

**Discovery of Two Aleocharine Staphylinid Species (Coleoptera)
Associated with *Coptotermes formosanus* (Isoptera:
Rhinotermitidae) from Central Japan, with a Review of the
Possible Natural Distribution of *C. formosanus* in Japan and
Surrounding Countries**

by

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ABSTRACT

Two termitophilous staphylinid beetles, *Japanophilus hojoi* Maruyama & Iwata and *Sinophilus yukoae* Maruyama & Iwata (Staphylinidae: Aleocharinae) are known to inhabit nests of a termite species, *Coptotermes formosanus* Shiraki (Rhinotermitidae). Previously, these beetles had only been collected from *C. formosanus* nests in the Nansei Archipelago, between Kyushu and Taiwan. Here, we report their existence in nests in the coastal regions of Wakayama Prefecture, Central Japan. A review of published records strongly supports the hypothesis that Nansei Archipelago, Kyushu and the coastal areas of Kii Peninsula of Honshu, constitute, at least, part of the natural geographic range of *C. formosanus*.

INTRODUCTION

The Formosan subterranean termite, *Coptotermes formosanus* Shiraki (Rhinotermitidae) is regarded as the world's most economically damaging termite species (Su & Tamashiro, 1987). Via accidental introductions, this species has expanded its range in warm temperate areas, and is currently inflicting significant destruction in urbanized parts of the southern United States (La Fage, 1987; Woodson *et al.* 2001). For an effective control strategy, precise determination of a pest species' natural range is important, since it

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is here that natural enemies may exist that may be exploited for biological control measures (Iwata, 2000). Although *C. formosanus* is thought to have originated in East Asia, its natural distribution has not been fully mapped. In particular, it is not known whether Japanese populations from the southwest part of Honshu, Shikoku, Kyushu, and Nansei Archipelago (Islands between Kyushu and Taiwan) are natural or introduced.

Termitophiles are organisms that live in close association with termites; they are often “species-specific”, as natural enemies are (Iwata, 2000). The presence of termitophiles within a termite colony may be a good indicator that the colony is within its natural geographic range: Kistner, in an elaboration of Emerson’s (1955) idea, argued that termite dispersal depends largely on short-range movement of winged reproductives; consequently, seas and oceans pose a barrier to the spread of termites, and also the movement of their termitophilous guests (Kistner, 1969, p. 538). The presence at a certain locality of species-specific inquilines, e.g. termitophilous staphylinids, may thus help delineate the natural distribution of a given termite species. Conversely, evidence that a colony has been introduced outside of its natural distribution may be the complete absence of termitophiles within nests at such localities. Herein, we call this hypothesis the “Emerson–Kistner Principle” (EKP).

Importantly, Kistner (1985) described *Sinophilus xiai* Kistner (Aleocharinae: Termitohospitini), the first termitophilous staphylinid species specifically associated with *C. formosanus*. *Sinophilus xiai* was recovered from nests in Zhejiang and Guangdong Provinces, South China. Based upon EKP, he designated this area of South China the putative origin (the center of the natural distribution) of *C. formosanus*. Later, Maruyama and Iwata (2002a) described two further termitophilous staphylinids, again, specifically associated with *C. formosanus* (two species and one genus): *Sinophilus yukoae* from Iheya, Ishigaki and Iriomote Islands (Nansei Archipelago), and *Japanophilus hojoi* from Yakushima, Tokara-Nakanoshima and Tokara-Suwanosejima Islands. They proposed that the natural distribution area of *C. formosanus* should be expanded to include this Japanese archipelago. Furthermore, they noted the similarity of *Japanophilus* with an unidentified staphylinid collected from a *C. formosanus* nest in Fukuoka Prefecture, Kyushu, Japan by Nawa (1914, writing under the pseudonym “Konchû-Ô”). This implied the additional inclusion of Kyushu in the natural range of *C. formosanus*, but until the present paper,

there have been no *bona fide* records of termitophilous staphylinid species from *C. formosanus* colonies on mainland Japan (excluding Kyushu).

Other inquilinous insects associated with *C. formosanus* likely fall into the category of “termitariophiles”: species having a weaker, often facultative relationship with termites, in which the nest may be used simply as shelter and food. Such species include *Madrasostes kazumai* Ochi, Johki & Nakata (Coleoptera: Ceratocanthidae), from Tokara-Nakanoshima Is. and other islands (e.g., Iwata *et al.*, 1992; Kôgata, 1999), and *Lorelus sasajii* Masumoto & Akita (Coleoptera: Tenebrionidae), from Iriomote, Ishigaki and Amami-Oshima Islands (Masumoto & Akita, 2001). It is not clear if these termitariophiles are host-specific; for example, *M. kazumai* has also been found in a nest of *Hodotermopsis sjostedti* Holmgren (Termopsidae) (Maruyama & Iwata, 2002b). Hence, these taxa are less useful guides for judging the natural range of *C. formosanus* according to EKP.

