unrealistic to fully eradicate *C. brevis* in some of the Azorean islands (Borges and Myles 2007). Lessening the dispersal flights of this species appears to be a possible management strategy, and an adequate long-term approach to monitor the species' spread and spatial distribution (Borges et al. 2007). The approach implemented in the Azores to monitor the distribution and dispersal of *C. brevis* is the use of yellow adhesive traps with a light attractant to catch flying reproductive specimens during the dispersal flight period (May to September).

The small scale distribution pattern of *C. brevis* in the main cities of the Azores was investigated using light trap data from three different projects. To our knowledge, this is the first time that a detailed study of *C. brevis* infestation has been performed in a municipality using standardized methods. The results show a continuous spread of the species.

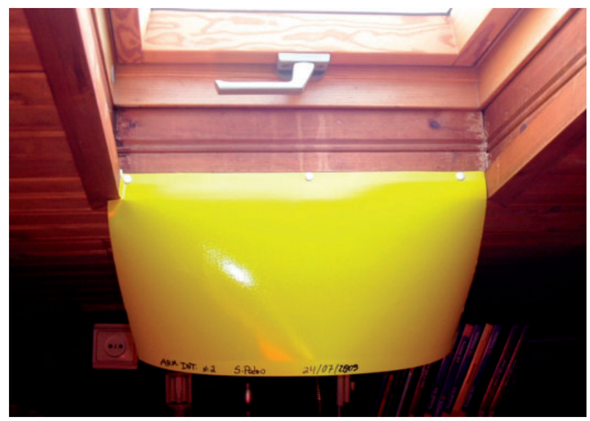

**Fig. 3.** Yellow adhesive light trap used to collect the young flying termites.

## Materials and Methods

**Study Area.** The Azorean archipelago stretches out over 615 km in the North Atlantic Ocean (37–40° N, 25–31° W), 1,584 km west of southern Europe, and 2,150 km east of the North American continent. It comprises nine main islands of recent volcanic origin, distributed in three groups (Fig. 2): the western group of Corvo and Flores; the central group of Faial, Pico, Graciosa, São Jorge, and Terceira; and the eastern group of São Miguel and Santa Maria. Data from standardized surveys in 2010 and 2011 were gathered on the distribution of infestation of *C. brevis* in the cities of Angra do Heroísmo in Terceira (402 km$^2$; 56,062 inhabitants) and Ponta Delgada in the largest island São Miguel (745 km$^2$; 137,699 inhabitants). In addition, some information is also provided on the small-scale distribution of this species on the islands of Faial, Pico, São Jorge, and Santa Maria, particularly in the towns of Horta, Lajes, Calheta, and Vila Porto, respectively.

**Sampling and Monitoring.** Under the framework of the long-term monitoring project TERMODISP funded by the Azorean Government, between June 2010 and September 2011, a total of 116 houses were carefully monitored in the towns of Angra do Heroísmo ($n = 86$) and Ponta Delgada ($n = 30$). Houses were sampled along 10 different streets covering several parts of the towns. The number of houses per street varied largely depending on the owners' availability to participate in the study. Initially, a total of 200 houses were selected (100 in each town), but only 116 were adequately monitored throughout the 2-yr period. In Angra do Heroísmo, a previous study was followed (Borges et al. 2004) that surveyed most of the town and gave a tentative indication of termite distribution. The owners agreed to provide access to the houses' attics to install the traps and replace them every 2 wk between the beginning of June and the end of September, which corresponds to *C. brevis'* flight season. The sampling device consisted of a yellow adhesive trap (45 by 24 cm) (BioSani; Fig. 3) placed in unlit attics with a light source. In attics with incoming outdoor lighting, sun light was used, and the traps were placed on the windows, skylights, glass tiles, or other natural light entries of the monitored building. When using an artificial light source, a light bulb (either fluorescent or incandescent) was used to attract the alates. Because *C. brevis* swarms in the evening, trap lights were controlled with an electric timer, or alternatively, the owners were asked to have lights on from 5:00 pm to 11:00 pm. All but one trap in Ponta Delgada (São Miguel Island) and all the traps in Santa Maria, Faial, São Jorge, and Pico used natural sun light. In Angra do Heroísmo, 55 houses used natural sun light and 31 houses artificial light source. As houses using artificial light source have almost the double of termites in traps, we present for Angra do Heroísmo analyses separating the two kinds of houses.

