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Termites (Isoptera) in the Azores: an overview of the four invasive species currently present in the archipelago

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In this contribution we summarize the current status of the known termites of the Azores (North Atlantic; 37-40° N, 25-31° W). Since 2000, four species of termites have been identified in the Azorean archipelago. These are spreading throughout the islands and becoming common structural and agricultural pests. Two termites of the Kalotermitidae family, *Cryptotermes brevis* (Walker) and *Kalotermes flavicollis* (Fabricius) are found on six and three of the islands, respectively. The other two species, the subterranean termites *Reticulitermes grassei* Clemént and *R. flavipes* (Kollar) of the Rhinotermitidae family are found only in confined areas of the cities of Horta (Faial) and Praia da Vitória (Terceira) respectively. Due to its location and weather conditions the Azorean archipelago is vulnerable to colonization by invasive species. The fact that there are four different species of termites in the Azores, all of them considered pests, is a matter of concern. Here we present a comparative description of these species, their known distribution in the archipelago, which control measures are being used against them, and what can be done in the future to eradicate and control these pests in the Azores.

Key words: Azores, *Cryptotermes brevis*, *Kalotermes flavicollis*, Invasive exotic termites, Reticulitermes

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INTRODUCTION

Termites are eusocial insects that comprise an order of their own, the Isoptera. These insects were first described to the Royal Society of London in 1781 by Henry Smeathman (Howse 1970). Their name comes from the characteristic of the reproductive adults that have two pairs of wings of almost equal size (iso = equal, ptera = wings). There are approximately 3,500 species of termites (Engel 2011) which are now classified into ten families with seven extant, two fossil families and one with uncertain status (Engel et al. 2009). These families are the Mastotermitidae, Termopsidae, Hodotermitidae, Archotermopsidae, Stolotermitidae, Kalotermitidae, Stylotermitidae, Rhinotermitidae, Serritermitidae, and Termitidae.

The isopterans are closely related to the cockroach order (Blattodea) (McKitterick 1964; Inward et al. 2007). All cockroaches place their eggs in an ootheca which is a capsule holding from about 20 to 40 eggs. One primitive living species of termite lays an ootheca as well (*Mastotermes darwiniensis*) (Nalepa & Lenz

2000), although all other termites lay their eggs singly. Termites are believed to have evolved from an extinct primitive type of wood feeding cockroach ancestor and it has been acknowledged that termites share several characteristics with the wood roaches of the Cryptocercidae family within the genus *Cryptocercus* (Cleveland et al.1934; Nalepa 1984), and it has even been proposed that the order Isoptera be sunk into a family within the order Blattodea (Inward et al. 2007).

Termites are truly social insects. They possess the three main characteristics to being eusocial: i) there is cooperative brood care in their colonies, ii) they are divided into different castes which perform different tasks within the colony, iii) and they have overlapping generations (Wilson 1971). In termites, the larvae not only must acquire symbionts from their nestmates but must also be fed for the first couple of instars because they cannot feed directly on wood themselves (Noirot & Noirot-Timothée 1969).

Termites are often separated into two groups, “higher termites” and “lower termites”. The group known as the “higher termites” (Termitidae), which makes up 75% of all termite species, has only bacteria present in the gut. In the “lower termites” protozoan symbionts can be found in the gut in addition to bacteria (Krishna 1969). These symbionts help with the digestion of cellulose. The lower termites are generally more primitive, having simple galleries but not well formed nests (with the exception of a few Australian *Coptotermes* (Rhinotermitidae) which have mounds for nests). Some have colonies without true workers, and generally eat only wood. Unlike most higher termites, lower termites usually occur in more temperate latitudes. Higher termites (Termitidae) are much more diverse ecologically. While some still consume wood, others have evolved different diets of herbage, grass, dung, humus, fungus, lichens, or organic material in soil. The higher termites rely either on internal digestion with gut bacteria or external digestion in fungus combs (Edwards & Mill 1986). The higher termites often build large nests or mounds, and are common in tropical areas, but are rare or absent in temperate climates. Termite families differ in the venation of the wings, soldier head capsule structure, and worker gut structure. There has been a progressive simplifying of the venation in more evolved groups, so the Termitidae have the simplest wings, while the Mastotermitidae have very complex wing venation.

Termites can also be separated into groups according to their habitat types. They can be earth-dwelling (below ground or epigeal nests), wood-dwelling, or arboreal (nest on trees) termites. There are several types of earth-dwelling termites, such as the subterranean termites and mound building termites. The wood-dwelling termites on the other hand, confine themselves to wood. Wood-dwelling termites can be classified as, either drywood termites, attacking dry, sound wood, or dampwood termites attacking damp usually decaying wood (Kofoid 1934). Termite colonies are comprised of individuals that are separated into three main castes which are differentiated morphologically and behaviourally. These castes are: 1) reproductives (king, queen, and unmated winged forms called alates); 2) soldiers; and 3) workers or false workers or pseudergates (Snyder 1926; Krishna 1969) (Fig. 1-A).

Alates are usually darker in colour with a fully developed, pigmented chitinous exoskeleton, and with well-developed compound eyes (Light 1934a). Alates have deciduous wings that are broken off along a basal suture after a dispersal flight (Myles 1988). After losing their wings (becoming dealates), the dealates become the primary reproductives of a colony. A colony begins with a single pair of heterosexual dealates with copulation occurring at different intervals throughout their lives (Krishna 1969). Besides the primary reproductives, a colony of termites may produce secondary reproductives which may develop either from unflown alates (adultoid reproductives), or from nymphs with external signs of wing buds (nymphoid reproductives), or from workers (ergatoid reproductives) (Myles 1999).