As yet, there have been no records of termitophiles from *C. formosanus* nests in southern parts of USA, Hawaii and other regions clearly outside the natural geographic range. This observation would seem to further substantiate EKP. Here, we present new records of two Japanese termitophilous Termitohospitini species (*J. hojoi* and *S. yukoae*) found in *C. formosanus* nests from the coastal areas of Kii Peninsula (Wakayama Prefecture), central mainland Japan, a region located far from the Nansei Archipelago. We discuss the implications of these records for the biogeography and biological control of *C. formosanus*.

RECORDS

The collection data are as follows: *Japanophilus hojoi*, 2 exs. (Fig. 1): Uragami, Nachi-Katsuura, Wakayama Pref., 1.vi.2009, leg. Katsuo Oya.

J. hojoi, 2 exs.; *Sinophilus yukoae*, 4 exs. (Fig. 2): Tahara, Kushimoto, Wakayama Pref., 24.x.2009, leg. Katsuo Oya.

J. hojoi, 2 exs.; *S. yukoae*, 8 exs.: Urakatsu, Nachi-Katsuura, Wakayama Pref. x. 2009, leg. Katsuo Oya.

Figure 3 incorporates all the localities of the termitophiles and termitariophiles mentioned in the present paper.



Figs. 1, 2. Two termitophilous staphylinids associated with *Coptotermes formosanus*. 1. *Japanophilus bojai* Maruyama & Iwata. 2. *Sinophilus yukoae* Maruyama & Iwata.

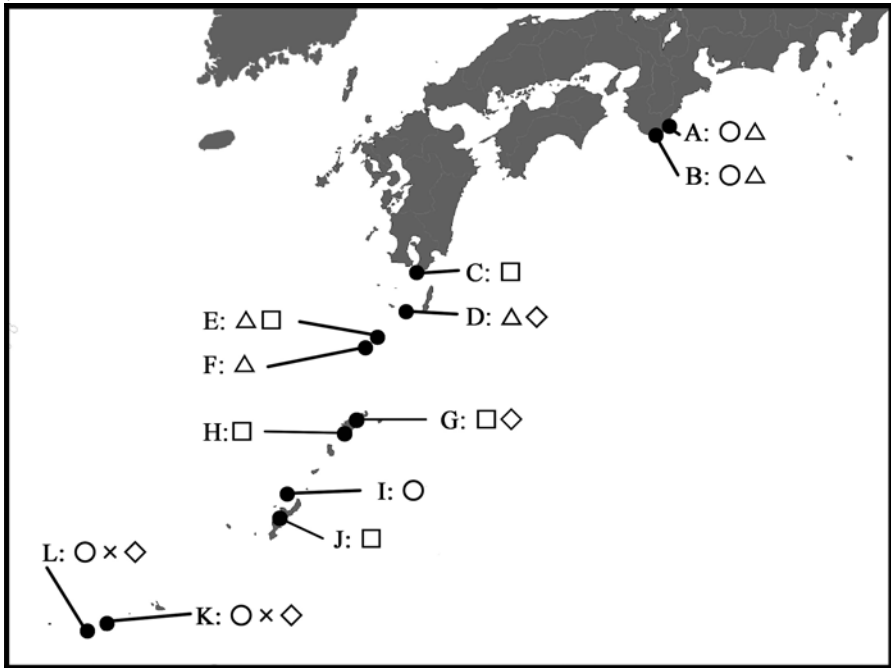


Fig. 3. Localities in Japan of the termitophiles and termitariophiles associated with *Coptotermes formosanus*. A, Nachi-Katsuura, Wakayama Pref.; B, Kushimoto, Wakayama Pref.; C, Sata-misaki, Kagoshima Pref.; D, Yaku Island; D, E: Naka-no-shima Island; F, Suwanose Island; G, Amami-ô-shima-shima; H, Kakeroma Island; I, Iheya Island; J, Okinawa Island; K, Ishigaki Island; L, Iriomote Island. Circle, *Sinophilus yukoae*; triangle, *Japanophilus hojoi*; square, *Madrasostes kazumai kazumai*; cross, *M. kazumai bisamatsui*, diamond, *Lorelus sasajii*.