Although some minor flights continued after September, these trap catches were not included herein. When traps were replaced, traps with termites were taken to the laboratory, immediately counted or frozen for later quantification. Two methods to estimate alates abundance in the traps were followed: 1) individual counting of all specimens when the number of specimens in the traps was low; 2) overall estimated abundance using a transparent plastic sheet with three 5- by 5-cm squares randomly positioned, over traps that were heavily covered with alates.

In addition to these core data for estimating spatial density, a wider presence or absence geographic survey was performed using data collected by the "Risk Communication Program" (RCP) more specifically from its "United we stand, divided we fall" campaign (Arroz et al. 2012).

To stimulate public participation, partnerships with the local and regional government were pursued to foster trust in decision makers' commitment to pest control. Four out of the five city councils in "at risk areas" shared the responsibility to freely provide, through the mail, two yellow adhesive traps of a smaller size (20 by 25 cm) to 14 out of 15 parishes for a total of 21,657 households. A magnet to be placed on the refrigerator door, financed by the Regional Environment Secretary, accompanied the traps providing instructions on how to use them. The following localities were included in the direct mailings: Santa Maria Island—City of Vila do Porto (Vila do Porto and Santo Espírito parishes) ($n = 1{,}758$); São Miguel Island—City of Ponta Delgada (S. José, S. Pedro, S. Sebastião, and Santa Clara parishes) ($n = 11{,}064$); Terceira Island—City of Angra do Heroísmo (S. Pedro, N.ª S.ª da Conceição, Sta. Luzia, Sé, and S. Bento parishes) ($n = 6{,}182$); Faial Island—City of Horta (Angústias, Matriz, and Conceição parishes) ($n = 2{,}653$). Only the City of Calheta de São Jorge (Calheta parish) ($n = 547$) in São Jorge Island was not covered, diminishing the aim to embrace all the localities "at risk" due to an absence of financial commitment from this municipality. The remaining three parishes currently at risk (Fajã de Baixo and São Roque) ($n = 3{,}094$) from the City of Ponta Delgada in São Miguel Island and (Ribeiras parish) ($n = 467$) from the City of Lajes do Pico in Pico Island were not included because they were only legally defined as "at risk" after the direct mailing campaign was already implemented. Mailings to Ponta Delgada were cancelled due to delays on the formal contract by the municipality. In total, 97.5% of the territory (21,657 out of 22,204 households) legally defined as "at risk" at the moment of the project's negotiation was covered.

The addressees were instructed to install the traps in which every rooms of their house had the most exposed wood, according to five possible scenarios: 1) on a window, 2) on a skylight, 3) on a ceiling's fluorescent lamp, 4) on a desk lamp, and 5) on a light bulb suspended from the ceiling "keeping the lights on from 5:00 p.m. to 1:00 a.m. and from 6:00 a.m. to 8:00 a.m." Residents were also asked to return the traps to their Parish Council (being entitled to a new one) as soon as the trap was covered with insects or 2 mo after its usage, until the 5th of September.

Another source of information on *C. brevis* occurrence was the reports provided by the Governmental Officials that perform evaluations of termite infestations in the houses (SCIT—Termites Infestation Certification System Data).

### Data Analyses.

*TERMODISP Data.* Termite abundance was measured as mean number of termites per trap, because more than one trap was used per house. Afterward, the number of captured alates was used to estimate the number of colonies per building according to the average number of individuals per colony (T.G.M., unpublished data) and percentage of nymphs alates present on a colony (Myles et al. 2007). On the basis of this, we estimated the existent number of colonies at each building site, dividing the number of alates in traps by the number of nymphs alates present in average on a colony. To obtain infestation levels, the abundance of alates were organized in a logarithmic scale using the following octave binning system: bin 1 = number of houses with 1 colony or less, bin 2 = number of houses with 2–3 colonies, bin 3 = 4–7, bin 4 = 8–15, bin 5 = 16–31, etc. (Gray et al. 2006). The octave scale was transformed into an infestation index: Incipient (bin 1; 1 colony); Slight (bin 2; 2 or 3 colonies); Moderate (bins 3 and 4; 4–15 colonies); Heavy (bins 5 and 6; 16–63 colonies); Very Heavy (bins 7 and 8; 64–255 colonies); and Destructive (bins 9 and higher; >255 colonies).