Soldiers have modified heads and mandibles to protect the colony. There are several mechanisms of defence by soldiers. They can have phragmotic heads which serve to plug entry holes to the colony (Fig. 1-D), they can have mandibles that are modified for biting, snipping, or slashing enemies, or in other groups the mandibles have evolved for snapping in which there is an elastic distortion of the mandibles that when released, snap, striking a hard blow to the approaching

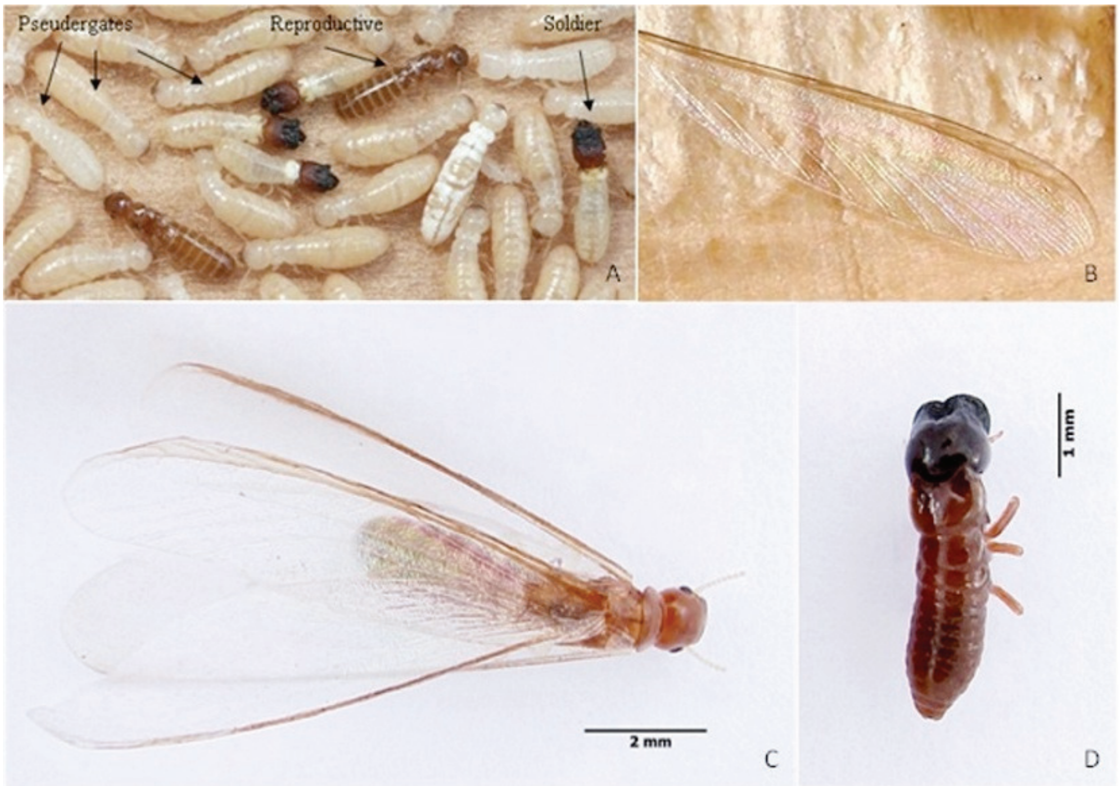

Fig. 1. The species *Cryptotermes brevis* (Walker). A. Different castes, where it is shown the reproductives, the soldiers and the pseudergates (indicated by the arrows; photo by R. Scheffrahn). B. A wing of an alate showing the iridescence (photos by R. Scheffrahn). C. Alate caste (photo by E. Mendonça). D. Soldier caste with the characteristic phragmotic head (photo by E. Mendonça).

enemy (Prestwich 1984). Soldiers also have chemical defenses with glandular structures in their heads that exude chemical compounds. The frontal gland is located in the front of the head above the mandibles which are found in Rhinotermitidae and Termitidae, and opens via a pore called the fontanelle The chemicals exuded can have different functions like keeping a wound from healing (lipids), causing irritation (irritants, repellents), causing toxicity (contact poisons), and acting like an entangling agent (glues) (Prestwich 1984). Some species of termites however do not have soldiers. The loss of soldiers has evolved three different times in the Termitidae (including a few genera related to *Amitermes* in Australia, and a few genera in SE Asia (*Protohamitermes* and *Orientotermes*). The largest assemblage of soldierless termites evolved in the Apicotermitinae, which occur in Africa and the New World. These soldierless termitids (subfamily Apicotermitinae, *Anoplotermes* group) have lost their soldiers and developed other forms of defense, such as biting, defecating or autothysis, which is the rupturing of the abdomen when in contact with a predator to exude their sticky gut contents and aggressive workers (Sands 1982).

The remaining castes of workers, pseudergates, and immature reproductives are usually light in colour, with no specialized morphology of the head or mandibles. The immature reproductives (brachypterous nymphs) may have wing buds of different lengths. The workers or the pseudergates in Kalotermitidae carry out all the work in the colony. The immature reproductives (nymphs) may also help with this (Edwards & Mill 1986). Work in the colony consists of taking care of the eggs and larvae and moving them when the nest is disrupted, foraging for food, feeding the larvae and the soldiers, building tunnels and nest structures, and excavating wood and soil.

The life cycle of termites is similar in all species. Mature colonies produce alates (winged forms), often at the start of the rainy season in drier or seasonal habitats. The alates will alight on a substrate (the ground or on a piece of dead wood) and pair up: one male with one female. The pair will select a suitable nest site, and then found a colony, either in the soil or in dead wood. They will mate and produce workers (or pseudergates) that begin to tend to the colony, either tending to the young, building nest structures or foraging for food. Later on, in the colony's development, soldiers are produced (with the exception of the soldierless termites). When the colony reaches maturity (3-5 years) alates are produced once more and the cycle continues. The percentage of alates that leave the colony for some species has been estimated, e.g.: *Pterotermes occidentis* (Walker), 30%; *Paraneotermes simplicicornis* (Banks), 14-16%; *Zootermopsis laticeps* (Banks), 39%; *Stolotermes victoriensis* Hill, 17.5%; and *Nasutitermes exitiosus* (Hill), 2.4% (Nutting 1969). Myles et al. (2007) estimated that approximately 25% of *C. brevis* colony matures into alates and leave the colony annually.

