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POTENTIAL INVASIVE TERMITES IN INDIA AND IMPORTANCE OF INTEGRATIVE TAXONOMY

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ABSTRACT

Termites are ubiquitously abundant in the tropics and subtropics. Globally 28 species are considered invasive among the 2937 species in nine families known. Among the invasive species, most are considered nuisance organisms to humans in urban areas, and a few have invaded natural forests. Generally, the invasive termites share three qualities: (i) they eat wood, (ii) make nests in wood, and (iii) they quickly generate secondary reproductives. These qualities are the most common in the Kalotermitidae and Rhinotermitidae (Blattodea: Isoptera), which enhance their opportunities for producing viable and reproductively capable individuals. Species of the Termitidae cannot produce secondary reproductives, and this is attributed as a reason for their lack of invasiveness. The 28 species recognized as strongly invasive have the potential to widen their geographical range from their present distribution locations. According to available data, 10 out of the 17 recognized invasive species have expanded their area of occurrence since 1969. Among the 28, three are known in India, although their exact distribution data in the Indian subcontinent, the damage they inflict, and consequent economic loss are yet to be worked out in detail. Climate change, intensifying urbanization, and globalization, acting either individually or in combination, are likely to exacerbate ecological and economic effects. Strict quarantine measures and appropriate treatment of every wood material imported are imperative. Efforts have been made to list the potential invasive termites in India based on imported-wood material. Approximately 70 species reported in the GenBank database for about 300 species known from India, emphasizing a dire need for accurate morphological and molecular determinations. Gene sequences of some of the Indian termite species submitted are incorrectly identified, as their presence and distribution in India is doubtful. Therefore, in this article, I discuss the importance of the combined and efficient use of morphological and molecular taxonomy in determining termites in India.

Key words: Identification, Kalotermitidae, Rhinotermitidae, traded commodity, woodeating, nest constructing, places of origin, invasives, number, Indian perspectives, NCBI accessions, threats to biodiversity

Exotic species invasion is one among the many of the world's serious environmental threats (Buczkowski and Bertelsmeier, 2017). Although growing human population and their injudicious actions are the critical reasons for climate change and urbanization, invasions by exotic species can be traced back to mobility of humans and movement of products to meet human needs. Huge numbers of exotic, pestiferous insects are moving from continent to continent as a result of globalization and trade, resulting in substantial economic loss (Sharma et al., 2018). In the last decade, various invasive insects are known from India and have been found to be establishing in 'new' habitats (Kalleshwaraswamy et al., 2015; Sharanabasappa et al., 2018; Sundararaj et al., 2020) and termites are no exception (Evans et al., 2013). Many species of termites are serious nuisance organisms, inflicting damage to the wood used in both human-made structures and agricultural and forest environments (Kalleshwaraswamy et al., 2018). They occur more abundantly in the tropical and subtropical regions of the world. We now know that the Isoptera have evolved from the subsocial Cryptocercidae (Blattodea: Blattoidea) (Inward et al., 2007; Evangelista, 2019). Hence, the termites are now classified under Isoptera, Epifamily Termitoidae within Blattodea. However, the family status of all extant termites is retained to avoid confusion arising out of this modified classification. About 3000 species of Isoptera were described from nine families in 2013 (Krishna et al., 2013) and from then onwards, a few new species have been added from different parts of the world. Among them, 1160 species are from the Oriental region. Two hundred and ninety-five species placed under 52 genera in six families are known from India. Among the 295, 188 are endemic to India (Rajamohana et al., 2019). Out of *c*. 3000 species known around the globe, 366 affect human dwellings in different parts of the world. Yet, we need to recognize that these taxa are one among the many critical invertebrate decomposers in arid and semi-arid environments, and they contribute to improving the physical and chemical properties of soil by their activities and especially by the construction of structures such as mounds, galleries, sheetings with varying physical and chemical qualities (Jouquet et al., 2018). On an average, the termites increase water infiltration above the natural rate by a factor of 1 to 4, depending on their activity, soil type, and rainfall intensity (Kaiser et al., 2017).

Diverged from cockroaches (Cryptocercidae : Blattodea) *c*. 150 mya (late Jurassic), the termites developed advanced social nature and caste system, which their ancestors lacked. They live in colonies with a large number of workers and soldiers that are usually sterile. Colonies have fertile males, the 'kings', and one or more fertile females, the 'queens'. Pheromones maintain the caste system, preventing all but a few termites from becoming reproductives and the rest will remain sterile, assuring a division of labour (Simpson et al., 2011). Primary reproductives and secondary reproductives are the two types of reproductives found in the Isoptera. Nymphs give raise to adults, which mate and reproduce the primary reproductive, hemimetabolically. In some species, such as *Coptotermes,* when primary reproductives are either lost or immatures are separated from their parent colony, nymphs or workers (= pseudergates) can give rise to either a king or a queen, referred to as secondary reproductives (Myles, 1999).

With the increased trade of wood, more termites are becoming invasive in different countries; India is no exception. Therefore, anticipating this potential megaproblem strict policy measures are vitally necessary. In this article, I have made an effort to enumerate the potentially invasive termite species in India, based on wood import from different countries, especially in the recent past. Monitoring and treatment of wood material imported are critical to minimize entry of exotic Isoptera into India. Examples of success stories restricting the entry of nuisance species of Isoptera have also been highlighted in this article. The importance of both morphological and molecular taxonomy of Indian Isoptera for correct determination of taxa enabling better management is also indicated.

A. Characteristics of invasive termites

Although various termite species are considered nuisance organisms of different crops (Rana et al., 2021), forest (Junqueira and Florencio, 2018) and urban ecosystems (Olaniyan et al., 2015), all of these are not invasive. Most of the invasive Isoptera have three qualities in common: (i) they eat wood, (ii) construct nests in the wood, and (iii) quickly generate secondary reproductives (Evans et al., 2013; Donovan et al., 2001). Many a time, in combination of the above, the termites have an increased likelihood of producing reproductively viable offspring. These qualities are especially common in the Kalotermitidae and Rhinotermitidae, which collectively constitute 23 species in the invasive termites list, in genera such as *Cryptotermes*, *Heterotermes*, and *Coptotermes* (19 species) (Table 1). The Termitidae comprising *c*. 70% of the Isoptera, includes only one invasive species, *Nasutitermes corniger*. The innate characters that make this species invasive need to be studied.

(i) Wood eating

In general, four types of food habits occur among the Isoptera (Donovon et al., 2001; Yamada et al., 2007; Jones and Eggleton, 2000; Kaur et al., 2013; Kaur et al., 2017). Type I and II eat undecomposed plant matter such as wood, grass, and leaf litter. Those of type III and IV eat decomposed plant matter; those of type III eat on the decomposing wood either covered with or embedded within soil (plant matter–soil interface), whereas those of type IV are exclusive soil feeders. Those of types III and IV make up *c*. 50% of all Isoptera. Wood eating is a common characteristic among the known invasives, that means they belong to either Type I or Type II.

(ii) Nest constructing

Nest construction is classified into four categories (Abe, 1987):

Single-piece nesters: Isoptera of this category nest and forage in either one piece of wood or wood pieces bound tightly together and feed within: *e.g.*, species of *Cryptotermes* (Kalotermitidae) and Archotermopsidae

Intermediate-piece nesters: Colonize a single piece of wood, but they move out searching food material and eat pieces of wood, where they construct nests and start new nests once the originally occupied piece of wood is completely eaten: *e.g*., species of *Coptotermes* (Rhinotermitidae).

Separate-piece nesters: build a nest in soil or nest separate from their food and forage away from their nest to find food: *e.g.*, mound-building Macrotermitinae (Termitidae).

Continuously mobile (no permanent nest): Do not settle in a nest permanently and are mobile continuously. Found among the Type III and IV soil-feeders that eat their way through the soil.

A majority of the invasive species are either single-piece nesters (12— Archotermopsidae and Kalotermitidae) or intermediate-piece nesters (Rhinotermitidae) (Table 1). The possible reason is either presence of all the castes within the nest or the ability to produce viable secondary reproductives (explained in the following paragraph).

(iii) Can generate secondary reproductive

If the nymphs or workers develop as reproductives, they are collectively referred as the nymphoids and ergatoids, respectively. Here sexual maturity is achieved without attaining a fully winged adult stage, and hence they are 'secondary reproductives'. There may be a situation when an infested wood log is transported, a small number of nymphs may be carried from their original habitat, there is a chance that secondary reproductives produced from those nymphs in a new habitat, making that species invasive. These few nymphs carried from the infested material could act as propagules. Because of this trait, many termite species are potential invaders in new habitats even though primary reproductives are not transported.

