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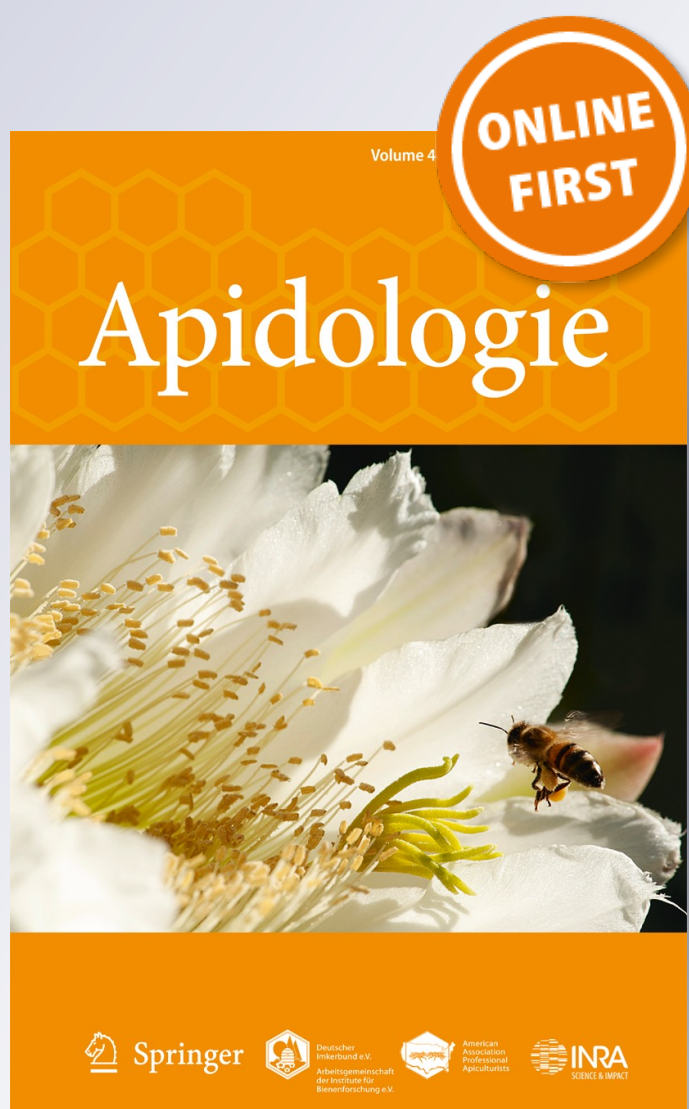
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Parasites, pathogens, and pests of honeybees in Asia

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Abstract – Asia is home to at least nine honeybee species, including the introduced *Apis mellifera*. In addition to *A. mellifera* and *Apis cerana* being widely employed for commercial beekeeping, the remaining nonmanaged species also have important ecological and economic roles on the continent. Species distributions of most honeybee species overlap in Southeast Asia. This promotes the potential for interspecific transmission of pests and parasites and their spread to other parts of the world by human translocation. The decline of honeybee populations is of great concern around the world, including in Asia. The global colony losses of *A. mellifera* are believed to be caused, in part, by parasites, pathogens, and pests originating from Asia, such as the mite *Varroa destructor*, the microsporidian *Nosema ceranae*, and some bee viruses. This review discusses important pests, pathogens, and parasites in both the introduced *A. mellifera* and native honeybees in Asia to provide an overall picture of honeybee health in the region and future threats to the apiculture industry.

Asia / bee virus / *Tropilaelaps* / Asian bee mites / honeybees / bee diseases

1. INTRODUCTION

The natural world is ripe with examples of species population dynamics driven by biotic environmental pressures such as parasites, predators, and pests. Honeybees (*Apis* spp.) are no exception (Ellis and Munn 2005). In recent years, both wild and managed honeybees have experienced dramatic reductions in numbers in various regions of the world (Neumann and Carreck 2010), which has led to a flurry of research into explanations for these observations. The vast majority of these efforts have focused on the western honeybee

(*Apis mellifera*), which is unquestionably the single most globally ubiquitous and economically important honeybee species (Crane 1999). The general consensus is that reductions in *A. mellifera* colony numbers are primarily the consequences of multiple concomitant environmental pressures, of which parasites, pathogens, and pests play an important role (e.g., van Engelsdorp and Meixner 2010; Williams et al. 2010; Neumann and Carreck 2010). Relative to *A. mellifera*, investigations into the health of other honeybee species have taken a backseat, despite their importance to economic and social systems around the world (Crane 1999).

In this review, we focus on parasites, pathogens, and pests of honeybees in Asia. The region hosts multiple species of native honeybees, as well as the introduced *A. mellifera*. Despite the

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importance of these species as a source of bee products and pollination services (Oldroyd and Wongsiri 2006; Sanpa et al. 2015; Pattamayutanon et al. 2015), the health of native Asian honeybees has been relatively less studied compared to that of *A. mellifera*. Furthermore, comparative insights into parasites and pests of *A. mellifera* with native species in Asia provides powerful insights into parasite-host responses among these organisms. This is particularly important because several devastating parasites have host-jumped from native Asian honeybees to *A. mellifera* to become of global concern (Rosenkranz et al. 2010; Fries 2010). First, we introduce honeybee species diversity in the region as well as the interactions of these species with humans. We then review parasite, pathogen, and pest interactions with honeybees in Asia and conclude by providing directions for further investigations that would promote honeybee health in both Asia and abroad.

2. APIS SPECIES DIVERSITY

Asia hosts at least eight native honeybee species, with diversity highest in the tropics (Crane 1999). Multicomb-making cavity-nesting species, *Apis cerana*, *Apis koschevnikovi*, *Apis nigrocincta*, and *Apis nuluensis*, are particularly ubiquitous as a group and are classified as medium-sized bees (Ruttner 1988; Otis 1996; Tingek et al. 1996; Hepburn et al. 2001; Radloff et al. 2005a, b; Hepburn and Hepburn 2006; Takahashi et al. 2007; Tan et al. 2008; Radloff et al. 2010). Residing in protective cavities such as tree hollows, they are also well-known to nest in human-made structures throughout the region (Oldroyd and Wongsiri 2006). Single comb-making open-air-nesting honeybees include the dwarf (*Apis florea* and *Apis andreniformis*) and giant (*Apis dorsata* and *Apis laboriosa*) honeybees (Sakagami et al. 1980; Otis 1996; Oldroyd and Wongsiri 2006; Hepburn and Radloff 2011). This group is limited to subtropical and tropical areas likely due to inherent vulnerability to the elements as a result of their open-nesting habits (Hepburn et al. 2005; Hepburn and Hepburn 2005; Oldroyd and Wongsiri 2006). These species can be found nesting on branches, cliff faces, and even under outcroppings of large urban structures (Crane 2003). Most recently, two new species, *Apis*

indica in southern India and *Apis breviligula* in the Philippines, have been proposed (Lo et al. 2010). They were previously included with *A. cerana* and *A. dorsata*, respectively. In addition to native species, the introduced *A. mellifera* is widespread throughout the region (Wongsiri and Tangkanasing 1987; Crane 1999; Oldroyd and Wongsiri 2006).