Termites are ecologically important (Bignell & Eggleton 2000), being key decomposers in numerous ecosystems, with their role in improving soil quality increasingly emerging (Holt & Lepage 2000). Termites, however, can be important pests of crops and timber. Of all the species of termites described (ca. 3,500) only 183 were recorded as pests (Edwards & Mill 1986) and presently only 80 termite species are considered serious pests that cause damage to wooden structures or furniture (Rust & Su 2012). Twenty eight termite species are considered invasive (Evans et al. 2013). For 2010, the global economic impact of termites was estimated in approximately $40 billion (Rust & Su 2012). Subterranean termites accounted for close to 80% of these costs. As for Europe, in France alone the estimated cost for termite treatment is about 200 million euros per year (Bagnéres et al. pers. comm.).

Species of termites in the Azores

The Azores is an archipelago of nine main islands (Fig. 2) located in the Atlantic Ocean about 1500 km from Lisbon, Portugal, and 3900 km from the East Coast of the United States of America. The archipelago was discovered in 1427 by the Portuguese and the first settlements on this uninhabited archipelago started in 1439 (Ashe 1813). Due to its strategic position, the Azores has been a stopping point for ships, yachts, and aircraft which make it vulnerable to invasive pests.

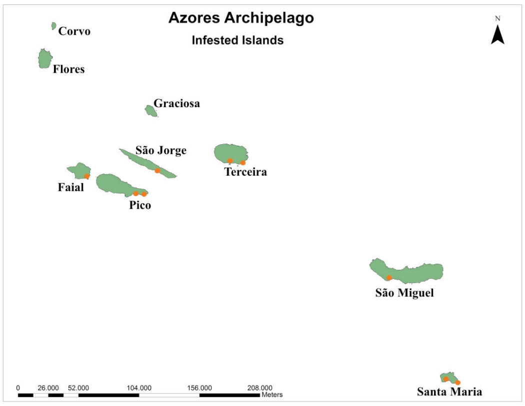

Fig. 2. Map of the distribution of *C. brevis* in the Azores. The species occurs on the islands of Terceira (Angra do Heroísmo city and Porto Judeu parish), São Miguel (Ponta Delgada city), Faial (Horta city), Pico (Calheta do Nesquim parish and Lajes do Pico village), São Jorge (Calheta parish), and Santa Maria (Maia parish, and Vila do Porto village).

The Azores is at temperate latitude but due to sea currents, enjoys a subtropical climate without extremes of either very hot or freezing temperatures. Because of the surrounding ocean the humidity is always high and therefore the climate is extremely favourable for termites, either of temperate or tropical origin. There are a total of four termite species identified in the Azorean archipelago. These are *Cryptotermes brevis* (Walker), *Kalotermes flavicollis* (Fabricius), *Reticulitermes grassei* Clément and *Reticulitermes flavipes* (Kollar) (Borges & Myles 2007; Austin et al. 2012). None of these termites are native to the archipelago.

Cryptotermes brevis

Cryptotermes brevis, also known as the West Indian drywood termite (Fig. 1), is in the family Kalotermitidae. It was first described from Jamaica (Walker 1853) and, with the exception of Asia, has a tropicopolitan distribution (Scheffrahn et al. 2009). Although drywood termites are a widespread pest, they still have certain temperature and moisture requirements (Edwards & Mill 1986). *Cryptotermes brevis* infests structural timbers of buildings as well as other items such as furniture, being mainly reported in the tropical and subtropical areas with some occurrences in warmer temperate regions (Light 1934b; Edwards & Mill 1986; Nunes et al. 2010). It is endemic to Chile and Peru where it has been found to occur in nature, in a rain free climate living in riparian habitats along the western slopes of the Andes Mountains (Scheffrahn et al. 2009).

Cryptotermes brevis is easily identified by the soldiers, which are very characteristic. The soldiers measure about 4 to 5 mm long having a plug-like (phragmotic) head that is nearly black, deeply wrinkled, about 1.2 to 1.4 mm wide. The pronotum of drywood termite soldiers is as wide as, or wider than the head capsule (Fig. 1-D). The alates are usually medium brown and are about 11 mm in length with wings (Fig. 1-C). The alates have two pair of hairless, membranous wings and have three or four darkened and enlarged veins (subcosta and branches of the radial sector) in the leading (costal) margin of each wing. Shed wings are about 9 mm long and the median vein, unlike other species of *Cryptotermes*, does not curve in the outer third to terminate in the costal margin. *Cryptotermes brevis* wings have a prismatic sheen when dry (Fig. 1-B). The alates lack arolia in the tarsi.

The life cycle of *C. brevis* is similar to other termites beginning with a dispersal flight where the alates leave their previous gallery system in order to form new colonies. The dispersal flights of termites occur at different times of the year depending on the species and the location. For example, *C. brevis'* main flight season in South Florida occurs between April and July, with a secondary smaller flight season in November (Minnick 1973). In the Azores, however, the flight season occurs between May and September (Borges et al. 2004) with no secondary flight season recorded. The dispersal flights are the only occasion that this species is found outside of wood (Kofoid 1934). Otherwise, it never leaves the nest to exploit new food sources (Korb & Katrantzis 2004) although they will bridge small gaps between wood members under the cover of galleries made from fecal secretions. A colony of *C. brevis* can survive with as few as four pseudergates and this species can produce more neotenics than other *Cryptotermes* species (Williams et al. 1980).