B. Number of invasive termite species

Termites were not thought to be invasive previously, despite accounts of their spread away from their native ranges. A first worldwide enumeration by Gay published in 1969 recorded 17 species of termites as invasive with the evidence of their establishment in new habitats. All the 17 determined species appear to be associated with either buildings or cultivated crops. Presently 28 species of termites are considered invasive worldwide, (Evans et al., 2013). This implies that the numbers of invasive species have increased from 17 in 1969 to 28 today and are expanding their geographic locations. In the past 50 years, 14 species have been added to the list; 10 of them have extensive distributions and four have no reported changes in distribution, and three species are no more considered invasive (Evans et al., 2013). It appears among the invasive termite species, most are pestiferous in urban areas, although six species have been found to invade natural forests (Evans et al., 2013; Chouvenc et al., 2016).

C. Transportation of live stages of termites

Most wood feeding termites (Kalotemitidae, Rhinotermitidae and Archotermopsidae) display the above-said three qualities and they can be transported from their original habitats to new habitats through the movement of wood. Many countries export wood and wooden material to different parts of the world. If the transported wood includes any developmental stage of the Isoptera, then they serve as propogules and become secondary reproductives (Evans, 2011; Myles, 1999). A recent report with dead stages of *C. gestroi* in the seaport of Goa (15.50° N, 73.83° E) (Venkateshan et al, 2021) from an imported wood consignment sends an alarm signal and seeks a close monitoring of the invasive Isoptera. Species-rich Termitidae cannot produce secondary reproductive, hence they lack the invasive capability.

D. Places of origin and continents invaded

Initial reports of termite invasion were mainly restricted to movement of Isoptera from continents to nearby islands (Gay, 1969). This is attributed to free trade of wood products. However, the reverse could be true, since species such as *Cryptotermes brevis* and *C. formosanus*, have reached the coast of Queensland, Australia, and Hawaii (USA) in the North Pacific Ocean and have invaded inland as well (Constantino, 2002; Austin et al., 2006; Jenkins et al., 2001). Among the 28 invasive species known to date a perusal of subcontinents or land mass from which the invasive species originated, Indo-Malayan region includes a maximum of seven species, indicating many endemic species have moved from this region to different parts of the world (Table 1). This is followed by South America (six), Australia (five), Africa (three), North America (two), the Caribbean Islands (one), East Asia (one), and Europe (one). *Heterotermes perfidus* and *Coptotermes truncatus* are of unknown origin.

Similarly, a perusal of invaded subcontinents indicates that the islands of the Pacific Ocean are the most invaded that include 13 species, followed by the Caribbean islands (nine), North America (eight), Indian Ocean (six), South America (five), Australia (four), Atlantic Ocean islands (four), East Asia (three), Africa (three), South and Southeast Asia (two), and Europe (one) (Evans et al., 2013). Coastal regions are more prone to invasion by the Isoptera and inflict damage to built-structures consisting of wood and crop ecosystems (Ferreira et al., 2013; Szalanski., 2004). The probable reason for this pattern is that the wood is mostly imported through sea-routes and the invasive Termitidae first establish themselves in coastal areas, and then propagate inwards.

Table 1. Invasive Isoptera, their country or bioregion of origin, and the country or continent invaded

Name of the species	Family	Native country or bioregion	Country or continent invaded and (probable year of invasion)	References
Mastotermes darwiniensis	Mastotermitidae	Northern Australia	Papua New Guinea (before 1959)	Gray, 1968; Thistleton et al., 2007
Zootermopsis angusticollis	Archotermopsidae	Western North America	Hawaii (1999)	Haverty et al., 2000; Grace et al., 2002
Zootermopsis nevadensis	Archotermopsidae	Western North America	Kawanishi, Japan (2000)	Kiritani and Morimoto, 2004
Porotermes adamsoni	Stolotermitidae	Southeast Australia	New Zealand 1941	Bain and Jenkins, 1983; Phillip et al., 2008
Incisitermes immigrans	Kalotermitidae	Pacific coast of Panama to Peru	Pacific Islands, Polynesia, Hawaii, Japan (1995)	Gay, 1969; Constantino, 1998; Grace et al., 2002; Kiritani and Morimoto, 2004
Incisitermes minor	Kalotermitidae	Southwestern United States and northern Mexico	Japan (1975), Eastern United States (1995); Toronto Canada (1989), Ninghai, Zhejiang Province, China (1937), Hawaii (1999)	Grace et al., 1991; Scheffrahn et al., 2001; Xie et al., 2001; Grace et al., 2002
Kalotermes banksiae	Kalotermitidae	Southeast coast of Australia	New Zealand (1942)	Bain and Jenkins, 1983
Glyptotermes breviconis	Kalotermitidae	Southeast coast of Australia	New Zealand (Pre 1983), Fiji (pre 1942)	Gay, 1969; Bain and Jenkins, 1983; Evenhuis, 2007
Cryptotermes brevis	Kalotermitidae	Coastal deserts of Peru and Chile	Egypt, Queensland, Australia (~ 1941), Azores (2002), Canary Island, Lisbon, Portugal (87)	Peters, 1990; Borges et al, 2007; Scheffrahn et al., 2009; Nunes et al., 2010; Ferreira et al., 2013
Cryptotermes cynocephalus	Kalotermitidae	Philippines	Throughout Southeast Asia, Australia (before 1942), Hawaii (2000), Sri Lanka	Gay and Watson, 1982; Scheffrahn et al., 2000; Hemachandra et al., 2012
Cryptotermes domesticus	Kalotermitidae	Southeast Asia	China, Australia (before 1942), Panama in Central America	Gay and Watson, 1982; Evans, 2010
Cryptotermes dudleyi	Kalotermitidae	Southeast Asia	India (Orissa in Lower Bengal) and Bangladesh (before 1950), East Africa, northern Australia (before 1942), Caribbean islands (Jamaica and Trinidad), South America (Panama, Costa Rica, Colombia and Brazil)	Williams, 1976; Gay and Watson, 1982; Constantino, 1998; Scheffrahn and Krecek, 1999; Constantino, 2002; Schabel 2006
Cryptotermes havilandi	Kalotermitidae	Tropical West Africa	Caribbean Islands, Brazil, East Africa, Tanzania, Indian Ocean (Madagascar), India and Bangladesh	Maiti, 1983; Bose, 1984; Constantino, 1998; Scheffrahn and Krecek, 1999; Schabel 2006; Scheffrahn et al., 2009
Heterotermes convexinotatus	Rhinotermitidae	South America, from Mexico to Argentina	Greater (Hispaniola and Puerto Rico) and Lesser Antilles (Antigua, Barbados etc) and in Gal´apagos	Peck, 2001; Szalanski, 2004
*Heterotermes perfidus**	Rhinotermitidae	Unknown origin	south Atlantic Ocean	-
Heterotermes philippinensis	Rhinotermitidae	Philippines	Madagascar and Mauritius	Cachan, 1949
Heterotermes tenuis	Rhinotermitidae	Central America	Lesser Antilles; Trinidad and Tobago	Szalanski, 2004

(contd.)

Table 1 contd...

Heterotermes sp.	Rhinotermitidae	Probably Caribbean Island	Miami, Florida	Szalanski, 2004
Reticulitermes flavipes	Rhinotermitidae	Eastern United States	Canada, Bahamas (1998), Europe (Vienna- 1837), Germany (before 1937),and Southwestern France (before 1840), South America (Uruguay -1960), Chile (1986)	Grace et al., 1991; Scheffrahn et al., 1999; Dronnet et al., 2005; Austin et al., 2005; Su et al., 2006
Reticulitermes grassei	Rhinotermitidae	Southwestern Europe (France and Spain)	Britain (Saunton, 1994), Faial Island of the Azores (2000)	Jenkins et al., 2001; DeHeer et al., 2005
Coptotermes acinaciformis	Rhinotermitidae	Australia	Auckland and New Plymouth, New Zealand (1930), Suva, Fiji (1939)	Phillip et al., 2008;
Coptotermes curvignathus	Rhinotermitidae	Southeast Asia	Southern China	Xie et al., 2001
*Coptotermes formosanus***	Rhinotermitidae	Southern China and Taiwan	Continental United States (~ 1950s), Japan (1700), Hawaii (1907), South Africa (1974)	King and Spink, 1969; Vargo et al., 2003; Sun et al., 2007
Coptotermes frenchi	Rhinotermitidae	Southern Australia	New Zealand	Miller, 1941
Coptotermes gestroi	Rhinotermitidae	Southeast Asia	Mauritius (1936), R´eunion Island (1957), Taiwan (2001), Hawaii (1963), Polynesia 1999) and Micronesia and Fiji (before 2009). Mexico (2000),Florida (1996), Greater Antilles and lesser Antilles (1937), India	Roonwal and Chhotani, 1965; Scheffrahn et al.,1994; Kirton and Brown, 2003; Tsai and Chen., 2003 ; Vargo et al., 2003; Scheffrahn and Su., 2005; Li et al., 2009
Coptotermes sjostedti	Rhinotermitidae	Tropical West Africa	Lesser Antilles (Guadeloupe Island, 1999)	Scheffrahn et al., 2005
*Coptotermes truncates**	Rhinotermitidae	Unknown origin	Madagascar, Republic of Seychelles (1897)	-
Nasutitermes corniger	Termitidae	Central to South America and the Caribbean Islands	Abaco Island of the Bahamas, Florida (before 2001), New Guinea	Scheffrahn et al., 2005; Evans, 2010