According to this scale, we mapped the buildings and applied an infestation probability on the surrounding area of 100 m (according to the average flying capability of this species studied by Guerreiro 2009). We also ranked the results by local areas and compared the data of 2010 with 2011 using the Wilcoxon signed-rank test a nonparametric statistical hypothesis test.

The data were then plotted using a Geographic Information System—gvSig.

*RCP—"United we stand, divided we fall" Campaign Data.* This program consisted only of presence or absence of data. The presence points were plotted using a geographic information system—gvSig. For each point, we created a 100-m buffer representing the species' spreading capability. This means that the presence point is a potential origin for spread of the infestation up to 100 m circumference or that the presence point was infested from another point 100 m nearby.

The map data were then combined and intersected with the TERMODISP program and SCIT information (see Termites Infestation Certification System Data) to provide a more comprehensive map of infested areas.

*SCIT—Termites Infestation Certification System Data.* In January 2011, the Azorean Government published a new law concerning termite pest management (Decreto Legislativo Regional no. 22/2010/A, de 30 de Junho; Portaria n.° 90/2011 de 9 de Novembro de 2011). The new law requires qualified inspections (certifying the presence or absence of the pest) every time a building is sold, rented, or subject to rehabilitation or reconstruction works. Government funding is available upon request to replace termite-damaged structural members. Therefore, the Regional Environment Department has been gathering information concerning the building locations where this certification has been issued. These data were also used in this study. The same 100-m buffer procedure for a SCIT point as previously described for the RCP program was followed. The presence information was plotted using a geographic information system—gvSig and compared with all the previously mentioned data.

## Results

During the 2 yr of monitoring, 407,405 alates were captured throughout the Azores (Table 1). We monitored 86 houses in Angra do Heroísmo (2010 and 2011) in which 57 increased the number of captures and 29 decreased this number (natural light—34 increased and 21 decreased; artificial light—23 increased and 8 decreased). In Ponta Delgada, 30 houses were monitored (2010 and 2011); in 17 the number of captures increased and in 13 the number of captures decreased. The mean number of captured termites per trap in Angra do Heroísmo with artificial light was 1,109 in 2010 and 1,900 in 2011 ($Z = -2.37$; $P < 0.02$) and with natural light was 549 in 2010 and 1,087 in 2011 ($Z = -3.28$; $P < 0.001$).

In Ponta Delgada, the mean captures were 614 in 2010 and 893 in 2011 ($Z = -1.12$; NS).

The level of infestation in the two main Azorean cities differed, with about 56% in 2010 and 63% in 2011of the houses in Angra do Heroísmo having high levels (Codes E, HE, or D) of infestation (Fig. 4a,b; see also Fig. 5), whereas in Ponta Delgada, the levels of high infestation were lower, i.e., 35% in 2010 and 33% in 2011 (Fig. 4c,d; see also Fig. 6).

The geographic distribution and potential spread, according to our monitoring data, could be seen in Figs. 5 and 6 for Angra do Heroismo and Ponta Delgada, respectively. These figures visualize the pattern described in Fig. 4 in geographical space, and we conclude that most of Angra do Heroismo is infested (Fig. 5) and that in Ponta Delgada, high levels of infestation are restricted to the city center (Fig. 6). A direct relationship to the infestation level is assumed here, and no attempt was made to correct the observed data for possible differences in building practices that minimized colonization of the structures.

**Table 1. Number of total alates captured during the 2-yr of monitoring**

| | São Miguel (SMG) | Terceira (TER) | Santa Maria (SMA) | Faial (FAI) | São Jorge (SJG) | Pico (PIC) | TY | T |
|---|---|---|---|---|---|---|---|---|
| 2010 | 29,630.2 | 203,185.6 | 925.0 | No data | No data | No data | 233,740.8 | 407,405 |
| 2011 | 36,816.0 | 129,518.2 | 1,116.0 | 2,661.0 | 1,346.0 | 2,207.0 | 173,664.2 | |

FAI, Faial; PIC, Pico; SJG, São Jorge; SMA, Santa Maria; SMG, São Miguel; TER, Terceira; TY, total termites captured per year; T, total termites captured in both years.