Cryptotermes brevis is the most destructive drywood termite pest in the world. Because of its ability to withstand wood with low moisture content it is able to attack all kinds of wood in service including structural timbers, beams, studs, flooring, molding, doors, window frames and even wooden articles such as carvings, tools, picture frames, musical instruments, etc. A colony of drywood termites can vary in number from hundreds to a few thousand termites (Nutting 1970) and several colonies can be found inside a single piece of wood. A *C. brevis* colony is estimated to have anywhere from 2 individuals (incipient colony) to 296 individuals with an average of 45 individuals (Myles et al 2007). The early development of a kalotermitid colony is slow and numbers are small in the first year (Nutting 1969). For *C. brevis*, the number of eggs in an incipient colony is very low with an average of 4 eggs laid per pair of female and male dealates in the first month (Ferreira 2008). In the first year there will be an average of 3.4 nymphs and no soldiers (McMahan 1960). These low numbers indicate that many colonies of *C. brevis* can cohabit a single piece of wood. Williams (1977) suggests that a colony of *C. brevis* will gradually move from highly-infested timber into timber that is less than 30% damaged if it can do so, although it maintains activity in more damaged timbers.

Cryptotermes brevis was found infesting structures in Portugal by Mateus and Goes (1953) in the Atlantic Island of Madeira. Later it was reported in Mozambique (Carvalho 1972), which was then a Portuguese colony. For decades this species had not been reported anywhere else on Portuguese territory until it was identified as the cause of structural damage in the Azorean Island of Terceira (Angra do Heroísmo city) in the year 2000 (Borges et al. 2004; Myles 2004) and later in Porto Judeu parish also in Terceira Island (Borges et al. unpub. data). Since then, it has been further reported in the Islands of Faial (Horta city), São Miguel (Ponta Delgada city), Santa Maria (Maia parish, and Vila do Porto village) (Borges 2007), São Jorge (Calheta parish), and Pico Island (Calheta do Mesquim parish and Lajes do Pico village) (Borges et al. unpubl. data) all islands belonging to the Azorean archipelago (Fig. 2). C*ryptotermes brevis* has now emerged as the main urban insect pest at this moment in the Azores. The level of infestation in the city of Angra do Heroísmo on the island of Terceira is very high, with about 43% of the buildings in the historical center infested, and of these, about 50% show high levels of infestation (Borges et al. 2004; Guerreiro et al. 2009). *Cryptotermes brevis* consumes all of the commonly used structural woods in the islands including *Pinus pinaster*, *Cryptomeria japonica* and *Eucalyptus globulus*.

The specific point of origin of the Azorean population of this species is unknown. However this population has been found to be genetically close to the endemic populations in South America (Ferreira 2011). This species has been presumed to have arrived to the archipelago either from the importation of infested wood, or dispersal flights from infested boats in Azorean harbors, or both (Scheffrahn personal observation).

Biological and ecological studies included population censuses of about 120 colonies on Terceira Island (Myles et al 2007). These studies indicated the colonies are numerous in individual items of wood, although the galleries are always separate between colonies. This high density of *C. brevis* colonies indicates that the species has a high capacity for successful re-infestation, that is, the development of new colonies from the original colony infesting a structure. The high re-infestation capacity derived in part from this species ability to utilize relatively small beetle emergence holes as points for re-infestation. Since much of the dry timber in the Azores is affected by small wood boring beetles such as anobiids, this facilitates re-infestation by *C. brevis* which is smaller than most other drywood termites and able to enter such small holes.

Kalotermes flavicollis

The drywood termite *Kalotermes flavicollis* (Fabricius) (Fig. 3) is a termite of the family Kalotermitidae. It was first described in 1793 by Fabricius and the name *flavicollis* comes from the characteristic yellow coloured pronotum present in the alates: *flavi* = yellow + *collis* = neck (Fig. 3-B). The adults reach 8–10 mm of length, the basic colouration of their body is pale yellow or dark brown with two pairs of membranous wings that are slightly smoky (Fig. 3-B). Like other kalotermitids, *Kalotermes* species are considered as 'one-piece' nesters, where individuals nest and feed in the same substrate. This species can be found in the Mediterranean area, namely in Spain, France, Italy, Greece, Slovenia, Near East, and North Africa. It is also found in the mainland Portugal (Nobre & Nunes 2001) and more recently has been identified infesting trees in the Azores (Borges et al. 2004). Variation within the genus *Kalotermes* in the Mediterranean region has been poorly studied and is therefore believed to be comprised of only this single species in Europe, *K. flavicollis* (Clément et al. 2001; Luchetti et al. 2004).

Kalotermes flavicollis usually infests living trees through scars, and progresses into the heartwood infesting partially dead branches on living trees, sometimes eating into the core and even into the basal stem and sometimes into the roots of live trees (Mazzantini 1953). In a census of six colonies Myles et al. (2007) found that *Kalotermes flavicollis* has colony sizes ranging from 201 to 1081 with an average size of 598 individuals.

This species has been reported to attack a wide variety of ornamental and fruit trees such as poplar, elm, cork, pine, olive, chestnut, fig, and pear (Monastero 1947; Prota 1965; López et al. 1996; Ferrero 1973; Kervina 1972). It has also been reported attacking grapevine (Springhetti 1957), being recognized as a serious pest in Spain and mainland Portugal (Pérez 1982; Lebrun 1976; López et al. 2000).