3. INTERACTIONS WITH HUMANS

Asians have been associated with honeybees for thousands of years for food, medicinal products, and trade (Crane 1999). Opportunistic honeybee hunting preceded ownership of wild nests by individuals or communities (Oldroyd and Wongsiri 2006). The earliest evidence of annual claims to *A. dorsata* nests occur on rock faces (e.g., China between 265 and 290) (Crane 1999). Managing honeybees in hives first developed using *A. cerana*, whereby hives were fashioned using hollow logs, clay pots, or straw baskets. In western Asian countries like Pakistan and Afghanistan, this management technique occurred as early as 300 BC. In the east, hive beekeeping began in China circa 200. Adoption of beekeeping in other countries was sporadic in history, with Malaysia being one of the last countries to adopt native honeybee hive beekeeping in 1936 (Crane 1999). More recently, large-scale commercial hive beekeeping using *A. cerana* has been developed in temperate areas of China and India (Figure 1a, b). The *A. cerana* subspecies native to these areas are more profitable because they are less likely to abscond than other subspecies found in subtropical and tropical regions (Oldroyd and Wongsiri 2006; Hepburn and Radloff 2011). Nevertheless, due to its relatively greater potential for profitability compared to *A. cerana*, *A. mellifera* was widely imported from Europe, North America, and Oceania starting first in Russia, east of the Urals in the late 1700s, followed by Japan, India, and Indonesia in the late 1800s. By the 1980s, nearly every country in Asia accommodated the introduced *A. mellifera* (Crane 1999; Wu et al. 2006; Arai et al. 2012; Sanpa and Chantawannakul 2009). Asia currently accommodates the largest number of managed *A. mellifera* honeybee colonies in the world (FAO 2014). Organized surveys of *A. mellifera* populations in Asia report lower losses



Figure 1. *Apis cerana* beekeeping in China. **a** Traditional hive (Hubei). **b** Modern box (Chongqing).

of managed colonies compared to Europe and North America (van der Zee et al. 2012). However, few work has focused on populations of native species, particularly because their migratory nature makes their study difficult. Anecdotal reports suggest *A. cerana* in China is under severe pressure from habitat and forage plant losses, displacement by the introduced *A. mellifera*, as well as interspecific transfer of pathogens and parasites (Yang 2005; He and Liu 2011; Li et al. 2012).

4. HEALTH STRESSORS

4.1. Mites

Asian honeybees are indigenous hosts of several species of parasitic mites. The sympatric

existence of different species of honeybees and their associated parasitic mites in Asia potentially promotes the exchange of parasites among them, as well as concurrent infestations by multiple mite species at the colony or individual levels (Anderson 1994; Anderson and Trueman 2000; Buawangpong et al. 2015).

4.1.1. *Varroa* spp.

Within the genus *Varroa*, four mite species are described, *Varroa jacobsoni* (Oudemans 1904), *Varroa underwoodi* (Delfinado-Baker and Aggarwal 1987), *Varroa rindereri* (de Guzman and Delfinado-Baker 1996), and *Varroa destructor* (Anderson and Trueman 2000), all of

which are known parasites of honeybees. First identified was *V. jacobsoni* parasitizing *A. cerana* in Java (Oudemans 1904). However, subsequent investigations in the region described additional species. *V. underwoodi* and *V. rindereri* were observed parasitizing *A. cerana* in Nepal and *A. koschevnikovi* in Borneo, respectively (Delfinado-Baker and Aggarwal 1987; de Guzman and Delfinado-Baker 1996). Reevaluation of *V. jacobsoni* revealed an additional species, *V. destructor*, infecting *A. mellifera* (Anderson and Trueman 2000). This redescription sent shock waves throughout Asia and abroad, as it became apparent that *V. destructor*, rather than *V. jacobsoni*, was the most prevalent *Varroa* mite parasitizing honeybees around the world. *Varroa* species nearly ubiquitously parasitize honeybees throughout Asia (Figure 2).

All species successfully parasitize cavity-nesting honeybees. *V. jacobsoni* infests five honeybee species, including *A. cerana*, *A. koschevnikovi*, *A. mellifera*, *A. nigrocincta*, and *A. nuluensis* (Woyke et al. 1987a; Delfinado-Baker et al. 1989; Koeniger et al. 2002; Otis and Kralj 2001; de Guzman et al. 1996). In contrast, *V. destructor* has only been recorded in *A. cerana* and *A. mellifera* colonies (Anderson and Trueman 2000). *V. underwoodi* is restricted to *A. cerana*, *A. nigrocincta*, and *A. nuluensis*. Unlike its congeners, *V. rindereri* appears to be a species-specific parasite. It was found successfully infesting *A. koschevnikovi*, but was collected from debris of *A. dorsata* in Borneo along with *V. jacobsoni* (Koeniger et al. 2002).

The general morphology and chaetotaxy of the four *Varroa* species are similar. However, several characters such as body size (Table 1) and shape, peritreme size, and length and number of marginal setae can be used to distinguish them. A wide genetic variation within and between *V. jacobsoni* and *V. destructor* populations exists in Asia and may play an important role in the pathogenicity of these parasites. Currently, 24 haplogroups, 15 for *V. jacobsoni* and 9 for *V. destructor*, are recognized (de Guzman and Rinderer 1998, 1999; de Guzman et al. 1997, 1998, 1999; Anderson and Trueman 2000; Fuchs et al. 2000; Zhou et al. 2004; Solignac et al. 2005; Warrit et al. 2006; Navajas et al. 2010), with the

Korean (K) and Japanese (J) haplotypes of *V. destructor* being the most successful parasites of *A. mellifera* (Rosenkranz et al. 2010). Of these, the K haplotype is competitively superior to J and represents the most pathogenic *Varroa* mite haplotype in Asia and abroad. Virulent parasites are generally more competitive than less virulent ones and may possibly displace them (Navajas et al. 2010). Failure to detect J haplotype mites in Thailand that were reported earlier (de Guzman and Rinderer 1999; Anderson and Trueman 2000; Navajas et al. 2010) may be a result of such a displacement event and not an erroneous finding as suggested by Warrit et al. (2006). Recent genetic analysis of *Varroa* mites in Asia revealed new invasions and hybridization between haplogroups (Navajas et al. 2010). The virulence of hybrid mites to honeybees has yet to be established.