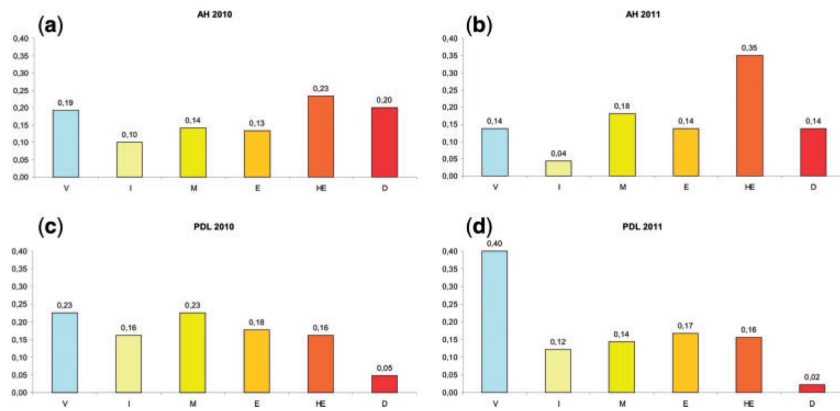


**Fig. 4.** Levels of infestation for Angra do Heroísmo (a, b) and for Ponta Delgada (c, d) in 2010 (a, c) and 2011 (b, d). V, incipient; I, slight; M, moderate; E, heavy; HE, very heavy; D, destructive.

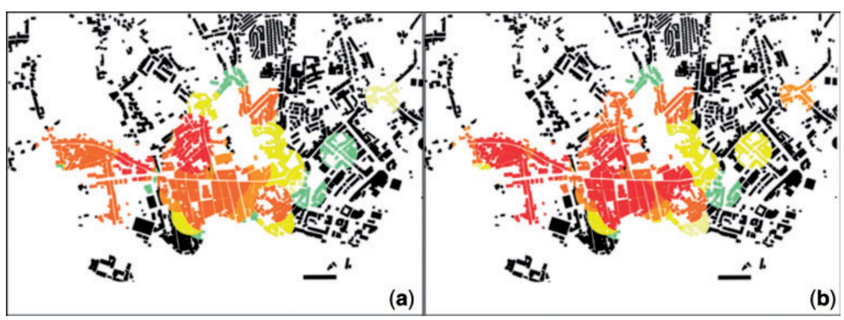


**Fig. 5.** Geographic distribution of the *C. brevis* in Angra do Heroísmo and potential spread for 2010 (a) and 2011 (b). Colors follow the notation of Fig. 4.

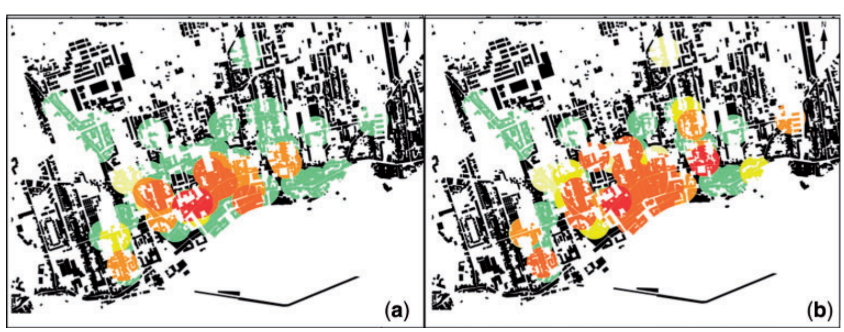


**Fig. 6.** Geographic distribution of the *C. brevis* in Ponta Delgada and potential spread for 2010 (a) and 2011 (b). Colors follow the notation of Fig. 4.