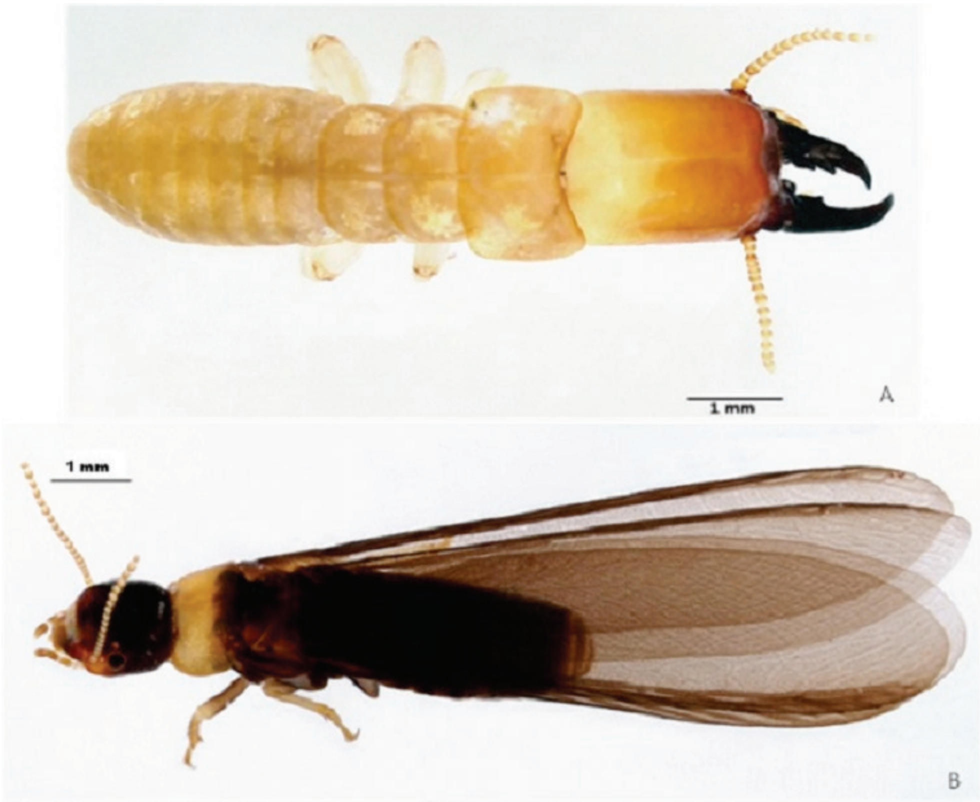

Fig. 3. The species *Kalotermes flavicollis* (Fabr.). A. Soldier caste. B. Alate caste with the characteristic "yellow neck"(photos by E. Mendonça).

Kalotermes flavicollis has been found in living trees in three of the islands in the Azores, Terceira, São Miguel, and Faial (Fig. 4), with few occurrences in wood structures (Myles et al. 2007). On the island of Terceira *K. flavicollis* has been found along the southern and eastern coastline from Cinco Ribeiras to Praia (Fig. 4) but has not been found anywhere on the northern or western coast. It has been found in several host plants including grapevines, olive trees, citrus trees, acacia trees, salt cedar, fire trees, and incense trees. The dispersal flight season in the Azores occurs between September and October, where alates can be observed flying during the afternoon. So far this termite has not become an important pest. Its presence is sporadic and no dead trees or structural damage of importance has been reported. Unlike *C. brevis* this species has a very low capacity to re-infest, or to start new colonies from the initial point of infestation.

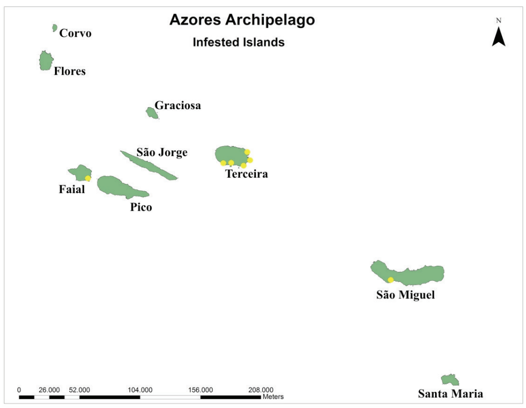

Fig. 4. Map of the distibrution of *K. flavicollis* in the Azores. The species occurs on the islands of Terceira (along the southern and eastern coastline from Cinco Ribeiras parish to Praia da Vitória city), São Miguel (Ponta Delgada city) and Faial (Horta city).

Reticulitermes grassei

The termite *Reticulitermes grassei* Clemént is a subterranean termite of the Rhinotermitidae family. It was identified by Clemént in 1978 and was, until 2001, considered a subspecies of *Reticulitermes lucifugus* (Rossi) but has since been elevated to a species on its own (Clément et al. 2001). This termite is native to mainland Portugal, Spain and South West France where it is found naturally occurring (Clément et al. 2001). The first reference for this species in mainland Portugal comes from the beginning of the 20th century (Seabra 1907), and the records of this species have since been updated (Nunes et al. 2000; Nobre & Nunes 2001, 2002). The alates are dark in colour and their size can reach a length of about 9 mm, while the soldier of *R. grassei*, normally reaches a maximum length of 5 mm (Fig. 5). The wings of the alates are typical of the *Reticulitermes* genus with two hardened and thickened veins that are visible along the entire front end and a reticulated pattern in the membrane (Fig. 6). The dispersal flights occur usually during the day time in early springtime.