*Not a valid species; **The establishment and spread of this species in the United States is the best-documented termite invasion

Buczkowski and Bertelsmeier (2017) employed two alternative representative concentration pathways (RCPs) to predict climate scenarios: RCP 4.5 and RCP 8.5, and two projection years (2050 and 2070 AD) to offer the first worldwide risk assessment for 13 of the world's most invasive termites. Representative concentration pathways (RCPs) are widely used to describe different climate future depending on the volume of greenhouse gases (GHG) emitted in the years to come and thereby predict population dynamics. Buczkowski and Bertelsmeier's findings reveal that, regardless of the climate or year, most of the species will have a substantial rise in their global spread by 2050 AD. The most appropriate places for invasion are the tropics and subtropics. All the continents have large land spaces and natural conditions suitable for more than four species to coexist. Climate change, growing urbanization, and accelerating economic globalization, working singly or in concert, are anticipated to exacerbate the enormous economic and ecological damage caused by invasive termites.

E. Invasive termites: an Indian perspective

India, being one of the largest importers of wood and wood-related material, is vulnerable to Isoptera invasives. Its tropical and subtropical climates also support rapid multiplication of individuals after they arrive. Earlier *Cryptotermes dudleyi* (Kalotermitidae), *C. havilandi* (Kalotermitidae), and *C. gestroi* (Rhinotermitidae) were the invasives known in India. Among these, the taxonomic authenticity of *C. dudleyi* is confirmed presently. The incidence of

C. havilandi is questionable, in spite of its reported spread from India to Bangladesh (Maiti, 1983, Bose 1984). As per Krishna et al. (2013), a world authority on the Isoptera, it is distributed in West Africa (from Sierra Leone to Nigeria), Brazil, Trinidad, the Guianas, Barbados and other west-Indian Islands. Similarly, *C. gestroi*'s original locality is Myanmar (Wasmann, 1896) and its report in Assam (Roonwal and Chhotani, 1965) and in north-eastern Puducherry (Harit et al., 2014) needs validation by further collection and molecular determination. Not many serious efforts have been made to determine the taxonomic identity, distribution, and damage of these species in the Indian landscape. There is no NCBI sequence for this species submitted for specimens collected from India, which may offer a valid confirmation of its presence in India. Originally described from Myanmar, *C. gestroi* is considered to occur in north-eastern India and Thailand. This species inflicts serious economic losses by feeding on wood in built structures in other Asian countries, such as Malaysia, Taiwan, Indonesia and in Brazil, the Caribbean islands, and in the peninsular Florida, USA. *Coptotermes gestroi* is the predominant termite species attacking buildings in urban area of Taiwan (Sornnuwat, 1996). Up to 27% of the trees in the city of São Paulo, Brazil, found infesting contributed by four subterranean species of termites but *C. gestroi* (Wasmann) being the dominant species (Zorzenon and Campos, 2014). However, such a serious damage has not been reported from India and hence intensive surveys and data collection on damage by the Isoptera may shed light on its presence and its impact on the economy.

Venkateshan et al. (2021) offer substantial evidences of both morphological and molecular characters of *C. gestroi* collected from the wooden packing material of a consignment received in Goa coming from Harrisonburg, Virginia, USA. In another report made in December 2018, a few Isoptera were received for identification from Visakapatnam Plant Quarantine Station collected from the timber of *Maclora tinctoria* (Moraceae) imported from Guyana (South America). In July and September 2019, I received different specimens of Isoptera for determination intercepted from the wood of a species of *Gmelina* (Verbenaceae) in Tuticorin port (Tamil Nadu) imported from Columbia, *M. tinctoria* and a species of *Erythrophleum* (Fabaceae) wood logs from Suriname. Using morphological and molecular characters, the intercepted specimens were identified as *C. testaceus* and C. *sjöstedti*. *Coptotermes testaceus*'s 16S rRNA gene sequences were deposited with NCBI GenBank with accession numbers MK559590, MK559591, MK559592, and MK559593. Whereas *C. sjöestedti* 16S rRNA gene got NCBI GenBank accession number MN540914 (Nagaraju et al., 2020). Such clarity is needed in taxonomy for identifying and reporting of any termites intercepted in India.

F. Potential invasive termites in India

The spatial spread of Termitidae is increasing due to trade, urbanization, and climate change (Buczkowski and Bertelsmeier, 2017). Extrapolating this scenario, India could be invaded by another 8-10 species by 2050 AD as predicted in the RCP 4.5 scenario, indicating a greater risk and potential damage to urban and agricultural ecosystems. India imports timber from South America, Africa, southeast Asia and from the Caribbean Island nations as evident in the data of non-compliance report of pest interceptions (Directorate of Plant Protection, Quarantine & Storage website, updated monthly http://plantquarantineindia.nic.in/PQISPub/html/ncrep.htm (accessed on 10 December 2021). There is a need for a thorough scrutiny of every wooden log imported into India. The countries mentioned have a high diversity of invasive Isoptera, which have the potential to enter and cause serious ecological and economic damage in India (Table 2). A list of potential invasive species from where wooden logs were imported into India in 2019 is presented in Table 2. This list is not comprehensive but will serve as a base for an early detection of species and to look for the possible entry of potentially damaging species from those countries.

G. Scope of integrative taxonomy

Because of their wide distribution and intraspecific character variations, taxonomic validity of many species of the Isoptera remains unclear. For example, *Coptotermes*, currently includes 69 named species, and among them, only 21 are considered valid (Chouvenc et al., 2016). According to Chouvenc et al. (2016), most of the described Chinese species of *Coptotermes* are invalid and need revision. Species identification in the Termitoidae is principally based on the measurement of different body parts of soldiers and hence intraspecific variation is highly possible. Hence adapting molecular taxonomy using more than one mitochondrial gene, such as mtCo1, 12S rRNA, and 16S rRNA and nuclear genes such as 28S rRNA, 18S rRNA may provide better clarity on valid species. There is a dire need to barcode all the morphologically identified Isoptera. Currently, barcode sequences are available only for approximately 70 Indian taxa, out of more than 300 species known. In this article, efforts have been to list the available NCBI

Table 2. Potential invasive Isoptera into India*

Country	Native or invasive species distributed at present
Brazil	*Nasutitermes corniger, Incisitermes immigrans, Cryptotermes havilandi, Cryptotermes brevis*
Cameroon	*Coptotermes sjostedti, Cryptotermes havilandi* , *Cryptotermes brevis*
Central African Republic	*Coptotermes sjostedti*
Colombia	*Heterotermes convexinotatus, Heterotermes tenuis*
Congo	*Cryptotermes havilandi*
Costa Rica	*Incisitermes immigrans, Nasutitermes corniger*
Ecuador	*Incisitermes immigrans, Nasutitermes corniger*
Equitorial Guinea	*Coptotermes sjostedti, Cryptotermes havilandi*
Ghana	*Coptotermes sjostedti, Cryptotermes havilandi*
Malaysia	*Coptotermes curvignathus, Coptotermes gestroi*
France	*Reticulitermes flavipes*
Guyana	*Nasutitermes corniger, Termes hispaniolae, Cryptotermes brevis*
Mexico	*Incisitermes minor, Heterotermes convexinotatus*
Papua New Guinea	*Mastotermes darwiniensis, Cryptotermes cynocephalus*
Suriname	*Nasutitermes corniger, Coptotermes testaceus*
Trinidad and Tobago	*Cryptotermes brevis, Cryptotermes domesticus, Cryptotermes dudleyi, Cryptotermes havilandi, Coptotermes testaceus, Heterotermes tenuis, Heterotermes convexinotatus, Nasutitermes corniger, Termes hispaniolae*
USA	*Cryptotermes brevis, Coptotermes formosanus* and *C. gestroi*
Benin	*Coptotermes sjostedti, Cryptotermes havilandi*
*Ecuador	*Heterotermes* sp.
Gabon	*Coptotermes sjostedti, Cryptotermes havilandi, Cryptotermes brevis*
Honduras	*Incisitermes immigrans, Nasutitermes corniger*
Indonesia	*Coptotermes curvignathus, Coptotermes gestroi*
Kenya	*Cryptotermes dudleyi*
New Zealand	*Cryptotermes brevis, Kalotermes banksiae Coptotermes acinaciformis, Porotermes adamsoni, Glyptotermes brevicornis*
Nigeria	*Coptotermes sjostedti, Cryptotermes havilandi*
Panama	*Incisitermes immigrans, Nasutitermes corniger*
Philippines	*Heterotermes philippinensis, Cryptotermes cynocephalus, Cryptotermes havilandi*
Sri Lanka***	*Cryptotermes cynocephalus, Cryptotermes domesticus, Cryptotermes perforans*, *Coptotermes formosanus*
Sudan**	*Coptotermes sjostedti*
Panama	*Cryptotermes dudleyi, Cryptotermes domesticus*
South Africa	*Coptotermes formosanus, Cryptotermes brevis*
Suriname	*Nasutitermes corniger,*
Togo	*Coptotermes sjostedti, Cryptotermes havilandi, Cryptotermes brevis*
Uruguay	*Reticulitermes flavipes*