In the Philippines, the Papua New Guinea (=Java) *V. jacobsoni* haplotype parasitizes *A. cerana* (de Guzman and Rinderer 1999), and three unresolved *V. destructor* haplotypes are known to reproduce in *A. cerana* drone brood (Anderson 2004). In *A. mellifera* and *A. cerana*, *V. jacobsoni* reproduces in drone brood only (Anderson 1994; Anderson and Sukarsih 1996; Anderson and Fuchs 1998), whereas reproduction of *V. destructor* in *A. cerana* is likely dependent on their haplotype or strain of the host bees (de Jong 1988). Inability of *V. jacobsoni* to reproduce in worker brood of *A. cerana* and *A. mellifera* has most likely limited its distribution and impact as drone brood is seasonally produced and relatively less crucial to overall colony functioning (de Guzman and Rinderer 1999). Variations in mite infestation or reproduction may be attributed to the combined effects of bee behavior, species, and haplogroup of mites. While grooming behavior removes mites from adult bees (Rinderer et al. 2010), hygienic behavior disrupts mite reproductive output when mites and infested developing bees are removed from brood cells (Kirrane et al. 2011). *A. cerana* is particularly well known for such behaviors (Peng et al. 1987a, b).

Although *A. cerana* is the indigenous host of *V. jacobsoni* and *V. destructor*, much of the life histories of the two are based on data using *A. mellifera* as the host. No biological

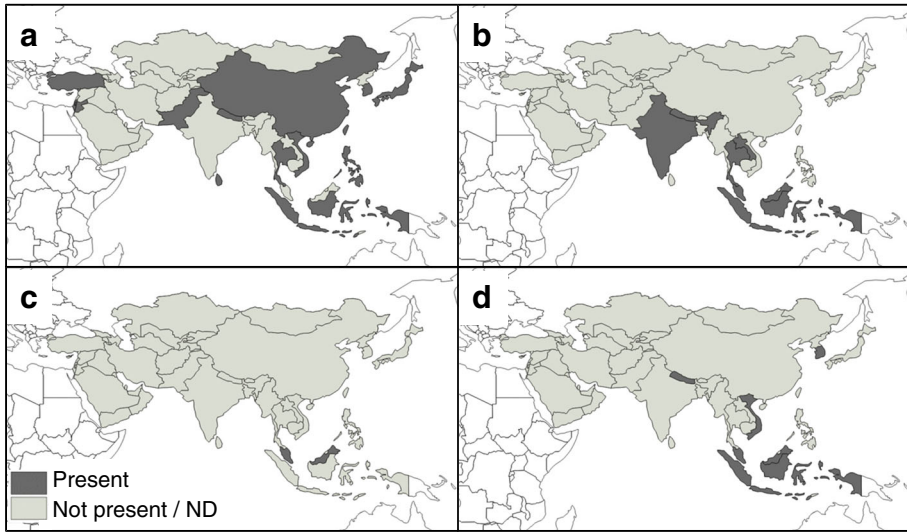


Figure 2. Distribution map of *Varroa* spp. in Asia. **a** *Varroa destructor*, **b** *Varroa jacobsoni*, **c** *Varroa rindereri*, and **d** *Varroa underwoodi*. Dark gray indicates Asian countries where the parasite has been detected in at least one honeybee species; light gray indicates Asian countries where the parasite has not been detected or no data (ND) are available.

observations are available for either *V. rindereri* and *V. underwoodi*. In *A. mellifera*, *V. destructor* reproduces in both worker and drone brood (Anderson and Trueman 2000; Rosenkranz et al. 2010). Female *Varroa* mites enter brood cells before capping, with total developmental time about 6 days (Ifantidis 1990). One female can produce an average of 1.8 and 3 mature daughters in worker and drone brood cells, respectively (Donzé et al. 1996). Mating occurs within the capped brood cell; young mated adults subsequently leave the cell with the emerging bee. Phoresy is a very important phase on the survival, dispersal, and even reproductive success of *Varroa* mites. The phoretic stage lasts from 4 days to a few months, depending on the availability of brood (Martin 1998; Beetsma et al. 1999). While phoretic, mites can feed on adult bees through soft membranes such as those between abdominal tergites (De D'Aubeterre et al. 1999).

Similar to other regions of the world, parasitism by *Varroa* can have devastating consequences for honeybees such as reduced longevity, immunosuppression, and increased viral prevalence and intensity (Rosenkranz et al. 2010). However, pathogenicity is largely specific to the particular mite and honeybee species considered,

with natural parasite-host associations typically less pathogenic. In *A. mellifera*, bee parasitic mite syndrome is a disease complex of colonies simultaneously infested with *V. destructor* mites and infected with viruses (Shimanuki et al. 1994). Detection of bee viruses in *Varroa* mites suggests that mites are potential vectors that facilitate the horizontal transmission of bee viruses among honeybees (Chen and Siede 2007). The coexistence of several bee viruses (Kashmir bee virus (KBV), Acute bee paralysis virus (ABPV), Deformed wing virus (DWV), Sacbrood virus (SBV), and Black queen cell virus (BQCV)) in a single mite suggests that *V. destructor* can be responsible for multiple infections by viruses in apiaries in Thailand (Chantawannakul et al. 2006). This combination of mite infestation and viruses likely aggravates the health of colonies.

4.1.2. *Tropilaelaps* spp.

Four species of *Tropilaelaps* have been described in the mite family Laelapidae. First identified, *Tropilaelaps clareae* was collected from dead *A. mellifera* bees and field rats near beehives in the Philippines (Delfinado and Baker 1961). Twenty years later, *Tropilaelaps koenigerum*

Table 1. Differences in body size for all parasitic mites of honeybees in Asia.

| Mite species | Bee host | Length (μm) | Width (μm) | Reference |
|--------------------------------|------------------|-------------|------------|--|
| Family Varroidae | | | | |
| <i>Varroa jacobsoni</i> | Ac | 1063–1077 | 1507–1596 | Anderson and Trueman (2000), de Guzman and Delfinado-Baker (1996) |
| <i>Varroa destructor</i> | Am, Ac | 1167 | 1709 | Anderson and Trueman (2000) |
| <i>Varroa rindereri</i> | Ak | 1180 | 1698 | de Guzman and Delfinado-Baker (1996) |
| <i>Varroa underwoodi</i> | Ac, Ani, Anu, Am | 690–820 | 1050–1360 | Delfinado-Baker and Aggarwal (1987), Anderson et al. (1997), de Guzman and Rinderer (1999) |
| <i>Eugarroa sinhai</i> | Af | 1040 | 1000 | Delfinado and Baker (1974) |
| <i>Eugarroa wongsirii</i> | Aa | 1000 | 1125 | Lekprayoon and Tangkanasing (1991) |
| Family Laelapidae | | | | |
| <i>Tropilaelaps clareae</i> | Am, Adbr, Adbi | 882–976 | 485–528 | Delfinado and Baker (1961), Anderson and Morgan (2007) |
| <i>Tropilaelaps mercedesae</i> | Am | 979 | 542 | Anderson and Morgan 2007 |
| <i>Tropilaelaps koenigerum</i> | Ad, Al | 684–713 | 428–456 | Delfinado-Baker and Baker (1982), Anderson and Morgan (2007) |
| <i>Tropilaelaps thaii</i> | Al | 890 | 492 | Anderson and Morgan (2007) |
| Family Tarsonemidae | | | | |
| <i>Acarapis woodi</i> | Am | 151 | 86 | Eckert (1961) |
| <i>Acarapis dorsalis</i> | Am | 151 | 81 | Eckert (1961) |
| <i>Acarapis externus</i> | Am | 170 | 105 | Eckert (1961) |