Both the RCP and the SCIT projects include new information concerning the distribution of *C. brevis*. For the RCP project, a total of 1,843 traps were assembled and returned to the parish councils by participant citizens, achieving a regional public participation index of 8.5%. Vila do Porto was the most engaged city with twice the regional return rate (17.7%) and Ponta Delgada the least one with less than half (4.1%). Angra do Heroísmo and Horta were very close to one another achieving 12.3% and 12.1%, respectively. The RCP data identified new infested areas in the cities of Angra do Heroísmo (Fig. 7c), Horta (Fig. 8), Vila do Porto (Fig. 9), and Santo Espírito parish (Fig. 9). The SCIT governmental program also contributed new data for *C. brevis* distribution with new infestation localities in Ponta Delgada (Fig. 7f). The *C. brevis* infestation map is now larger and far more complete than the maps from previous years (Borges et al. 2004, Borges and Myles 2007, Guerreiro 2009), particularly in Angra do Heroísmo (Fig. 7g) and Ponta Delgada (Fig. 7h). On the other islands, it is also clear that this pest will spread widely beyond known localities as seen in Faial—Horta (Fig. 8); Santa Maria—Maia, Vila do Porto, and Santo Espírito

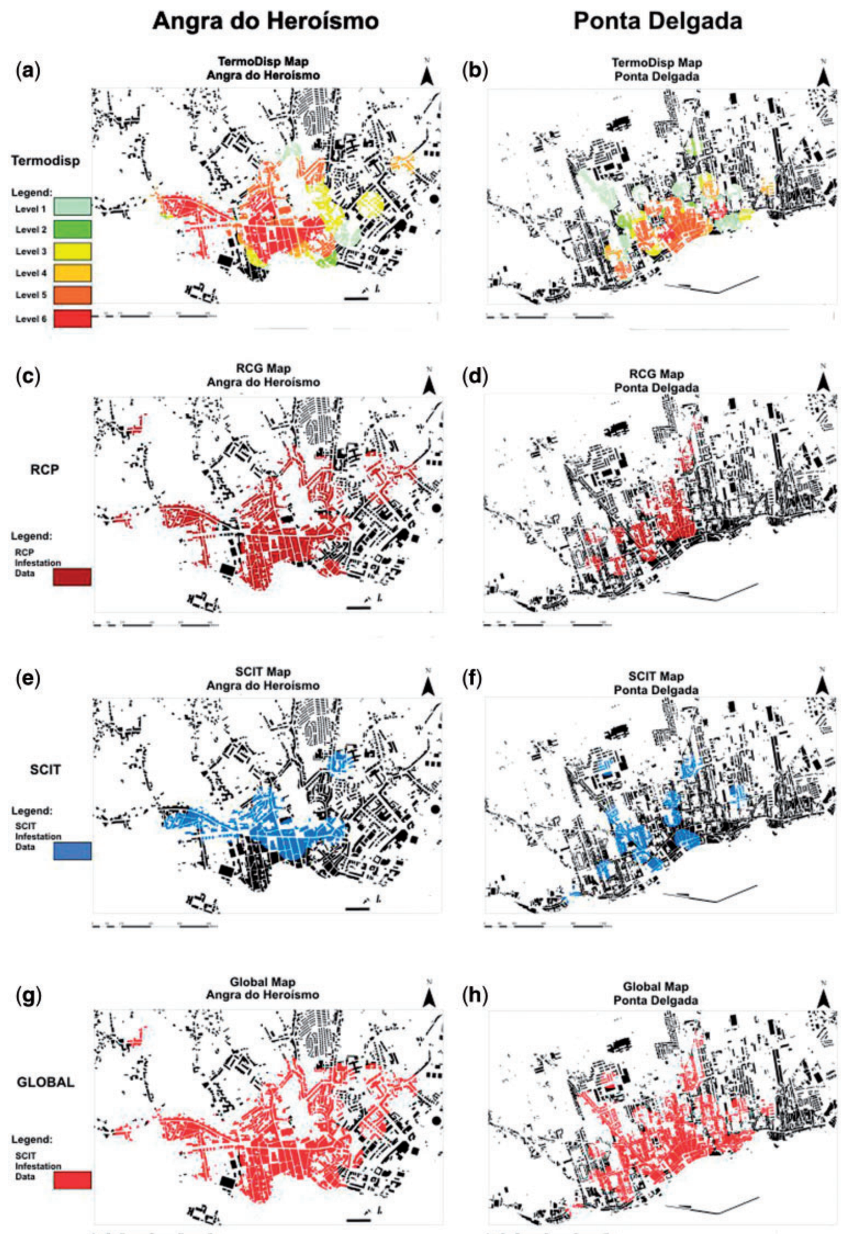


**Fig. 7.** Infestation Data, results from different programs during 2011 in the cities of Angra do Heroismo (a, c, e, g) and Ponta Delgada (b, d, f, h).