*Based on Evans et al. (2013); *Dahlsjö et al., 2020; **Pears et al., 1995; *** Hemachandra et al., 2015

submissions so far made from India. Apparently, the genes targeted were 12s rRNA and 16s rRNA, that are not robust for species delimitation. A few submissions are with Mt COI and Mt COII used universally for molecular identification of insects. Moreover, there is a need of high-throughput mtCOI or mt COII DNA extraction procedure so as to determine valid species of the Isoptera. Vidyashree et al. (2018) successfully sequenced 12 Isoptera species from the Western Ghats and developed a DNA extraction procedure. However, they reported for 12S rRNA and hence there is a need of standardization of preservation technique of collected termite specimens and storage for successful DNA extraction.

The following example may clarify the imperative need for molecular data in resolving taxonomic confusions in the Indian species of *Coptotermes*. A total of seven species are known from India (Rajamohana et al., 2019): *C. beckeri*, *C. ceylonicus*, *C. gauri*, *C. gestroi*, *C. heimi*, *C. kishori*, and *C. premarasmii*. Among these, the presence and distribution of *C. gestroi* and

Table 3. NCBI GenBank database available for Indian Isoptera

Species	Gene	NCBI GenBank accession number	Authors	Remarks
Anacanthotermes viarum	28S ribosomal RNA	JQ957910	Deivendran et al., 2012	
Glyptotermes ceylonicus	12S ribosomal RNA	MZ191059	Joseph and Mathew, 2021	
	mtCOII	MZ191060	Joseph and Mathew, 2021	
Neotermes koshunensis	12S ribosomal RNA	KM657485	Ramya et al., 2014	
Neotermes nilumburensis	16S ribosomal RNA	MZ234128	Kalleshwaraswamy et al., 2021	
Neotermes viraktamathi	16S ribosomal RNA	MW699667	Kalleshwaraswamy et al., 2021	
Coptotermes gestroi	16S ribosomal RNA	MZ540797	Ranjith et al., 2021	
	mtCOI	MW575256	Ashika and Venkatesan, 2021	
Coptotermes heimi	12S ribosomal RNA	KT828711, KT828711 KT828710, KT828709 KU665478	Mahapatro and Singh., 2016	
		KR078331	Mahapatro and Singh, 2015	
		KT820660	Mahapatro and Singh, 2015	
	16S ribosomal RNA	EU553818	Sobti et al., 2008	
		EU553816	Sobti et al., 2008	
		AY558908	Scheffrahn et al., 2004	
		MW680951	Kalleshwaraswamy et al., 2021	
		GQ422885	Salunke et al., 2009	
		GQ422882	Salunke et al., 2009	
		EU553817	Sobti et al., 2008	
	28S ribosomal RNA	JQ957911	Deivendran et al., 2012	
Coptotermes sjoestedti	16S ribosomal RNA	MN540914	Mahadeva swamy et al., 2019	
Coptotermes testaceus	16S ribosomal RNA	MK559593	Mahadeva Swamy et al., 2019	
		MK559592	Mahadeva Swamy et al., 2019	
		MK559591	Mahadeva Swamy et al., 2019	
		MK559590	Mahadeva Swamy et al., 2019	
Coptotermes sp.	mtCOII	MN913607	Tiwari et al., 2020	
Heterotermes balwanthi	16S ribosomal RNA	KU574658	Vidyashree et al., 2016	
Heterotermes indicola	12S ribosomal RNA	KT820657	Mahapatro and Singh., 2016	
		KF170428	Mahapatro and Kumar, 2013	
		KF769546	Poonia and Sharma, 2013	
		KM077441	Poonia and Sharma, 2014	
	16S ribosomal RNA	HF968496	Mahapatro, G.K. and Kumar, 2013	
		MZ183973	Kalleshwaraswamy et al., 2021	
		KF170427	Mahapatro and Kumar, 2013	
		KF769554	Poonia and Sharma, 2013	
Heterotermes malabaricus	16S ribosomal RNA	KU574645	Vidyashree et al., 2016	
		MZ540855	Ranjith et al., 2021	
		MZ558168	Santhrupthi et al., 2021	
		OK285073	Joseph and Mathew, 2021	
	mtCOII	OK284904	Joseph and Mathew, 2021	

(contd...)

Table 3 contd...

Hypotermes makhamensis	*Mt CoI*	KT898536 KT898532 KT898526 KT724954	Patel and Jadhav., 2015	This species is not reported from India (native to Thailand, Vietnam and Cambodia). Hence needs collection details and morphological authentication
	Mt CoI	KY614388	Murthy and Lubna., 2017	
Hypotermes xenotermitis	12S ribosomal RNA	KY825251	Murthy and Lubna, 2017	
	mtCOI	KU687341	Murthy et al., 2016	As per the authors, specimens were collected from south India. This species is not reported from south India (reported only from North India). Needs morphological authenticity and morphometry data.
		KY293420	Murthy and Lubna, 2016	
		KT224387	Murthy et al., 2016	
		KX646190	Murthy et al., 2016	
		KU687340	Murthy et al., 2016	
		KT898553 to KT898566 KT898535 to KT898551 KT898527 to KT898531 KT898507 to KT898525 KT887698 to KT887717 16.KT879833 to KT879849 KT879830, KT724955, KT898533	Patel and Jadhav, 2015	
Macrotermes convulsionarius	16S ribosomal RNA gene	MZ540857	Ranjith et al., 2021	
	28S ribosomal RNA	JQ957912	Deivendran et al., 2012	
Microtermes incertoides	16S ribosomal RNA	MZ571483	Ranjith et al., 2021	
Microtermes mycophagus	12S ribosomal RNA	KU665477	Mahapatro and Singh, 2016	
		KP765715	Mahapatro and Singh, 2015	
		KP748241	Mahapatro and Singh, 2015	
		KF769547	Poonia and Sharma, 2013	
		KT820658	Mahapatro and Singh, 2015	
		KM657479	Ramya et al., 2014	
		JX263668	Singla et al., 2012	
		JX045651	Singla et al., 2012	
		EU553821	Sobti et al., 2008	
		EU553819	Sobti et al., 2008	
	16S ribosomal RNA	KF769555	Poonia and Sharma, 2013	
		EU553822	Sobti et al., 2008	
		EU553820	Sobti et al., 2008	
Microtermes obesi	12S ribosomal RNA	EU551158	Sobti et al., 2008	
		KM657488	Ramya et al., 2015	
		KT820661	Mahapatro and Singh, 2015	
	16S ribosomal RNA	MZ558085	Santhrupthi et al., 2021	
		EU306616	Sobti et al., 2007	
		KU574654	Vidyashree et al., 2016	
	mtCOI	EU242522	Sobti et al., 2007	
	mtND1	EU306614 EU306613 EU306615	Sobti et al., 2007	

(contd...)

Table 3 contd...