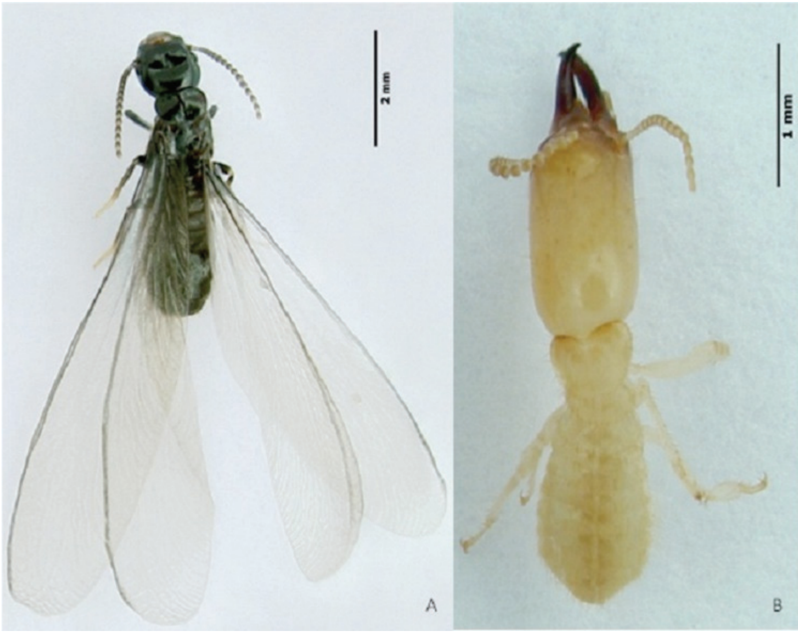

Fig. 5. The species *Reticulitermes grassei* Clemént. A. Alate caste, characteristically dark coloured. B. Soldier caste (photos by E. Mendonça).

The colonies of subterranean termites can reach very high numbers with a colony having up to hundreds of thousands or even millions of individuals. Unlike kalotermitids, the rhinotermitids live outside of their food source, usually building their nest structures underground (hence the name subterranean), and workers will leave the nest to forage for food. Typically subterranean termite infestations can be recognized by the presence of foraging tubes called shelter tubes. These tubes are constructed out of particles of soil and the termite faeces, and serve to protect the foraging workers. Unlike most of the drywood termite infestations, the subterranean termite infestations require a source of moisture (soil, leaky roof, etc). The nests are usually located outside of the infested structure, in large dead wood items such as stumps or logs, and foragers will bring the food (i.e. wood) from the source back to the nest. They do not build a nest in the soil, as many higher termites do. Instead, the nest of *Reticulitermes* species always remains associated with galleries in wood in the ground. Because of their very large populations, and also the capacity to generate numerous nymphoid reproductives, structural infestations can become severely damaging in a short period of time.

Reticulitermes grassei was first recorded in the Azores on the island of Faial, where it was found infesting a coastal neighbourhood in southern part of the city of Horta (Myles et al. 2007) (Fig. 7). Since then it has been identified in other structures in the city, causing significant damage. Even though *R. grassei* is found in nature in the Iberian Peninsula, it is a serious structural pest. This termite is widespread in mainland Portugal (Nunes et al. 2000), and very likely the infestation in the Azores of *R. grassei* originated from the mainland through import of soil in containerized plants, or infested boats. However, the infestation seems to be confined to that one area of the city, and has not yet been reported anywhere else.

Reticulitermes flavipes

Reticulitermes flavipes (Kollar) also known as the American Eastern subterranean termite was first identified by Kollar (1837) and has been synonymized with *Reticulitermes santonensis* Feytaud (Austin et al. 2005). This species is native to the United States and is the most widely distributed, being found in the entire eastern region of North America as far north as Ontario, Canada, and south to Key Largo, Florida and from Colourado to north-eastern Mexico (Austin et al. 2005). The alates are dark brown, and are approximately 10 mm long including wings. The alate wings are typical of *Reticulitermes* species as noted with *R. grassei* (Fig. 6). The soldiers in subterranean termites have a pronotum that is narrower than the head, unlike the kalotermitids where they are equally as wide. *Reticulitermes* soldiers have a rectangular-shaped head with long dark mandibles with thick bases (Fig. 6).

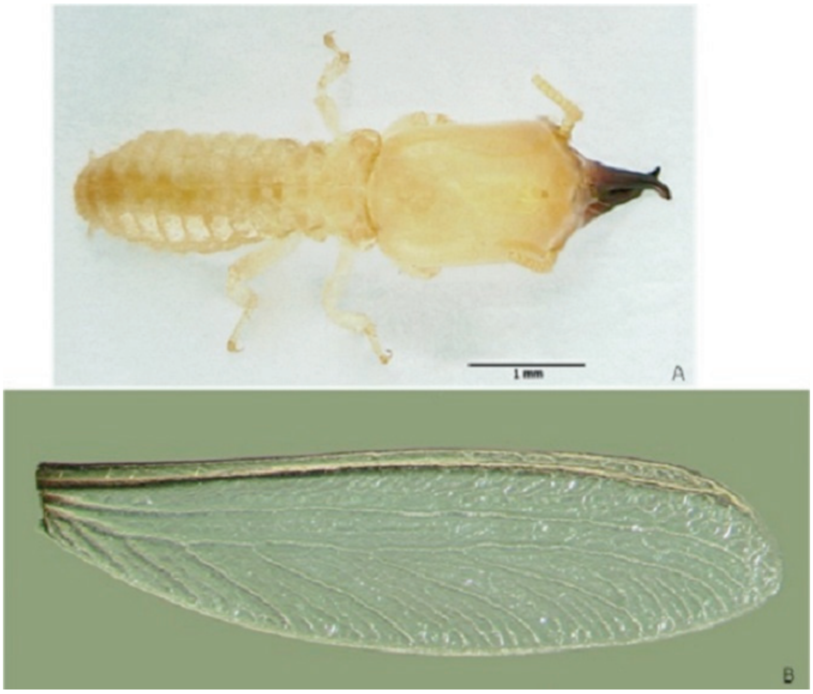

Fig. 6. The species *Reticulitermes flavipes* Kollar. A. Soldier caste (photo by E. Mendonça). B. Wing showing the characteristic reticulated pattern of the genus and the two thickened veins along the front end (photo by R. Scheffrahn).