(Fig. 9); Pico—Ribeiras and Calheta do Nesquim (Fig. 10); and S. Jorge—Calheta (Fig. 11).

## Discussion

The Azores were discovered and colonized in the 15th century by the Portuguese and for centuries have been important stepping stones for the travelers coming and going to India, Africa, and Americas. Therefore, it is not surprising that several exotic termite species have arrived and established in the archipelago. In spite of the relatively recent introduction in the Azores, the West Indian drywood termite is already causing some severe economic losses for home owners and also for the state (Borges and Myles 2007). To optimize state and private management, it is critical to study the geographic distribution and density of the termite populations.

Results obtained in three complementary studies reported here (Termodisp; RCP and the SCIT) indicate that there are clear "hotspots" of abundance in the historical central parts of the cities of Angra do Heroísmo and Ponta Delgada. These two cities are harbor cities with heavy traffic of both commercial and recreational vessels. Ports and marinas can be points of entry for the infestations as the older historical areas of these cities tend to be closer to these sites. The dockage of boats has been associated with termite infestations for other invasive species [*Coptotermes gestroi* (Wasmann) and *Coptotermes formosanus* Shiraki] (Hochmair and Scheffrahn 2010), and the infestations in Horta, Angra do Heroísmo, and Ponta Delgada seem to follow that pattern as well.

In Ponta Delgada, the alate density decreases from the city center to the periphery (Fig. 6), which could be caused by two factors: 1) older houses conducive to infestation are mainly in the historical centers and 2) the first infestation spots were originally located in the center of the town. However, in Angra do Heroísmo, the situation is different with some of highly infested houses located in the margins of the main town (at São Pedro and St. Luzia parish). In Ponta Delgada, the only exception to this trend is one highly infested house in the S. Pedro parish that was detected in the year 2011. This isolated active site may have been the result of human transport of infested goods from the already infested

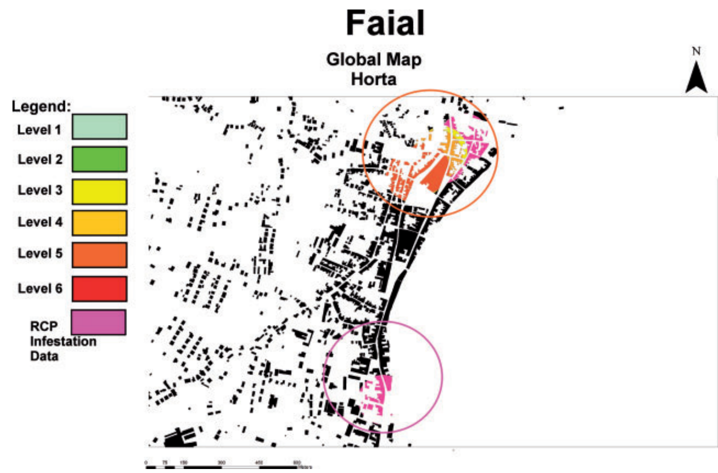


**Fig. 8.** Results from different programs: Termodisp with different levels of infestation and RCP, during 2011 in the Island of Faial.

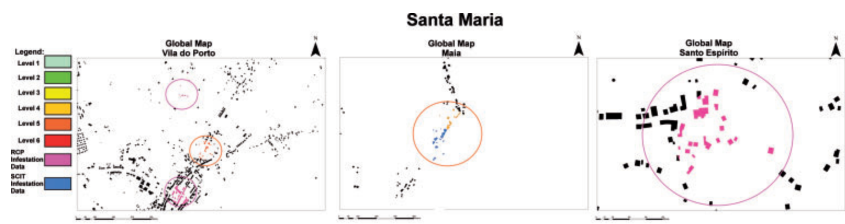


**Fig. 9.** Results from different programs: Termodisp with different levels of infestation, RCP and SCIT during 2011 in the Island of Santa Maria.