Microtermes unicolor	12S ribosomal RNA	JX263667	Singla et al., 2012	
Microtermes sp.	ITS-2	KX495579	Murthy et al., 2016	
	16S ribosomal RNA	KM275840	Poonia and Sharma, 2014	
	12S ribosomal RNA	KF703855	Poonia and Sharma, 2013	
Odontotermes anamallensis	16S ribosomal RNA	MZ562513	Santhrupthi et al., 2021	
Odontotermes assmuthi	16S ribosomal RNA	KF769556	Poonia and Sharma, 2013	
		KU574651	Vidyashree et al., 2016	
		MZ558070	Santhrupthi et al., 2021	
	28S ribosomal RNA	JF792835	Deivendran and Suresh, 2011	
		FJ966379	Suresh et al., 2009	
Odontotermes bellahuniensis	16S ribosomal RNA	KU574650	Vidyashree et al., 2016	
Odontotermes bhagwatii	12S ribosomal RNA	KF769552	Poonia and Sharma, 2013	
		KM523663	Ramya et al., 2014	
		KM523662	Ramya et al., 2014	
		EU551161	Sobti et al., 2008	
	16S ribosomal RNA	KF769559	Poonia and Sharma, 2013	
		EU258632	Kumari et al., 2007	
		EU258631	Kumari et al., 2007	
	mtCOII	EU242525	Sobti et al., 2008	
	mtND1	EU262586	Sobti et al., 2007	
		EU262585	Sobti et al., 2007	
		EU262587	Sobti et al., 2008	
Odontotermes boveni	16S ribosomal RNA	MZ344981	Kalleshwaraswamy et al., 2021	
Odontotermes brunneus	12S ribosomal RNA	KT820659	Mahapatro and Singh., 2016	
	16S ribosomal RNA	KF792982	Poonia and Sharma., 2017	
		MZ540811	Ranjith et al., 2021	
	28S ribosomal RNA	JF792836	Deivendran and Suresh, 2011	
	12S ribosomal RNA	KF769549	Poonia and Sharma, 2013	
		JX263664	Singla et al., 20012	
Odontotermes ceylonicus	12S ribosomal RNA	KY908410	Murthy et al., 2017	
Odontotermes escherichi	12S ribosomal RNA	KY495155	Murthy and Lubna., 2017	Not reported from India (recorded only from Sri Lanka). Needs morphological authenticity
	mtCOI	KT224389	Murthy et al., 2015	
		KY495154	Murthy and Lubna., 2017	
Odontotermes feae	12S ribosomal RNA	KU947966	Mahapatro and Singh, 2016	
		KY908402	Murthy et al., 2017	
		KY676779	Murthy and Lubna, 2017	
		KY908403	Murthy et al., 2018	
		KR296660	Mahapatro et al., 2015	
	16S ribosomal RNA	KU574649	Vidyashree et al., 2016	
Odontotermes gurdaspurensis	12S ribosomal RNA	KM523667	Ramya et al., 2015	
		KM523664		

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Table 3 contd...

Odontotermes horni	12S ribosomal RNA	EU551159	Sobti, et al., 2008	
	16S ribosomal RNA	GQ422892	Salunke et al., 2009	
		GQ422890	Salunke et al., 2009	
		GQ422889	Salunke et al., 2009	
		GQ422888	Salunke et al., 2009	
		GQ422887	Salunke et al., 2009	
		GQ422886	Salunke et al., 2009	
		GQ422879	Salunke et al., 2009	
		EU258629	Kumari et al., 2007	
		KU574646	Vidyashree et al., 2016	
		EU258630	Sobti et al., 2007	
	28S ribosomal RNA	JF792837	Deivendran and Suresh, 2011	
	mtCOII	EU242523	Sobti, et al., 2007	
Odontotermes obesus	12S ribosomal RNA	KY908407	Murthy et al., 2017	
		KP410731	Mahapatro et al., 2015	
		EU551160	Sobti et al., 2008	
	16S ribosomal RNA	KU574648	Vidyashree et al., 2016	
		MZ423304	Kalleshwaraswamy et al., 2021	
		MN511317	Amina etal., 2019	
	mtCOI	KY474376	Murthy and Lubna, 2007	
		MZ823814	Ranjith et al., 2021	
	mtCOII	EU242524	Sobti, et al., 2007	
	mtND1	EU262594	Sobti, et al., 2007	
Odontotermes longignathus	*Mt CoI*	KY930907; KY930908; KY775488	Murthy and Lubna., 2019	This species is not reported from India (native to south east Asia). Needs morphological authenticity
	12S ribosomal RNA gene	KY495156; KY563712	Murthy and Lubna., 2017	
	Mt CoI	MN205551	Alina et al., 2019	
Odontotermes parvidens	12S ribosomal RNA	KF769551	Poonia and Sharma, 2013	
	16S ribosomal RNA	KF769558	Poonia and Sharma, 2013	
Odontotermes redemanni	12S ribosomal RNA	KF769553	Poonia and Sharma, 2013	
	16S ribosomal RNA	KU574647	Vidyashree et al., 2016	
		KF792983	Poonia and Sharma., 2017	
Odontotermes wallonensis	28S ribosomal RNA	JF792838	Deivendran et al., 2012	
Odontotermes yadevi	16S ribosomal RNA	KU574656, KU574655 MZ189521	Vidyashree et al., 2016 Kalleshwaraswamy et al., 2021	
Euhamitermes hamatus	12S ribosomal RNA	KM657484	Ramya et al., 2015	Not reported from India (recorded only from Thailand, Malaysia, Singpur, Bangladesh). Needs morphological authenticity
Eurytermes buddha	16S ribosomal RNA	MW678776	Kalleshwaraswamy et al., 2021	
	mtCOI	MW664866	Kalleshwaraswamy et al., 2021	

(contd...)

Table 3 contd...

Ampoulitermes wynaadensis	12S ribosomal RNA	MZ044682 MZ044681	Kalleshwaraswamy et al., 2021 Kalleshwaraswamy et al., 2021	
Grallatotermes niger	16S ribosomal RNA	MZ262750	Kalleshwaraswamy et al., 2021	
Nasutitermes anamalaiensis	16S ribosomal RNA	KU574659 MW692352 MW694353	Vidyashree et al., 2016 Kalleshwaraswamy et al., 2021 Kalleshwaraswamy et al., 2021	
Nasutitermes brunneus	16S ribosomal RNA	MZ262702 MZ540856	Kalleshwaraswamy et al., 2021 Ranjith et al., 2021	
Nasutitermes indicola	16S ribosomal RNA	KU574660	Vidyashree et al., 2016	
Nasutitermes kali	16S ribosomal RNA	MZ262715	Kalleshwaraswamy et al., 2021	
Nasutitermes octopilis	12S ribosomal RNA gene	KM657478	Ramya et al., 2015	Not reported from India (recorded only from Africa-Guyana). Needs morphological authenticity
Trinervitermes_ biformis	16S ribosomal RNA	KU574657 MZ558074	Vidyashree et al., 2016 Santhrupthi et al., 2021	
Trinervitermes togoensis	12S ribosomal RNA gene And MtCo1	KY569523 KX711183	Murthy and Lubna., 2017 Murthy etal., 2016	This species is not reported from India (native to Africa). Needs morphological authenticity.
Amitermes belli	12S ribosomal RNA	KR078330	Mahapatro and Singh., 2015	
	16S ribosomal RNA	MZ269706	Priya and Gupta, 2021	
Angulitermes sp.	12S ribosomal RNA	KP780274	Mahapatro and Singh, 2015	
Dicuspiditermes achankovili	mtCOI	MT272760 MT272755 MT272750	Amina et al., 2020 Amina et al., 2020 Amina et al., 2020	
Dicuspiditermes fontanellus	16S ribosomal RNA	MZ270643	Kalleshwaraswamy et al., 2021	
Dicuspiditermes gravelyi	12S ribosomal RNA	MZ825163 MZ825164	Ranjith et al., 2021 Ranjith et al., 2021	
	16S ribosomal RNA	MZ270644 MZ823812	Kalleshwaraswamy et al., 2021 Ranjith et al., 2021	
Dicuspiditermes obtusus	16S ribosomal RNA	MZ270642	Kalleshwaraswamy et al., 2021	
Homallotermes pilosus	mtCO1	MT272758 MT272753 MT272747	Amina et al., 2020 Amina et al., 2020 Amina et al., 2020	
Indocapritermes aruni	mtCOI	MT272742	Amina et al., 2020	
Krishnacapritermes thakuri	mtCOI	MT272759 MN507713 to MN507729	Amina et al., 2020 Amina et al., 2019	
Krishnacapritermes dineshan	mtCOI	MN507708 to MN507712	Amina et al., 2019	

(contd...)

Table 3 contd...