In Europe, *R. flavipes* was first reported in Vienna, Austria (Kollar 1837). In the 1920's it was found in France (Feytaud 1924), although at the time it was believed to be a different species (*R.*

santonensis). Later on, in the 1930's it was recorded in Hamburg, Germany (Weidner 1937). More recently *R. flavipes* has been identified infesting structures in Lombardy, Italy (Ghesini et al. 2011). These infestations found in Europe are believed to have originated from the populations in the United States, through human aided dispersal.

Reticulitermes flavipes was reported in the Azores in an United States Military air base on Terceira island about 25 years ago (Myles et al. 2007; Austin et al. 2012). For years there were no more records, until more recently when it was recorded in the area surrounding this air base in Praia da Vitória city (Fig. 7) (Borges et al. unpubl. data).

Reticulitermes flavipes is considered to be one of the most economically important pests of structures in the United States (McKern et al. 2006), and there has been much traffic of goods from the U.S. into the Military base. Because of the location of the infestation it is believed that these termites may have been introduced through military shipment at the Lajes Air base. So far the infestation has been registered only in one neighborhood near Lajes Air base (Fig. 7).

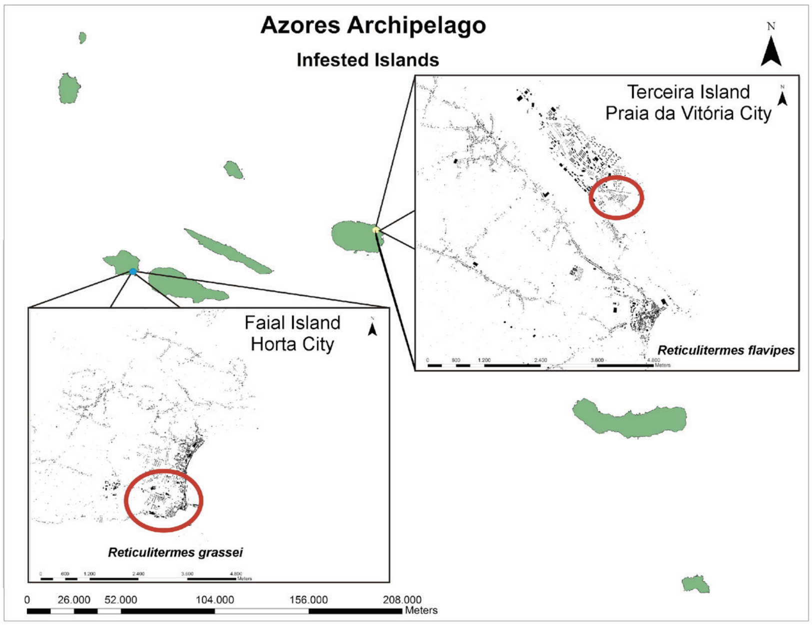

Fig. 7. Map of the distribution of *R. grassei* (blue dot) and *R. flavipes* (yellow dot) in the Azores. *Reticulitermes grassei* is reported only in a small area of Horta city (shown in the detail of Faial Island), and *R. flavipes* is reported in a small area of Praia da Vitória city (shown in the detail of Terceira Island)

Future Directions

The termites currently present in the Azores have different levels of infestation. So far the one with the highest level of infestation and damage is *C. brevis*. This species is widespread throughout the islands with occurrence in almost all of the islands. The trading of goods between the islands, and between the islands and other parts of the world makes it easy for new infestations to occur even if the original infestation were to be eradicated, and right now there is no possibility to eradicate this species from the archipelago.

Treatment against termites varies depending on the type of termite found. Subterranean termites and drywood termites have their nests in different types of habitat, have different ways for foraging, and are more or less cryptic. Consequently, the treatment options have to be properly directed at the biology and ecology of each species. For remedial control of termites an example of whole structure treatment that can be used in the Azores is the use of heat. Heating of structures has been shown to produce 96% mortality (Lewis & Haverty 1996), however the heat treatment does not prevent new infestations from occurring, and a wood preservative should be applied for preventing new colony formation, which adds more costs. Localized treatments used against termites can be of two kinds, either chemical or non-chemical. In the chemical treatments, there are several insecticides that are currently used in Europe including cypermethrin, permethrin, and other borates. Non-chemical localized treatments against drywood termites have been studied and include electrocution, microwaves, heat, cold, and entomopathogenic fungi with variable efficacy found (Lewis & Haverty 1996, 2001; Nars & Moein 1997; Rust et al. 1997; Myles 2002; Chouvenc et al. 2008, 2011). The use of baits against subterranean termites has become an alternative to treating the soil with chemicals because there is less usage of chemicals and the efficacy of colony functional elimination is greater than the previously used methods (Su & Scheffrahn 1998). Chitin synthesis inhibitors like hexaflumuron and noviflumeron are used in the baits against termites in the United States. Preventative treatments against subterranean termites consist mainly of creating barriers against these. The barriers can be chemical by applying the chemical to the soil underneath and surrounding the structure. They can also be physical barriers to prevent subterranean termite entry into structures. Examples of physical barriers include, metal termite shields, sand barriers or stainless steel mesh barriers. These have been commercially available in places like Australia (Termi-Mesh, TMA Corporation Pty Ltd), (Granitgard – Granitgard Pty. Ltd., Victoria), and Hawaii (Basaltic Termite Barrier – Ameron Hawaii, Honolulu) as a termite prevention method. Preventative treatments may also be used to reduce or prevent alates from flying into a structure and forming a new colony. Physical prevention can be of various types, from traps for alates to resistant materials used in materials used in construction, mosquito screening, caulking, and other exclusion treatments. Light traps can be optimized to capture alates before they enter wood, preventing colonization. Studies have shown that subterranean termites like *C. formosanus* and drywood like *C. brevis* are more attracted to lights in the blue colour spectrum (Yamano 1987, Chang et al. 2001, Ferreira et al. 2012). Insecticides like disodium octoborate tetrahydrate, imidacloprid, and fipronil can be used as a surface treatment to prevent colony foundation (Scheffrahn et al. 1998, 2001).