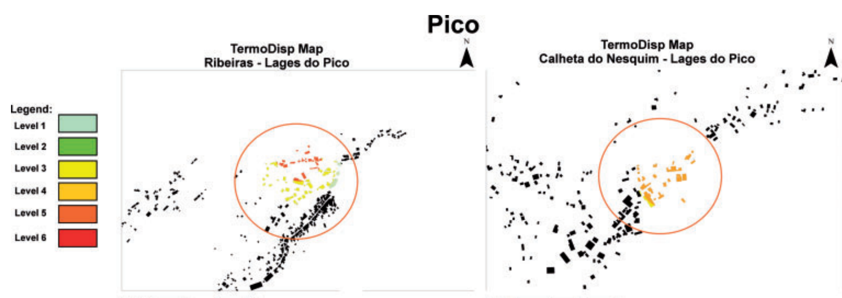


**Fig. 10.** Results from Termodisp with different levels of infestation during 2011 in the Island of Pico.

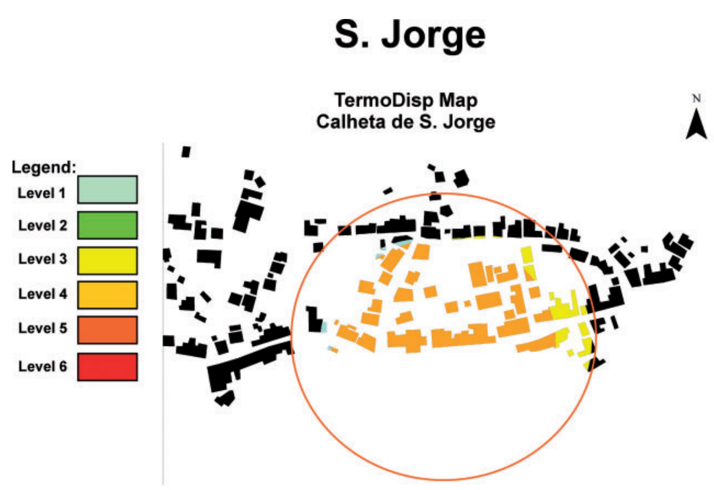


**Fig. 11.** Results from Termodisp with different levels of infestation during 2011 in the Island of São Jorge.

areas in the city center or from a foreign location. According to Ferreira (2011), the *C. brevis* infestation in the Azores had more than one origin. Therefore, this infestation, which is distant from the center by more than 500 m, may have been established from a different source than the one in center of the city.

In the remaining islands the spread of the species will be largely dependent of the geographical location of the current populations and better surveys. In the case of Horta (Fig. 8), the distribution of *C. brevis* needs to be better investigated, because there is a large gap between the two main centers of occurrence. In Santa Maria, the species is currently located in isolated pockets in the island suggesting independent colonization from abroad or within island transport of furniture between localities. The same seems to apply to Pico Island (Fig. 10). In the case of São Jorge, the small size of Calheta (Fig. 11) will facilitate the control of its spread.

It is known that local abundance dynamics of insects (Kaspari et al. 2000) and termite alates, in particular (Minnick 1973, Bhanot et al. 1984), are largely determined by environmental factors such as local and temporal variation in temperature and humidity. Steward (1982) had seen that pseudoworkers had a preference for a range of relative humidity (68–75%). Relative humidity along with air pressure has been shown to have an effect in the occurrence of alate flights, where there is a range of values when flights occur: 759–764 mmHg air pressure and 59–83% relative humidity with peaks occurring at 761 mmHg and 68% (Ferreira 2008). The variability of these flight occurrences and the lack of optimal conditions for flights to occur can explain the difference between the islands as well as explain small-scale variation in densities between years. It is therefore necessary to continue the monitoring of alates to determine whether the differences found are just fluctuations between years or if the infestation is becoming truly more severe and spreading to new locations.

The heavy infestation observed in Angra do Heroísmo and the clear increase of infestation observed between 2010 and 2011 is a reason for concern. The current distribution of the species in the several studied islands should call attention for an urgent application of an IPM strategy to control this termite pest in Azores.

## Acknowledgments

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