Labiocapritermes distortus	16S ribosomal RNA	MZ558073	Santhrupthi et al., 2021	
	mtCOI	MT272756	Amina et al., 2020	
		MT272752	Amina et al., 2020	
		MT272744	Amina et al., 2020	
		MT272743	Amina et al., 2020	
Microcerotermes beesoni	12S ribosomal RNA	JX263665	Singla et al., 2012	
Microcerotermes fletcheri	16S ribosomal RNA	KU574652	Vidyashree et al., 2016	
Microcerotermes pakistanicus	16S ribosomal RNA	KU574653	Vidyashree et al., 2016	
		MZ414220	Kalleshwaraswamy et al., 2021	
		MZ427480	Kalleshwaraswamy et al., 2021	
Pericapritermes topslipensis	mtCOI	MT272762	Amina et al., 2020	
		MT272761	Amina et al., 2020	
		MT272749	Amina et al., 2020	
		MT272745	Amina et al., 2020	
		MT272741	Amina et al., 2020	
Procapritermes keralai	mtCOI	MT272748	Amina et al., 2020	
		MT272757	Amina et al., 2020	
Pseudocapritermes fletcheri	16S ribosomal RNA	MW686909	Kalleshwaraswamy et al., 2021	
		MW687081	Kalleshwaraswamy et al., 2021	
	mtCOI	MT272754	Amina et al., 2020	
		MT272751	Amina et al., 2020	
		MT272746	Amina et al., 2020	
		MW672524	Kalleshwaraswamy et al., 2021	
Synhamitermes quadriceps	16S ribosomal RNA	MW680954	Kalleshwaraswamy et al., 2021	
	mtCOI	MW680303	Kalleshwaraswamy et al., 2021	
Neotermes koshunensis	12S ribosomal RNA gene	KM657485	Ramya et al., 2015	Not reported from India (recorded only from Japan). Needs morphological authenticity
Rinacapritermes abundans	mtCOI	MT274296	Amina et al. 2022	
Rinacapritermes silvius	mtCOI	MT274294	Amina et al. 2022	

C. travians are doubtful. Among the remaining five, taxonomic validity of *C. beckeri*, *C. ceylonicus* and *C. kishori* is uncertain, because they are possibly junior synonoms of *C. amanii*, *C. brunneus* and *C. kalshoveni* (Chouvenc et al., 2016). Among these, *C. amanii* is of African origin, *C. brunneus* is of Australian origin and *C. kalshoveni* is a serious nuisance organism in Indonesia and Malaysia. This example may throw light on the need for an integrated taxonomy of the Indian Isoptera. There is a greater need for extensive collection, morphological and molecular characterization of Indian Isoptera.

H. Threats to biodiversity

The ecological and economic importance of the Isoptera is extensive. The most positive environmental relevance is their role as soil engineers. The most important negative relevance is their activity as nuisance organisms since they damage built structures and agricultural crops, a majority of them belonging to the Termitidae, Rhinotermitidae, and Kalotermitidae (Jouquet et al., 2018). In recent decades the tendency of expansion of the range of harmful Isoptera has led to an increase in economic damage.

Invasive termites spread with infested timbers and invade human environments, before spreading into natural ecosystems. A recent study utilized occurrence data and climate modeling to predict the potential habitats of *C. formosanus* and *C. gestroi* in Florida and demonstrated that future distribution projections for both species are influenced by urban development and climate change (Buczkowski and Bertelsmeier, 2017). Another negative outcome of increased Isoptera invasions is a potential increase in pesticide use in urban and natural landscapes. Although chemicals are hazardous to the environment, farmers and structural engineers all over the world use them extensively for the management of agricultural pests and in structures. Termites are eusocial, live in nests constructed with well protected soil or many inches below the soil surface and move in galleries which themselves protected from outside threats hence management of termites with termiticides is a difficult task. However, some termiticides such as imidacloprid, chlorpyrifos, fipronil, spinosad, chlorfenapyre, bifenthrin, cypermethrin, permethrin, disodium octaborate tetrahydrate, calcium arsenate, lindane, endosulfan, and chlorantraniliprole have been used worldwide for the management of termites (Ahmad et al., 2019). Leaching of termiticide is toxic to non-target organisms, due to indirect accumulation, which simultaneously affects human population through food chains (Arias-Estévez et al., 2008).

The known 28 invasive species have the potential to expand in the range of distribution, just as 10 of the 17 known invasive species have expanded between 1969 and today (Table 1). The spatial spread of the invasive Isoptera is a consequence of a combination of intrinsic and extrinsic factors that shape the population dynamics of the involved species. Intrinsic factors include dispersal, growth, survival, and reproductive constraints dictated by the species' physiological capabilities. Extrinsic factors include factors such as the spatial and temporal availability of suitable habitat for survival, growth, and reproduction. Human-induced environmental changes, most notably climate change and urbanization, are likely to affect both intrinsic and extrinsic factors. For example, invasive termites have been shown to adapt their reproductive phenology in response to climate change. In parts of Florida, the dispersal flight season of *C. formosanus* and *C. gestroi* has begun to overlap due to changes in local climate. Mating pairs of heterospecific individuals were observed in the field with *C. gestroi* males preferentially engaging in mating with *C. formosanus* females rather than females of *C. gestroi*. This leads to hybridization between the two species and the potential evolution of highly destructive "super-termites" due to hybrid vigour (Chouvenc et al., 2016).

I. Management of invasive termites

In most cases of invasive Isoptera, attempts were made to eradicate them applying synthetic pyrethroids and organochlorine insecticides, and by baiting. Baiting has been a successful tactic using area-wide management strategy. However, many attempts to eradicate the invasive Isoptera have proved futile (Bravey and Verkrek, 2010). Thus, only instances of successful management refer to those of *C. formosanus* in South Africa and *C. frenchi* in New Zealand (Chouvenc et al., 2016). Therefore, monitoring their entry and successful management are the viable options presently.

At the time of shipment, log fumigation must reduce the risk of introductions. It is possible to use a less environmentally harmful fumigant like sulfuryl fluoride. A strict policy for the importing country and strict monitoring of imported material could minimize the intrusion into a new geographical region, reducing both economic and ecological risks. Imported wood should be fumigated with methyl bromide @ 48g/m^3 for 24 h to destroy infestation to avoid their entry (https://plantquarantineindia.nic.in/ accessed on 10 December 2021). The treatment is as per the Plant Quarantine (Regulation of Import into India) Order, 2003 which regulates import and prohibition of import of plant and plant products into India and amended recently (S.O. 3686 (E), dated 9 September 2021). The treatment should be endorsed on Phytosanitary Certificate issued at the country of origin or re-export (https://plantquarantineindia.nic.in/ accessed on 10 December 2021).

CONCLUSIONS

Tropical, subtropical conditions of India are highly congenial for the rapid multiplication of termites. If any species is introduced accidentally, there is every chance of successful establishment. Hence monitoring, observation, reporting their identity and intervention to avoid the establishment is the need of the hour. Training and recruiting taxonomists with a centralized diagnostic centre is one possible solution to strengthen the activity of the quarantine stations.

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REFERENCES

Abe T. 1987. Evolution of life types in termites. In: Kawano S, Connell JH, Hidaka T (Eds.). Evolution and coadaptation in biotic communities. University of Tokyo Press, Tokyo. pp. 126-148.

Ahmad F, Fouad H, Liang S-Y, Hu Y, Mo J-C, 2019. Termites and Chinese agricultural system: applications and advances in integrated termite management and chemical control. 28(1): 2-20.

Arias-Estévez M E, López-Periago E, Martínez-Carballo J, Simal-Gándara J C, Mejuto J C, and García-Río L. 2008. The mobility and degradation of pesticides in soils and the pollution of groundwater resources. Agriculture, Ecosystems and Environment 123(4): 247-260.

Austin J W, Szalanski A L, Scheffrahn R H, Messenger M T, Dronnet S, Bagnères A G. 2005. Genetic evidence for the synonymy of two *Reticulitermes* species: *Reticulitermes flavipes* and *Reticulitermes santonensis*. Annals of the Entomological Society of America 98(3): 395-401.

Austin J W, Szalanski A L, Scheffrahn R H, Messenger M T, McKern J A, Gold R E. 2006. Genetic evidence for two introductions of the Formosan subterranean termite, *Coptotermes formosanus* (Isoptera: Rhinotermitidae), to the United States. Florida Entomologist 89: 183-193.

Bain J, Jenkins M J. 1983. *Kalotermes banksiae*, *Glyptotermes brevicornis* and other termites (Isoptera) in New Zealand. New Zealand Entomologist 7(4): 365-371.

Borges P A V, Myles T G, Lopes D H, Ferreira M, Borges A, Guerreiro O, Simões A. 2007. Estratégias para combate e gestão das térmitas nos Açores. In: P.A.V. Borges & T. Myles (eds.), Térmitas dos Açores. Princípia, pp. 112-122, Lisboa.

Bose, G. 1984. Termite fauna of southern India. *Records of the Zoological Survey of India* 49: 1-270.

Bravey T, Verkerk R. 2010. *Termite eradication programme*. Information Leaflet. Update No. 19, UK Dep. Communities Local Gov. London.

Buczkowski G, Bertelsmeier C. 2017. Invasive termites in a changing climate: A global perspective. Ecology and Evolution 7(3): 974-985.

Cachan P. 1949. Les termites de Madagascar. Mémoires de l'Institut Scientifique de Madagascar. Série A: Biologie Animale, 3(2), 178-275.