Aa, *A. andreniformis*; Ac, *A. cerana*; Ad, *A. dorsata*; Adbi, *A. d. binghami*; Adbr, *A. d. breviligula*; Af, *A. florea*; Ak, *A. koschevnikovi*; Al, *A. laboriosa*; Am, *A. mellifera*; Ani, *A. nigrocincta*; Anu, *A. nuluensis*

was observed parasitizing *A. dorsata* in Sri Lanka (Delfinado-Baker and Baker 1982). More recently, Anderson and Morgan (2007) described two species, *Tropilaelaps mercedesae* and *Tropilaelaps thaii* parasitizing *A. dorsata* and *A. mellifera* in mainland Asia and *A. laboriosa* in the Himalayas, respectively. Similar to the reclassification of *V. jacobsoni* and *V. destructor* (Anderson and Trueman 2000), *T. mercedesae* was initially described as *T. clareae* (Anderson and Morgan 2007).

Tropilaelaps mites are believed to be indigenous parasites of the giant honeybees, *A. dorsata*, *A. laboriosa*, and *A. breviligula* (Laigo and Morse 1968; Delfinado-Baker et al. 1985; Anderson and Morgan 2007). Since its discovery, all reports on *Tropilaelaps* are from the distribution range of the giant honeybees and therefore

suggest coevolution (Anderson and Morgan 2007). *T. clareae* was first observed infesting *A. mellifera* in the Philippines and recently found parasitizing *A. breviligula* in the Philippines and Sulawesi Island in Indonesia (Anderson and Morgan 2007). Reclassification of *T. mercedesae* by Anderson and Morgan (2007) suggests that the mite parasitizes *A. dorsata* and *A. mellifera* throughout southern mainland Asia and Indonesia, apart from Sulawesi Island, as well as *A. laboriosa* in the Himalayas (Figure 3). Earlier studies classifying *T. mercedesae* as *T. clareae* (Delfinado-Baker 1982; Kapil and Aggarwal 1987; Delfinado-Baker et al. 1989; Wongsiri et al. 1989; Abrol and Putatunda 1995; Koeniger et al. 2002) need to be reexamined. *T. koenigerum* is a parasite of *A. dorsata* in Sri Lanka, mainland Asia, and Indonesia apart from Sulawesi and

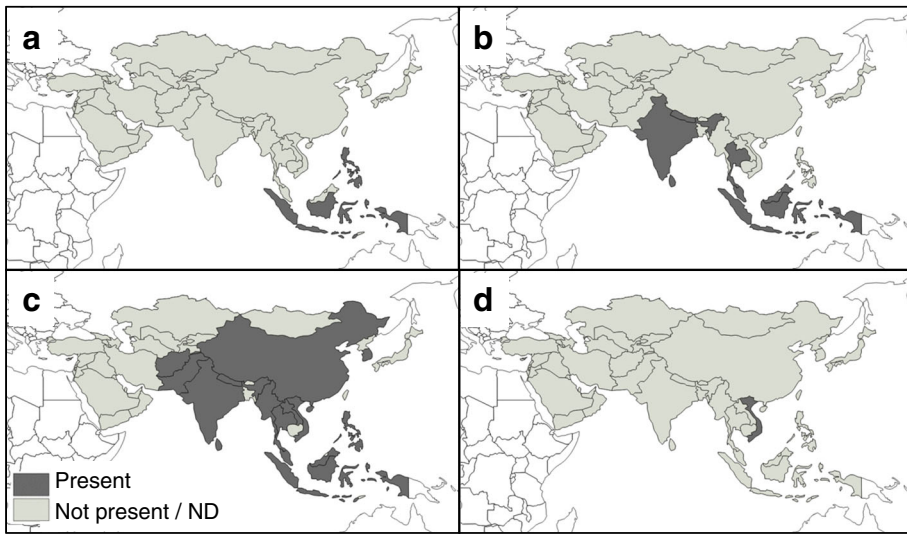


Figure 3. Distribution map of *Tropilaelaps* spp. in Asia. **a** *Tropilaelaps clareae*, **b** *Tropilaelaps koenigerum*, **c** *Tropilaelaps mercedesae*, and **d** *Tropilaelaps thaii*. Dark gray indicates Asian countries where the parasite has been detected in at least one honeybee species; light gray indicates Asian countries where the parasite has not been detected or no data (ND) are available.

Borneo (Delfinado-Baker and Baker 1982; Anderson and Morgan 2007) and is known to coinfect *A. dorsata* colonies in Borneo and Thailand with *T. mercedesae* (Delfinado-Baker et al. 1989; Koeniger et al. 2002). Reproduction by *T. koenigerum* on *A. cerana* brood was observed in India (Abrol and Putatunda 1995) and by one adult *T. mercedesae* in Thailand (Anderson and Morgan 2007). *T. koenigerum* has only been observed in *A. mellifera* debris in Thailand (Kavinseksan, personal communication). Conversely, *T. thaii* has only been observed parasitizing *A. laboriosa* in Vietnam (Anderson and Morgan 2007).

Molecular and morphological techniques can be used to identify *Tropilaelaps* and to study their evolutionary history (Anderson and Morgan 2007). Morphologically, several characters are used to distinguish them, including body size, apex of the epigynial plate, anal plate shape, structure of the apical tooth of the chelicerae, and configuration of the apex of male spermatodactyl. *T. mercedesae* is larger than *T. clareae* or *T. thaii*, with *T. koenigerum* the smallest (Table 1). Molecularly, the most comprehensive survey of *Tropilaelaps* mites to date by Anderson and Morgan (2007) using multiple gene

sequences revealed that of 89 widespread isolates, 46 haplotypes fell into four lineages that can each be considered a separate species. Genetic differences within species were also identified, but require further investigation to better understand their intraspecies phylogenetic relationships.