DISCUSSION

Validity of the EKP (Emerson–Kistner Principle)

Estimating natural geographic ranges using the EKP comes with some caveats. For example, the EKP may be violated by cases in which an entire nest of termites, or soil containing live termites, has been transferred along with any resident termitophiles. One case that at first appears to contradict EKP comes from Snyder (1934), who reported a human-aided introduction of a European termite species (*Reticulitermes lucifugus*) to Massachusetts, USA, and mentioned a nest in which “beetle termitophiles” were found. Since Snyder did not describe the termitophilous species, it is unclear whether the beetle was of European or North American origin. It is possible that a

North American termitophile host-shifted from American *Reticulitermes* to the introduced *R. lucifugus*. Indeed, the establishment of a European termitophilous beetle has not been reported from Massachusetts since then. There have been cases in Japan where *Kistnerium japonicum* Naomi & Iwata, a termitophilous staphylinid (Aleocharinae: Mesoporini) with rather a low host-species specificity, changes its host from the major host, *Reticulitermes speratus* (Kolbe) to *C. formosanus* and even to an ant species (Iwata *et al.*, unpublished). Therefore, Snyder's (1934) case does not "disprove" EKP; however, until thorough phylogeographic studies are carried out, employing genetic markers, it remains a largely conceptual hypothesis, which, although useful, lacks solid empirical support.

Literature survey on *Reticulitermes* spp. and *Coptotermes formosanus* as endemic to Japan

Amongst the Japanese termite taxa, *Reticulitermes* spp. (*R. speratus* and its allies; excluding *R. kanmonensis*, a putative introduced species: Takematsu & Morimoto, 1999) are, based on molecular evidence, thought to have all derived from an East China stock in the early Pleistocene (Park *et al.*, 2006). Notably, one North American representative [*R. flavipes* (Kollar)] of this holarctic termite genus engages in a very distinct symbiosis with a highly derived termitophilous staphylinid *Trichopsenius* (Aleocharinae: Trichopsenini), in which the beetle is provided with cuticular hydrocarbon compositions identical to those of the host (Howard *et al.*, 1980). Such a *Reticulitermes*–*Trichopsenius* association also exists in Japan (Iwata & Naomi, 1998), a fact that firmly verifies the resident *Reticulitermes* spp. (excluding *R. kanmonensis*) as endemic to Japan.

As for the populations of *C. formosanus* in Japan (Ogasawara Islands, south Kanto District, south Chubu District, south Kinki District, south Chugoku District, Shikoku, Kyushu, Nansei Archipelago), Ikehara (1966), in discussing the termite biogeography and fauna of Nansei Archipelago, did not mention whether Japanese *C. formosanus* is endemic or introduced, but suggested a recent expansion, due to the fact that it is not distributed in Daito Island, an island off the Nansei Archipelago. Bess (1970) included Japan in its geographic range, without including it in its artificial range, and there have been other statements that Japan comprises part of its natural range (Gay,

1969; Coaton & Sheasby, 1976). However, since Su & Tamashiro (1987) explicitly illustrated the expansion history of *C. formosanus* as an invasion from South China into Japan in the 16th Century (stating “300 years have elapsed since its introduction to Japan”), almost all termitologists have followed this view (e.g. Mori, 1987). Ohmura & Tokoro (2003) even mentioned “Goshuin-sen Bôeki” (Shogunate-authorized ship trade with China) as the cause of its introduction to Japan. Yet, the introduction hypothesis has never been substantiated by any data.

***Coptotermes formosanus*: DNA analyses**

More recently, Vargo *et al.* (2003), under an assumption that Japanese *C. formosanus* consists of introduced populations, investigated the microsatellite markers of populations from the mainland and Gotô-Rettô (Nagasaki Prefecture, Kyushu District). They obtained no evidence of a “bottle-neck effect” due, they stated, to “the more than 300-year history of this species in Japan”, but found that “the Japanese populations contained 26% fewer alleles than did a native population from Guangdong Province, China, at the six microsatellite loci studied”. They ascribed this fact to the introduction history. These results seem somewhat equivocal, and the interpretation *ad hoc*. The genetic diversity of *C. formosanus* in Hawaii (an introduced population) is known to be extremely low (Broughton & Grace, 1994), yet, that of populations in South China is also low, despite the fact that this species is endemic there. This may be due to human activity and disturbance (Fang *et al.*, 2008). On the other hand, a phylogenetic study using mitochondrial COII DNA from the US populations also revealed an extremely low genetic diversity, giving the conclusion that at least two *C. formosanus* introductions to the mainland of USA had occurred (Austin *et al.*, 2006). Such low genetic diversity is common in populations from Taiwan (Li *et al.*, 2009) and Japan (A. Yamada, pers. comm.).