Chouvenc T, Li H, Austin J, Bordereau C, Bourguignon T, Cameron S L, Cancello E M, Constantino R, Costa-Leonardo A M, Eggleton P, Evans T A, Forschler B, Grace J K, Husseneder C, Křeček J, Lee C, Lee T, Lo N, Messenger M, Mullins A, Robert A, Roisin Y, Scheffrahn R H, Sillam-Dussès D, Šobotník J, Szalanski A, Takematsu Y, Vargo E L, Yamada A, Yoshimura T, Su N. 2016. Revisiting *Coptotermes* (Isoptera: Rhinotermitidae): a global taxonomic road map for species validity and distribution of an economically important subterranean termite genus. Systematic Entomology 41: 299-306.

Constantino R. 1998. Catalog of the living termites of the New World (Insecta: Isoptera). Arquivos de Zoologia 35(2): 135-230.

Constantino R. 2002. The pest termites of South America: taxonomy, distribution and status. Journal of Applied Entomology 126(7-8): 355-365.

Dahlsjö C A, Romero V C S, Iñiguez E C I. 2020. Termite diversity in Ecuador: a comparison of two primary forest national parks. Journal of Insect Science 20(1): 1-6.

DeHeer C J, Kutnik M, Vargo E L, Bagnères A G. 2005. The breeding system and population structure of the termite *Reticulitermes grassei* in southwestern France. Heredity 95: 408-415.

Donovan S E, Eggleton P, Bignell D E. 2001. Gut content analysis and a new feeding group classification of termites (Isoptera). Ecological Entomology 26: 356-66.

Dronnet S, Chapuisat M, Vargo EL, Lohou C, Bagnères A G. 2005. Genetic analysis of the breeding system of an invasive subterranean termite, *Reticulitermes santonensis*, in urban and natural habitats. Molecular Ecology 14: 1311-1320

Evangelista DA, Wipfler B, Béthoux O, Donath A, Fujita M, Kohli MK, Legendre F, Liu S, Machida R, Misof B, Peters RS, Podsiadlowski L, Rust J, Schuette K, Tollenaar W, Ware JL, Wappler T, Zhou X, Meusemann K, Simon S. 2019. An integrative phylogenomic approach illumine tes the evolutionary history of cockroaches and termites (Blattodea). *Proceedings of Biological Science* 286 (1895): 2018-2076.

Evans T A, Forschler B T, Grace J K. 2013. Biology of invasive termites: a worldwide review. Annual Review of Entomology 58: 455-474.

Evans T A, Inta R, Lai, J C. 2011. Foraging choice and replacement reproductives facilitate invasiveness in dry wood termites. Biological Invasions 13(7): 1579-1587.

Evans T A. 2010. Invasive termites. pp 519-562. In: Bignell D E, Roisin, Y Lo, N. Biology of Termites: A Modern Synthesis, (eds). Dordrecht, Netherlands: Springer. p576.

Evenhuis N L. 2007. Checklist of the Isoptera of Fiji. Technical Report 38(12), Bishop Museum Honolulu, HI. p38.

Ferreira M T, Borges P A V, Nunes L, Myles T G, Guerreiro O, Scheffrahn R H. 2013. Termites (Isoptera) in the Azores: an overview of the four invasive species currently present in the archipelago, Arquipelago. Life and Marine Sciences 30: 39-55.

Gay F J Watson J A L. 1982. The genus *Cryptotermes* in Australia (Isoptera: Kalotermitidae). Australian Journal of Zoology, Supplementary Series, 30(88): 1-64.

Gay F J. 1969. Species introduced by man. In Biology of Termites, ed. K Krishna, F M Weesner, New York: Academic press 1: 459-494.

Grace J K, Cutten G M, Scheffrahn R H, McKevan D K. 1991. First infestation by *Incisitermes minor* of a Canadian building. Sociobiology 18(3): 299-304.

Grace J K, Woodrow R J, Yates, J R. 2002. Distribution and management of termites in Hawaii. Sociobiology 40(1): 87-94.

Gray B. 1968. Sustainable termite management using an integrated pest management approach. Pacific Insects 10(2): 301-323.

Harit A K, Gajalakshmi S, Abbasi S A. 2014. Swarming of the termite *Coptotermes gestroi* in north-eastern Puducherry. Zoology and Ecology 24(1): 62-69.

Haverty M I, Woodrow R J, Nelson L J, Grace J K. 2000. Cuticular hydrocarbons of termites of the Hawaiian Islands. Journal of Chemical Ecology 26(5): 1167-1191.

Hemachandra J P, Edirisinghe W A I P, Karunaratne, Gunatilleke C V S. 2012. An annotated checklist of termites (Isoptera) of Sri Lanka. National Science Foundation Colombo, Sri Lanka

Inward D, Beccaloni G, Eggleton P. 2007. Death of an order: a comprehensive molecular phylogenetic study confirms that termites are eusocial cockroaches. Biology letters 3(3): 331-335.

Jenkins T M, Dean R E, Verkerk R, Forschler B T. 2001. Phylogenetic analyses of two mitochondrial genes and one nuclear intron region illuminate European subterranean termite (Isoptera: Rhinotermitidae) gene flow, taxonomy, and introduction dynamics. Molecular Phylogenetics and Evolution 20(2): 286-293.

Jones D T, Eggleton P. 2000. Sampling termite assemblages in tropical forests: testing a rapid biodiversity assessment protocol. Journal of Applied Ecology 37:191-203.

Jouquet P, Chaudhary E, Kumar A R V. 2018. Sustainable use of termite activity in agro-ecosystems with reference to earthworms. A review. Agronomy for Sustainable Development 38(1): 1-11.

Junqueira L K and Florencio D F. 2018. Termite damage in agriculture areas and implanted forests: an ecological approach. pp. 37-50. In: Khan M A. and Ahmad W. *Termites and sustainable management* (eds.). Springer. p324.

Evans T A. 2010. Invasive termites. pp519-562. In: Biology of Termites: A Modern Synthesis, (eds). Bignell D E, Roisin, Y Lo, N. Dordrecht, Netherlands: Springer. p576.

Kalleshwaraswamy C M, Pavithra H B, Vidyashree A S, Sathisha G S. 2018. Comparative termite (Isoptera) diversity in three different habitats of Shivamogga district, Karnataka, India. Journal of Entomological Science 53(2): 219-229.

Kalleshwaraswamy C M, Shankaramurthy M. Viraktamath C A, Krishna Kumar, N. K. 2015. Occurrence of *Tuta obsoluta* (Lepidoptera: Gelechidae) in the Malnad and Hyderabad-Karnataka regions of Karnataka, India. Florida Entomologist 98 (3): 970-971.

Kaiser D, Lepage M, Konaté S, Linsenmair K E. 2017. Ecosystem services of termites (Blattoidea: Termitoidae) in the traditional soil restoration and cropping system Zaï in northern Burkina Faso (West Africa). Agriculture Ecosystem and Environment 236:198-211.

Kaur G, Anantharaju T, Gajalakshmi S, Abbasi S A. 2017. Inventory of termite species in thickly vegetated region of Northeastern Puducherry, India. International Journal of Biodiversity and Conservation 9(8): 265-272.

Kaur G, Gajalakshmi S, Abbasi S A. 2013. Termite biodiversity in Pondicherry university campus: a reappraisal on the basis of feeding preference studies. International Journal of Chemical and Environmental Engineering Systems 4:30-38

King E G, Spink W T. 1969. Foraging galleries of the Formosan subterranean termite, *Coptotermes formosanus*, in Louisiana. Annals of the Entomological Society of America 62: 536-542.

Kiritani, K, Morimoto N. 2004. Invasive insect and nematode pests from North America. Global Environmental Research 8(1): 75-88.

Kirton L G, Brown V K. 2003. The taxonomic status of pest species of *Coptotermes* in southeast Asia: resolving the paradox in the pest status of the termites, *Coptotermes gestroi*, *C. havilandi* and *C. travians* (Isoptera: Rhinotermitidae). Sociobiology 42: 43-63.

Krishna K, Grimaldi D A, Krishna V, Engel M S. 2013. Treatise on the Isoptera of the World: Volume 3. Bulletin of the American Museum of Natural History 377: 623-973.

Li H F, Ye W, Su N Y, Kanzaki N. 2009. Phylogeography of *Coptotermes gestroi* and *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Taiwan. Annals of the Entomological Society of America 102: 684-693.

Maiti P K. 1983. Temite (Isoptera) fauna of West Bengal, India, their recognition, biology and ecology. Records of the Zoological survey of India (Occasional Paper) 42: 1-152.

Miller D. 1941. The species of termites in New Zealand. New Zealand Journal of Forestry 4: 333-334.