Much of the life cycle of *Tropilaelaps* is based on *T. mercedesae* infesting *A. mellifera* colonies during a period when it was previously classified as *T. clareae*. Hence, reexaminations are warranted. Like *Varroa* or *Euvarroa*, *Tropilaelaps* also enters brood cells before they are sealed to complete their life cycle (Sammataro 2011). Foundress mites start to lay eggs shortly before the brood cell is capped, which allows nearly all progeny to reach adulthood before the adult bee emerges (Ritter and Schneider-Ritter 1988). The development time for mites is estimated to be approximately 6 and 8.7 days in vivo (Woyke 1987c) and in vitro, respectively (Kitprasert 1984), and a single foundress can produce up to four progeny (Woyke 1987b). Unlike *Varroa* and *Euvarroa* in its indigenous host, *A. dorsata*, *Tropilaelaps* appear to not show a gender preference between worker and drone brood (Koeniger et al. 2002; Buawangpong et al. 2013). The phoretic period of *Tropilaelaps* is short, surviving approximately 1–

3 days on adult bees in vitro (Kitprasert 1984; Woyke 1984; Koeniger and Musaffar 1988; Rinderer et al. 1994). As a result, rapid oviposition, reduced life cycle period, and reproduction in both worker and drone brood cells contribute to relatively higher populations of *Tropilaelaps* in colonies compared to *Varroa* or *Eugarra* (Buawangpong et al. 2015). When both *T. mercedesae* and *V. destructor* are experimentally introduced into an individual brood cell of *A. mellifera*, normal reproduction of both mites was observed (Buawangpong et al. 2015). Natural coinfection of *Varroa* and *Tropilaelaps* does occur in *A. mellifera* brood; however, this is rare (<0.1 %) (Buawangpong et al. 2015). Additionally, *T. koenigerum* and *T. mercedesae* have been found infesting the same *A. dorsata* colony, but not the same brood cell (Delfinado-Baker et al. 1989; Koeniger et al. 2002).

Like *Varroa* and *Eugarra*, pathogenicity of *Tropilaelaps* is believed to be closely tied to specific parasite-host associations. Few studies have evaluated the effects of these mites on honeybees, particularly their native hosts. Anecdotal reports suggest *T. mercedesae* and *T. clareae* severely affect *A. mellifera* throughout the region, whereas *T. koenigerum* and *T. thaii* are believed to be harmless to *A. mellifera* (Burgett et al. 1983; Anderson and Morgan 2007). By using artificial mite inoculation in *A. mellifera* brood, the proportion of nonreproductive *T. mercedesae* was found to be lower than that of *V. destructor*. Both mites produced similar numbers of progeny. In natural infestations of *A. mellifera* in Thailand, the average worker brood infestations of *T. mercedesae* (19.9 %) were significantly higher than that of *V. destructor* (0.7 %). This higher prevalence and reproductive ability of *T. mercedesae* in concurrently infested colonies reaffirm the competitive advantage of *T. mercedesae* over *V. destructor* and their reported negative impact to *A. mellifera* colonies (Buawangpong et al. 2015). Additionally, *T. mercedesae*-inoculated *A. mellifera* pupae showed higher levels and incidence of DWV compared to uninfested pupae (Khongphinitbunjong et al. 2015). The mite has been shown to promote wing deformation and reduce bee longevity in Thailand

(Khongphinitbunjong et al., submitted). Both surveys in China and Thailand suggest the mite can vector DWV (Dainat et al. 2008; Forsgren et al. 2009; Khongphinitbunjong et al. 2015). However, no other bee viruses could be found in *T. mercedesae* and suggest that the major impact of mite infestation is caused by the mite itself (Khongphinitbunjong et al. 2015).

In contrary, *Tropilaelaps* populations are generally found to be low in their natural giant honeybee hosts (Buawangpong et al. 2013). Likely the result of parasite-host coevolution, *A. dorsata* exhibits a high grooming behavior against *T. mercedesae* when compared to *A. mellifera* (Büchler et al. 1992; Koeniger et al. 2002; Khongphinitbunjong et al. 2012). Under artificial mite inoculation, *A. mellifera* removed brood infested with *T. mercedesae* (52.6 %) and peaked during the second and third days post-inoculation (Khongphinitbunjong et al. 2014). Information on hygienic behavior of giant honeybee against *Tropilaelaps* is not available. However, frequent absconding, possibly triggered by high mite infestation, or migration away from the nest, may also play important roles in the suppression of *Tropilaelaps* populations (Koeniger et al. 2002), as would its inability to feed on adult bees (Kitprasert 1984; Woyke 1984; Koeniger and Musaffar 1988; Rinderer et al. 1994; Kavinseksan et al. 2003).

Control of *Varroa* and *Tropilaelaps* mites. Numerous strategies for managing economically important mites of honeybees exist, including the use of chemotherapy, physical, and cultural methods (Sammataro 2011). When unmanaged, *Varroa* and *Tropilaelaps* are responsible for the rapid decline in colony health of *A. mellifera* colonies in Asia (Wongsiri and Tangkanasing 1987; Buawangpong et al. 2015). Although all Asian honeybees have mites associated with them, only *A. mellifera* colonies are managed for mite control because of the relative ease of their management and because the severe economic penalties this species faces when mites are not controlled (Wongsiri and Tangkanasing 1987). Many acaricides used for *V. destructor* control also likely work for *Tropilaelaps* (Sammataro 2011), including tau-fluvalinate, amitraz, formic acid, and

thymol for *T. clareae* on *A. mellifera* in Thailand (Wongsiri and Tangkanasing 1987; Burgett and Kitprasert 1990), Vietnam (Woyke 1987a), and Pakistan (Raffique et al. 2012), respectively. Currently, the use of fluvalinate and coumaphos is widespread throughout the region (Wongsiri and Tangkanasing 1987; Akatanakul 1990). Due to the apparent short lifespan of *Tropilaelaps* on adult bees, interrupting brood rearing by queen caging or by removing all brood from colonies are effective to control *T. mercedesae* in Pakistan (Woyke 1984, 1985). Furthermore, leaves of alagaw (*Premna odorata*) and lemon grass (*Andropogon citratus*) are used to manage both mites with mixed success in the Philippines (Cervancia 1993; Booppha et al. 2010). Breeding for *Varroa* or *Tropilaelaps* resistance has not gained much popularity among Asian countries.

4.1.3. *Euvarroa* spp.

To date, two species from the genus *Euvarroa* are believed to be associated with five honeybee species in Asia: the open-air nesters *A. andreniformis*, *A. florea*, *A. dorsata*, as well as the cavity nesters *A. cerana* and *A. mellifera*. *Euvarroa sinhai* was first observed from *A. florea* samples collected in 1971 in India (Delfinado and Baker 1974), and *Euvarroa wongsirii* was first observed in *A. andreniformis* in Thailand (Lekprayoon and Tangkanasing 1991). These two *Euvarroa* species can be easily distinguished by the shape of their body and number of marginal setae. *E. sinhai* is pear-shaped with 39–40 marginal setae, whereas *E. wongsirii* is triangular or wider posteriorly with 47–54 long setae (Delfinado and Baker 1974; Lekprayoon and Tangkanasing 1991).