In the case of the Azores it is then important to focus on three priorities: 1) methods to minimize the rate of spread (light trapping and quarantines against movement of potentially infested wooden items), 2) preventative methods to prevent population build up in structures (preventative sprays and drill and injection treatments), 3) and control options that are cost effective for individual homeowners who are affected (e.g., heat treaments). For this to occur, stronger enforcement of existing laws, as well as the creation of new regulations should be looked into. Steps have been taken in legislature towards fighting termite spread. In 2006 a decree was established in order to dispose of termite infested wood properly to prevent this from being a source of infestation. Later on, in 2010 new legislation came out in the Azores that states that properties cannot be sold without being inspected for presence of termites by certified inspectors. However drywood termites are very easily transported and infested wood is hard to identify, which means that a tight control of any wood products entering the archipelago would be necessary. The dockage of boats has been associated with termite infestations for other termite species (*Coptotermes gestroi* and *Coptotermes formosanus*) (Hochmair & Scheffrahn 2010). Scheffrahn & Crowe (2011) saw that the interception of termite infestations in vessels in Australia, where *C brevis* is present, seems to be more effective due to the strict rules applied in entry ports. Vessels with timber in their cargo or construction must be inspected by the Australian Quarantine and Inspection Service (AQIS). The inspection can be conducted by an AQIS quarantine officer or AQIS entomologist and approved termite detection methods. If termites are found upon inspection, the vessel must be fumigated with methyl bromide (AQIS method T9047) or sulfuryl fluoride (AQIS method T9090) at the owner's expense (Scheffrahn & Crowe 2011). This seems to have prevented further introductions of termite pests throughout the years and might be a good example for any new legislation created. As for treatment against *C. brevis*, one solution that seems to be viable in the archipelago is the use of compartmental heat treatments. Most of the infested areas are in attics that can be compartmentalized and treated. Along with the treatment the use of preventative chemicals after treatment to avoid re-infestation would be necessary. Right now this option is still not available in the Azores, and the only treatments against this termite have been by drill and injection, and topical applications of insecticides. In order to reach more manageable levels, whole structure treatments will be necessary in the more affected areas of the cities where this species is present. Investing in preventative treatments and materials in areas that are not affected yet is the best choice to prevent spread of this pest within the infested cities in the archipelago.

The remaining termites present in the Azorean islands are not as widespread as *C. brevis,* but can eventually become a serious concern. *Kalotermes flavicollis* seems to be mainly confined to ornamental trees and has not so far become a problem for agriculture. Even where present, the damage caused does not seem to kill the trees, with no records of loss of vitality. The prevention of colonization in trees by *K. flavicollis* usually involves the capture of alates, or the covering of the pruning scars, because these are the best routes of entry into the plant, the removal of woody debris from the plot, and in the case of vines using non woody materials to support the vines. Chemical preventative control against termites in vineyards and orchards involves the use of regular approved insecticides against common pests and injections of imidacloprid into the galleries. As far as becoming an urban pest, this termite usually requires high humidity and has been found in structures only in few cases in Horta (Faial) and Porto Martins (Terceira), where it has been reported in urban structures with water infiltration issues. Generally, correction of moisture problems and minor carpentry repairs of affected timber are adequate measures to deal with the infestations of *K. flavicollis*. Even though this species does not appear to have the potential to become a serious problem, careful observations have to be maintained and public awareness is key to prevent *K. flavicollis* from becoming a pest in agriculture in the Azores.

The subterranean termites *R. grassei* and *R. flavipes* are so far confined to a very small area of Horta city and Praia da Vitória city respectively. However these termites are serious pests in other areas of the world, especially where wood-frame housing is the norm. Legislation in some countries already takes subterranean termite prevention into account when building new structures. In parts of the United States, such as Florida, it is mandatory to provide termite protection with registered termiticides or other approved methods of termite protection labeled for use as a preventative treatment to new construction (Section 1816 of Florida building code). In Europe, legislation in France, for example, has also stated that all new constructions have to be protected against termites by the implementation of a physical barrier, a physico-chemical barrier or a specific device to prevent subterranean termites. This could be a path to follow when constructing new structures in areas where the presence of these termites is known. There was an initially reported case of eradication of *R. grassei* in the UK (Verkerk & Bravery 2004). However, the infestation reoccurred with termite activity found in bait stations in 2010 (Bravery & Verkerk 2010 in Evans et al. 2013). The use of baiting and non-repellent soil insecticides can be an option for the *Reticulitermes* infestations in the Azores. Because these infestations are in their early stages it is still possible at this point to assume an eradication plan against these populations. Elimination of all visible surface wood in a perimeter area around these infested zones would also be an important way to minimize the potential for these infestations to spread.

The Azorean archipelago due to its location and weather conditions is an "easy target" for invasive species. The fact that there are four different species of termites in the Azores, all of them considered pests is a matter of concern. Two of the species found, *R. grassei* and *R. flavipes* are not well established yet. The other two species, *C. brevis* and *K. flavicollis* are established and have demonstrated the capacity to spread throughout the islands. This shows that there is a possibility for the subterranean termites to spread out to other localities and even other islands in the archipelago. Also there are other species, like *Coptotermes formosanus, Coptotermes. gestroi, Cryptotermes dudleyi, Cryptotermes havilandi, Nasutitermes corniger* that can be introduced to the islands if no further action towards regulation of wood imports and preventative building practices is taken. At this point in time it is still possible to eradicate two of the existing species, and maintain the other two under manageable levels. It is, therefore, important to avoid any new introductions of termites, in order to preserve the structures in the Azores (some of which are UNESCO World Heritage) and to prevent much greater control and building maintenance costs in the future.

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