***Coptotermes formosanus*: Colony reproduction analyses**

Lenz & Barrett (1982) and Lenz *et al.* (1986) stated that in the genus *Coptotermes*, as well as in the other rhinotermitid genera, alate swarming is generally followed by new colony foundation by the royal pair, and that this is the main reproduction method in the natural range of the species. Brachypterous neotenic formation upon removal of the primary queen, leading

to reproduction and satellite nest formation, is an alternative method, and this latter process is thought to predominate in recently-introduced populations (Lenz & Barrett, 1982). In studying *C. formosanus*, Husseneder *et al.* (2005) classified colonies into two categories, namely “simple family” (colony headed by a single pair of outbred reproductives) and “extended family” (colony headed by low numbers of multiple kings and/or queens that were likely the neotenic descendants of the original colony). However, no obvious relationship could be found between the mode of colony reproduction and the invasion success of this species. In investigating colony reproduction in *C. formosanus* from South China, Hawaii and southern mainland of USA, Husseneder *et al.* (2008) found that, surprisingly, in only south China did all colonies contained multiple inbreeding neotenic; in Hawaii and southern mainland of USA, only about half to two thirds of colonies contained neotenic, the rest being founded by royal pairs. These results together suggest that the theory proposed by Lenz & Barrett (1982) cannot be applied to *C. formosanus*. However, it may be that it is valid for a limited time window after the introduction of *C. formosanus*.

***Coptotermes formosanus* in Japan and adjacent areas: introduced or endemic?**

Molecular biological studies over last 10 years have described the biogeographical and genetic relationships among *C. formosanus* populations from China, Japan, Hawaii and mainland USA (e.g. Wang & Grace, 2000; Husseneder & Grace, 2001; Vargo *et al.*, 2003). Nevertheless, the origin and the natural distribution range of *C. formosanus* remain unclear. Data on the distribution of *Japanophilus hojoi* and *Sinophilus yukoae* associated with *C. formosanus* (Kii Peninsula, Kyushu and Nansei Archipelago), combined with EKP appear to support the idea that Kyushu and Kii Peninsula of Honshu comprise part of the natural geographic range. Our conclusion thus differs from that of Su & Tamashiro (1987), who suggested that *C. formosanus* was introduced to Japan from China relatively recently.

What about the existence of *C. formosanus* in other regions of Japan and surrounding countries? Populations of *C. formosanus* in south Kanto Districts, including Yokosuka (Kanagawa Pref.) and Tateyama (Chiba Pref.), may indeed be the result of introduction, since there are no prewar distribution

records (Iwata, 2004). Likewise, *C. formosanus* was not distributed in the Ogasawara Islands in prewar times, and the outbreak of swarming activities after 1976 clearly suggests the artificial introduction by the occupying US Forces (Minamiyama, 1978; Mori, 1979). In Taiwan, *C. formosanus* populations are considered endemic, forming the center of the species' distribution, as the specific epithet indicates, and are genetically most allied to Japanese populations (Li *et al.*, 2009). Its presence in Lanyu Island, an accompanying island of Taiwan, is thought to be via introduction from mainland Taiwan (Li *et al.*, 2008). In the northern part of Vietnam, as an extension from the putative distribution center, south China, *C. formosanus* was found exclusively in cultivated land and residential areas (Vu *et al.*, 2007), again suggesting the likelihood of artificial introduction.

Yaga (1997) stated that Okinawa (the southern part of the Nansei Archipelago) has a history of termite control dating back more than 2500 years, although he did not describe this in detail. This strongly suggests that in this region, the threat of *C. formosanus* has been recognized since prehistory. Due to global warming, *C. formosanus* may well expand its range in Japan (Iwata, 2004); indeed the species was recently recorded in the metropolitan area around Tokyo (e.g. Tomioka *et al.*, 2009). In this case, host-specific termitophiles, like *Japanophilus* and *Sinophilus*, may be unable to expand their ranges as rapidly as their host, as the EKP predicts. In conclusion, we propose that the EKP is a viable method for determination of the natural distribution of *C. formosanus*. Future detailed surveys of host-specific termitophiles in Japan, China and surrounding countries will further resolve the natural geographic range of this species. Such work may prove of great use in efforts to effectively control this notorious pest species in an ecologically-sound manner.

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