Infestations by *E. wongsirii* have only been reported in *A. andreniformis* in Thailand and Malaysia (Lekprayoon and Tangkanasing 1991). *E. sinhai* has been reported in *A. florea* in India, Iran, Sri Lanka, and Thailand (Delfinado and Baker 1974; Koeniger et al. 1983; Mossadegh 1991) and *A. andreniformis* in Thailand (Delfinado-Baker et al. 1989). *E. wongsirii* has not been observed in *A. florea* nests. Nevertheless, both mites have been collected from hive

debris, with *E. sinhai* from *A. mellifera* colonies in India and Thailand (Kapil and Aggarwal 1987; Lekprayoon and Tangkanasing 1991) and *E. wongsirii* from *A. dorsata* in Borneo (Koeniger et al. 2002) (Figure 4). *Euvarroa* infestations are generally low in honeybee colonies, with decreased infestation likely due to host hygienic behavior of dwarf honeybee workers removing dead brood together with their infesting mites (Kitprasert 1995). Limited food supply of the single comb open-air nesters, as well as reduced brood cell diameter of dwarf honeybees, may also contribute to suppressed mite populations (Rinderer et al. 1996). Drone reproduction is also seasonal and swarming further reduces *Euvarroa* populations within colonies by disrupting bee brood and hence mite reproduction (Kitprasert 1995).

Compared to *Varroa*, the life history of *Euvarroa* is not well studied. The limited biological information available is based on observations of *E. sinhai* only, but the life history of the species appears to be similar to that of *Varroa* by parasitizing brood (Sammataro 2011). In vitro study using *A. mellifera* worker brood determined that the life cycle of *E. sinhai* is 5 days for males and 6–7 days for females, which can produce 4.3 progeny per infested *A. mellifera* (Mossadegh 1990). *E. sinhai* also prefers *A. florea* drones over workers (Akatanakul 1975; Mossadegh 1991; Kitprasert 1995). In some cases, a single brood cell can have up to 15 mites (Akatanakul 1975), which may lead to the death of the drone brood (Kitprasert 1995). It appears that the average reproduction of a foundress mite is higher in queenless (3.6 progeny/host) than in queenright (3.3 mites/host) colonies, with seven maximum progeny (Kitprasert 1995). Post-emergence, the mite can survive on adult workers for 4 to 10.5 months during broodless periods (Mossadegh 1990). In the laboratory, *E. sinhai* displayed higher survival on adult *A. mellifera* workers compared to *A. cerana* (Koeniger et al. 1993).

4.1.4. *Acarapis* spp.

Three species of mites are known from the genus *Acarapis*; all are parasites of adult honeybees. First classified was *Acarapis woodi* in the early 1900s in England's Isle of Wight (Rennie

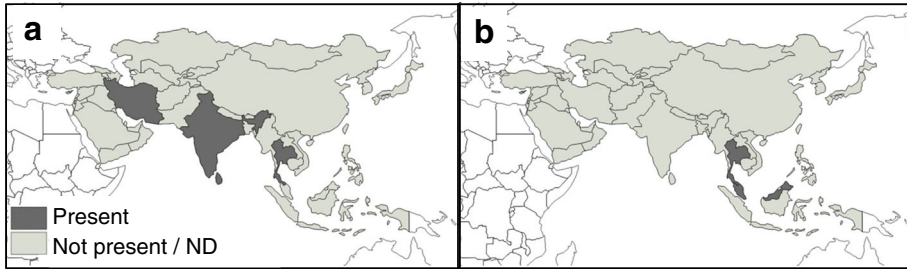


Figure 4. Distribution map of *Euvarroa* spp. in Asia. **a** *Euvarroa sinhai* and **b** *Euvarroa wongsirii*. Dark gray indicates Asian countries where the parasite has been detected in at least one honeybee species; light gray indicates Asian countries where the parasite has not been detected or no data (ND) are available.

1921), followed by *Acarapis dorsalis* and *Acarapis externus* on several continents (Morgenthaler 1934). All three species parasitize honeybees in Asia.

The distribution of the three *Acarapis* species in Asia is not well established. The first report of *A. woodi* parasitizing honeybees in the region came from India (Michael 1957; Milne 1957). The species has since been observed parasitizing *A. mellifera* in Egypt, Iran, Israel, Jordan, Kuwait, Lebanon, Palestine, and Syria (Matheson 1993; Rashad et al. 1985; Gerson et al. 1994; Mossadegh and Bahreini 1994; Amr et al. 1998; OIE 2004), and *A. indica* in India, Pakistan, Bangladesh, and China (Delfinado and Baker 1982). Recently, *A. woodi* was observed in dead bees from collapsing colonies of *A. cerana japonica* in Japan (Kojima et al. 2011). It was also detected in Bhutan, Nepal, Hong Kong and Thailand; however, the honeybee host was not identified (Matheson 1993; Matheson 1995). Only in Iran has *A. dorsalis* and *A. externus* been reported, in this case parasitizing *A. mellifera* colonies (Mossadegh and Bahreini 1994).

The three *Acarapis* species are morphologically similar and are usually identified by the location where they are observed on a honeybee host, in addition to specific morphological differences (Eckert 1961; Delfinado-Baker and Baker 1982). *A. externus* is the largest (Table I). Examination of the distal line of the sternal plates is the most definitive defining feature of each species (Eckert 1961). Molecular tools have also been developed to identify *Acarapis* species (Evans et al. 2007). The total developmental time for *A. woodi* is 11 days, whereas *A. dorsalis* and *A. externus*

take 8–9 days (Royce et al. 1988; Ibay 1989; de Guzman et al. 2001). Eckert (1961) claimed that a female *A. dorsalis* or *A. externus* can lay 2–5 eggs compared an average of 6 eggs for *A. woodi* (Royce et al. 1988).

Although all three *Acarapis* species feed on bee hemolymph, only *A. woodi* is considered to be of economic importance despite the death of colonies highly infested with *A. externus* (Ibay 1989; de Guzman et al. 2001). General symptoms of parasitism by *A. woodi*, at least in *A. indica* and *A. mellifera*, includes bees crawling in front of the hive, a distended abdomen, K-wing, and damaged trachea (Atwal 1971; Sammataro 2011). Virus-like particles have been observed in *A. woodi* (Liu 1991); however, thorough examinations of the potential for the mite to vector viruses like *Varroa* and *Tropilaelaps* mites are lacking.