Myles T G. 1999. Review of secondary reproduction in termites (Insecta: Isoptera) with comments on its role in termite ecology and social evolution. Sociobiology 33: 1-91.

Nagaraju D K, Kalleshwaraswamy C M, Iyyanar D, Singh M, Jain R K, Kasturi N, Ranjith M, Mahadevaswamy H M, Asokan R. 2020. First interception of two wood feeding potential invasive *Coptotermes* termite species in India. International Journal of Tropical Insect Science 41(2): 1043-1052.

Nunes L. 2010. Termite infestation risk in Portuguese historic buildings. In wood science for conservation of cultural heritage –Braga 2008, ed. J Gril, pp. 117-22. Florence, Italy: Firenze Univ. Press.

Olaniyan A, Ibikunle O A, Olayanju A B, Olagoke B E, Olawoor W A. 2015. Effects of termites on construction timbers in Ibarapa east local government area of Oyo state in Nigeria. *International Journal of Latest Research in Engineering and Technology*, 1(7), 40-48.

Peck S B. 2001. Smaller Orders of Insects of the Galápagos Islands, Ecuador: Evolution, Ecology and Diversity. Ottawa: National Research Council Press.

Peters B C. 1990. Infestations of *Cryptotermes brevis* (Walker) (Isoptera: Kalotermitidae) in Queensland, Australia. 1. History, detection and identification. Australian Forestry 53:79-88

Phillip B, Pearson H, Bennett S. 2008. Australian termites in New Zealand. Biosecurity 82: 12-13.

Plant Quarantine Information System, Ministry of Agriculture and Farmers Welfare, Government of India, http://plantquarantineindia.nic.in (accessed on 10 December 2021).

Rajamohana K, Basak J, Poovoli A, Sengupta R, Baraik B, Chandra K. 2019. Taxonomy of termites: A beginner's manual. ENVIS Centre on Biodiversity (Fauna), Zoological Survey of India, Kolkata. Pp. 71.

Rana A, Chandel R S, Verma K S, Joshi M J. 2021. Termites in important crops and their management. Indian Journal of Entomology 83(3): 486-504.

Roonwal M L, Chhotani O B. 1965. Zoogeography of termites of Assam region, India, with remarks on speciation. The journal of the Bombay Natural History Society 62(1): 19-31.

Schabel H G. 2006. Forest entomology in East Africa: forest insects of Tanzania. Springer, Dordrecht, The Netherlands. pp.328.

Scheffrahn R H, Chase J A, Mangold J R, Krěcěk J, Su N Y. 1999. First record of *Reticulitermes* (Isoptera: Rhinotermitidae) from the West Indies: *R. flavipes* on Grand Bahama Island. Florida Entomologist 82(3): 480-482.

Scheffrahn R H, Darlington J P E C, Collins M S, Krěcěk J, Su N Y. 1994. Termites (Isoptera: Kalotermitidae, Rhinotermitidae, Termitidae) of the West Indies. Sociobiology 24: 213-238.

Scheffrahn R H, Křeček J, Ripa R, Luppichini P. 2009. Endemic origin and vast anthropogenic dispersal of the West Indian drywood termite. Biological invasions 11:787-799.

Scheffrahn R H, Krecek J, Szalanski A L, Austin J W, Roisin Y. 2005. Synonymy of two arboreal termites (Isoptera: Termitidae: Nasutitermitinae): *Nasutitermes corniger* from the Neotropics and *N. polygynus* from New Guinea. Florida Entomologist 88: 28-33.

Scheffrahn R H, Krecek J. 1999. Termites of the genus *Cryptotermes* Banks (Isoptera: Kalotermitidae) from the West Indies. Insecta Mundi 13(3-4): 111-171.

Scheffrahn R H, Su N Y, Chase J A, Forschler B T. 2001. New termite (Isoptera: Kalotermitidae, Rhinotermitidae) records from Georgia. Journal of Entomological Science 36(2): 109-113.

Scheffrahn R H, Su N Y, Chase J A, Mangold J R, Grace J K, Yates J R. 2000. First record of *Cryptotermes cynocephalus* Light (Isoptera: Kalotermitidae) and natural woodland infestations of *C. brevis* (Walker) on Oahu, Hawaiian Islands. Proceedings of the Hawaiian Entomological Society 34:121-125.

Scheffrahn R H, Su N Y. 2005. Distribution of the termite genus *Coptotermes* (Isoptera: Rhinotermitidae) in Florida. Florida Entomologist 88: 201-203.

Sharma K R, Jaiswal D K, Babu S R, Saraoj A K. 2018. Impact of invasive insect pests species on agroecosystem in India and their management. Indian Journal of Agriculture and Allied Sciences 4(1): 19-26.

Sharanabasappa, Kalleshwaraswamy C M, Asokan R, Swamy H M, Maruthi M S, Pavithra H B, Hegde K, Navi S, Prabhu S T, Goergen G. 2018. First report of the fall armyworm, Spodoptera frugiperda (J. E. Smith) (Lepidoptera: Noctuidae), an alien invasive pest on maize in India. Pest Management in Horticultural Ecosystems 24: 23-29.

Simpson S J, Sword G A, Lo N. 2011. "Polyphenism in Insects". *Current Biology*. 21 (18): 738-749.

Sornnuwat Y. 1996. Studies on damage of constructions caused by subterranean termites and its control in Thailand. Wood Research: Bulletin of the Wood Research Institute Kyoto University 83: 59-139.

Su N Y, Ye W, Ripa R, Scheffrahn R H, Giblin-Davis R M. 2006. Identification of Chilean *Reticulitermes* (Isoptera: Rhinotermitidae) inferred from three mitochondrial gene DNA sequences and soldier morphology. Annals of the Entomological Society of America 99: 352-363.

Sun J Z, Lockwood M E, Etheridge J L, Carroll J, Hollomon C Z, Coker C E H, Knight P R. 2007. Distribution of Formosan subterranean termite (Isoptera: Rhinotermitidae) in Mississippi. Journal of Economic Entomology 100: 1400-1408.

Sundararaj R, Selvaraj K, Kalleshwaraswamy C M, Ranjith M, Sumalatha B V. 2020. First record of the invasive woolly whitefly, *Aleurothrixus floccosus* (Maskell) from India. Indian Journal of Entomology, 81(4): 88-91.

Szalanski A L, Scheffrahn R H, Austin J W, Krecek J, Su N Y. 2004. Molecular phylogeny and biogeography of *Heterotermes* (Isoptera: Rhinotermitidae) in the West Indies. Annals of the Entomological Society of America 97: 574-585.

Thistleton B M, Neal M, Peki M, Dobunaba J. 2007. *Mastotermes darwiniensis* in the Lae area of PNG: an assessment of current and potential status of the incursion, and options for management, final report. Canberra, Australian Centre for International Agricultural Research, Australian Government.

Tsai C C, Chen C S. 2003. First record of *Coptotermes gestroi* (Isoptera: Rhinotermitidae) from Taiwan. Formosan Entomologist 23: 157-161.

Vargo E L, Hussender C, Grace J K. 2003. Colony and population genetic structure of the Formosan subterranean termite, *Coptotermes formosanus*, in Japan. Molecular Ecology 12: 2599-2608.

Venkatesan T, Kalleshwaraswamy C M, Ankita G, Ashika T R. 2021. Intrusion pathway of invasive Asian subterranean termite, *Coptotermes gestroi* (Wasmann) from the Neotropics into the Indian mainland. Current Science 120 (11): 1778-1781.

Vidyashree A S, Kalleshwaraswamy C M, Mahadevaswamy H M, Asokan R, Adarsha S K. 2018. Morphological, molecular identification and phylogenetic analysis of termites from Western Ghats of Karnataka, India. Journal of Asia-Pacific Entomology 21(1): 140-149.

Wasmann E. 1896. Neue Termitophilen und Termiten aus Indien, I-III. Annali del Museo Civico di Storia Naturale di Genova 36(2) 16: 613-630.

Williams R M C. 1976. Factors limiting the distribution of building-damaging dry-wood termites (Isoptera, *Cryptotermes* spp.) in Africa. Material und Organismen 3: 393-406.

Xie Y, Li Z, Gregg W I, Li D. 2001. Invasive species in China: an overview. Biodiversity and Conservation 10: 1317-1341.

Yamada A, Inoue T, Wiwatwitaya D, Ohkuma M. 2007. A New concept of the feeding group composition of termites (Isoptera) in Tropical ecosystems: Carbon source competitions among fungus growing termites, soil feeding termites, litter layer microbes and fire. Sociobiology 50: 135-153.

Zorzenon F J. Campos A E C. 2014. Subterranean termites in urban forestry: Tree preference and management. *Neotropical Entomology*, 44: 180-185.

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