4.2. Viruses

Viruses of honeybees are nearly ubiquitously distributed throughout the world, with more than 18 isolated to date (Bailey and Ball 1991; Allen and Ball 1996; Chen and Siede 2007). Among them, seven are common including BQCV, DWV, KBV, SBV, ABPV, Chronic bee paralysis virus (CBPV), and Israeli acute paralysis virus (IAPV) (Chen and Siede 2007). In Asia, these seven viruses have been reported to infect different honeybee species throughout the region (Sanpa and Chantawannakul 2009; Ai et al. 2012; Forsgren et al. 2015). Based on their genomic structures, SBV and DWV are classified under

Iflaviridae, whereas BQCV, ABPV, KBV, and IAPV belong to the Dicistroviridae.

4.2.1. Iflaviridae

Of the viruses, SBV is the first virus discovered in *A. mellifera* (White 1913). Historical records from Asia showed that Sacbrood disease was first detected in *A. cerana* from Thailand in 1976 (Bailey et al. 1982). It was named Thailand sacbrood virus (TSBV, also known as Chinese sacbrood virus) since it was serologically related to SBV but physiochemically distinct (Bailey et al. 1982). TSBV caused death of greater than 90 % of domesticated *A. cerana* populations in Kashmir (Abrol and Bhat 1990) and was also found in *A. dorsata* and *A. florea* in India (Allen and Ball 1996). In *A. cerana*, it was observed in India, Thailand, South Korea, Japan, Nepal, China, and Vietnam (Shah and Shah 1988; Allen and Ball 1996; Choi et al. 2008; Kojima et al. 2011; Grabensteiner et al. 2007; Ai et al. 2012; Forsgren et al. 2015). SBV infection of *A. mellifera* colonies was detected in Thailand, South Korea, Japan, China, and Vietnam (Sanpa and Chantawannakul 2009; Yoo et al. 2009; Kojima et al. 2011; Ai et al. 2012; Forsgren et al. 2015).

DWV appears to be more prevalent than SBV in four honeybee hosts. In *A. mellifera*, it was detected in Sri Lanka, Nepal, Thailand, Japan, China, and Vietnam (Berényi et al. 2007; Sanpa and Chantawannakul 2009; Kojima et al. 2011; Ai et al. 2012; Forsgren et al. 2015). DWV infections of *A. cerana* have been reported in China, South Korea, Japan, and Vietnam (Kojima et al. 2011; Ai et al. 2012; Li et al. 2012; Forsgren et al. 2015) and of *A. florea* and *A. dorsata* in China (Zhang et al. 2012). The virus was detected in *V. destructor* and *T. mercedesae* mites, and higher levels of DWV were detected in *A. mellifera* infested by the mites in Thailand (Chantawannakul et al. 2006; Khongphinitbunjong et al. 2015).

4.2.2. Dicistroviridae

BQCV was first isolated from queen larvae and pupae of *A. mellifera* found dead within their cells (Bailey and Woods 1977). The virus is highly

prevalent in *A. mellifera* in Thailand, South Korea, China, Japan, and Vietnam (Sanpa and Chantawannakul 2009; Ai et al. 2012; Yang et al. 2013; Reddy et al. 2013; Kojima et al. 2011; Forsgren et al. 2015); in *A. cerana* in South Korea, China, Vietnam, Thailand, and Japan (Li et al. 2012; Choe et al. 2012; Yang et al. 2013; Forsgren et al. 2015; Mookhploy et al. 2015); and in *A. florea* and *A. dorsata* from China and Thailand (Zhang et al. 2012; Mookhploy et al. 2015). Genetic variations of BQCV strains across four species of honeybees have been studied. Based on the capsid coding region, the phylogenetic analysis revealed that BQCV isolates from northern Thailand, China, South Korea, and Japan displayed a close relationship within Asia and split separately from South Africa and European regions, regardless of the host bee species from which the samples originated (Mookhploy et al. 2015). Similar findings were reported with the BQCV strains in Korea and Japan where the viral isolates from the same country or continent showed high levels of similarity (Kojima et al. 2011; Noh et al. 2013). The role of BQCV in honeybee mortality is currently poorly understood, particularly in association with other parasites such as the microsporidian *Nosema apis* (Bailey et al. 1983).

ABPV, KBV, and IAPV are part of a complex of related viruses (Chen and Siede 2007; de Miranda et al. 2010). KBV was first confirmed in *A. cerana* in India (Bailey and Woods 1977) and subsequently in South Korea (Choe et al. 2012). Surveys of bee viruses in *A. mellifera* colonies found KBV in Thailand (Sanpa and Chantawannakul 2009). Interestingly, KBV was not found in China and Vietnam during the disease surveys in both *A. cerana* and *A. mellifera* (Ai et al. 2012; Forsgren et al. 2015). ABPV has only been detected in *A. cerana* (Choe et al. 2012) and in *A. mellifera* in China (Ai et al. 2012; Forsgren et al. 2015) and Thailand (Sanpa and Chantawannakul 2009). IAPV has been detected in both *A. mellifera* and *A. cerana*: in *A. mellifera* in China (Ai et al. 2012), South Korea (Reddy et al. 2013), Japan (Morimoto et al. 2012), and Israel (Maori et al. 2007) and in *A. cerana* in China (Ai et al. 2012) and Japan (Kojima et al. 2011).

These viruses have been associated with honeybee colony losses, particularly when colonies are coinfecting with *V. destructor* (Cox-Foster et al. 2007; de Miranda et al. 2010). In northern Thailand, KBV was only found when *V. destructor* prevalence was high in *A. mellifera* colonies (Sanpa and Chantawannakul 2009).

4.3. Fungi

4.3.1. *Nosema* spp.

Two species of parasites belonging to this genus are known to infect honeybees, and both occur in Asia (Klee et al. 2007). *N. apis*, first described in the early 1900s in Europe (Zander 1909), is believed to historically parasitize *A. mellifera* (Fries 1993). *N. ceranae* appears to have an Asian origin (Botías et al. 2012) since it was first detected in *A. cerana* in China in the late 1990s (Fries et al. 1996).

Surveys have identified *N. apis* in *A. mellifera* (e.g., Klee et al. 2007) and *A. cerana* (Rice 2001) only. In contrast, *N. ceranae* parasitizes a broader array of hosts such as *A. mellifera*, *A. cerana*, *A. florea*, *A. dorsata*, and *A. koschevnikovi* (e.g., Klee et al. 2007; Chaimanee et al. 2010; Botías et al. 2012). Although both parasites have been detected throughout the region, *N. ceranae* appears to be more widespread (Figure 5a, b). In *A. mellifera*, *N. ceranae* was identified in Taiwan (Huang et al. 2007), Vietnam (Klee et al. 2007), China (Liu et al. 2008), Thailand (Chaimanee et al. 2010), Turkey (Whitaker et al. 2011), Indonesia (Botías et al. 2012), Solomon Islands (Botías et al. 2012), Japan (Yoshiyama and Kimura 2011), and Jordan (Haddad 2014). *N. apis* was detected in Israel (Gatehouse and Malone 1999), Indonesia (Rice 2001), and Turkey (Whitaker et al. 2011). *A. mellifera* colonies in China (Liu et al. 2008), Thailand (Chaimanee et al. 2010), or Jordan (Haddad 2014) were not infected with *N. apis*. Investigations of the incidence of *Nosema* spp. on honeybees native to Asia have been less thorough. In *A. cerana*, *N. ceranae* was identified in China, Vietnam, Indonesia, Solomon Islands, and Thailand (Fries et al. 1996; Klee et al. 2007; Li et al. 2012;

Forsgren et al. 2015; Botías et al. 2012; Chaimanee et al. 2010) and also detected in *A. florea* and *A. dorsata* in Thailand (Chaimanee et al. 2010).

Studies comparing the phylogenetic relationships among *N. ceranae* isolated from four different honeybee species in Thailand using polar tube proteins, important for microsporidian host invasion, showed three distinct clades (Chaimanee et al. 2011). *N. ceranae* isolated from *A. mellifera* grouped into the same clade as *N. ceranae* isolated from *A. cerana*, while *N. ceranae* isolated from *A. florea* and *A. dorsata* formed distinct clades. *A. mellifera* and *A. cerana* are cavity-nesting honeybees and are therefore more related to each other than to open-air, single comb-nesting species such as *A. dorsata* and *A. florea* (Alexander 1991). Therefore, the formation of a single clade for *N. ceranae* isolates from the cavity-nesting species reflects the genetic lineage of *A. mellifera* and *A. cerana* and suggests ongoing coevolution of this pathogen and its host. This is interesting considering that the parasite supposedly came from *A. cerana*. In China, however, studies using the 16S ribosomal RNA gene demonstrated that *N. ceranae* infecting *A. cerana* in the north and south were distinct and also different from *N. ceranae* circulating in *A. mellifera* worldwide. Thai isolates fell into the same clade as those from southern China (Li et al. 2012).

Although *Nosema* are considered to be generalists, parasitizing a broad array of honeybee hosts, their prevalence and intensity of infection are different for each species. For *N. ceranae*, it appears that prevalence of infections in native honeybees is much lower compared to *A. mellifera*, as colonies surveyed in Thailand revealed infection prevalences of 77.5, 22.2, 45.4, and 37.5 % for *A. mellifera*, *A. cerana*, *A. florea*, and *A. dorsata*, respectively (Chaimanee et al. 2010). When infected with *N. ceranae* obtained from *A. mellifera* from Thailand, all four honeybee species became infected. However, different levels of intensity were observed. The infection rate of *A. dorsata* was similar to that found in *A. mellifera*, but *A. florea* was lower and *A. ceranae* the lowest (Chaimanee et al. 2011). Suwannapong et al. (2011) also

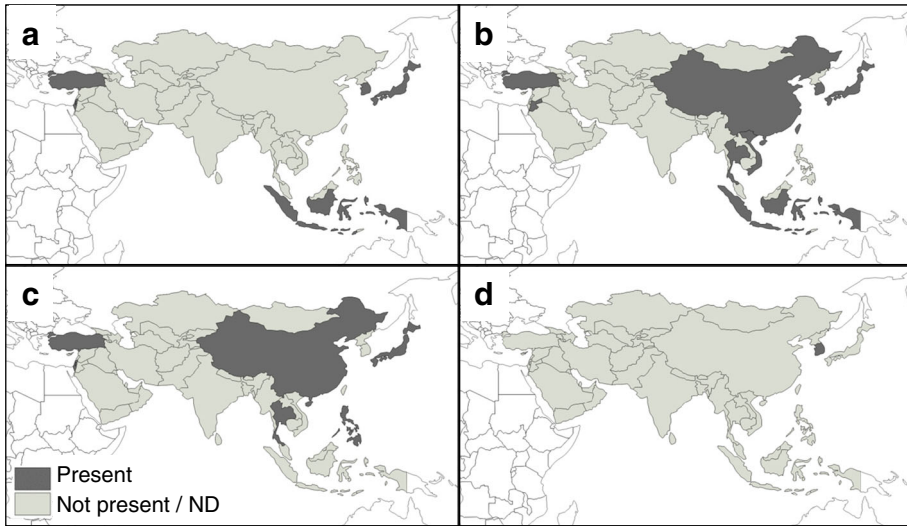


Figure 5. Distribution map of fungal pathogens and diseases in Asia. **a** *Nosema apis*, **b** *Nosema ceranae*, **c** Chalkbrood, and **d** Stonebrood. Dark gray indicates Asian countries where the parasite has been detected in at least one honeybee species; light gray indicates Asian countries where the parasite has not been detected or no data (ND) are available.

observed that *N. ceranae* isolated from *A. florea* could infect *A. ceranae* and affect hypopharyngeal protein production and shorten their lifespan.

The virulence between *N. ceranae* strains from the original host *A. cerana* and *A. mellifera* has been explored in these two cavity-nesting species. *N. ceranae* isolated from *A. mellifera* had higher infectivity than the isolate from *A. cerana* in both *A. mellifera* and *A. cerana* (Chaimanee et al. 2013). It appears that no difference in infection rate occurred, but rather each host species had displayed varied immune-related gene expression patterns in response to the infection (Chaimanee and Chantawannakul 2015).

In response to infection, *A. cerana* workers infected by *N. ceranae* tended to have lower bacterial populations, particularly *Bifidobacterium* and Pasteurellaceae that produce several antibiotic compounds important to host defense against parasites (Li et al. 2012). *N. ceranae* may also promote the outbreak of other bee diseases, such as Chalkbrood (Hedtke et al. 2011).

Both parasites can be managed by the fungicide fumagillin, but to varying degrees of success that require further examination of timing and

quantity of treatments (Akratanakul 1990; Williams et al. 2008, 2011; Huang et al. 2013).

4.3.2. *Ascosphaera apis*

The fungus *A. apis*, which causes Chalkbrood disease in honeybees, was first described in the early twentieth century in *A. mellifera* in Europe (Maassen 1913) and now is found throughout the world. In Asia, incidence of Chalkbrood has been reported in China, Israel, Japan, Korea, the Philippines, Russia, Thailand, and Turkey (Figure 5c) (Oldroyd and Wongsiri 2006; Aronstein and Murray 2010). In Turkey, it was believed to have been introduced from contaminated beeswax which was imported to the country (Tutkun et al. 1993). In the Philippines and Thailand, beekeepers often reported higher incidence of fungal infection during the wet season (Cervancia 1993; Chantawannakul and Puchanichanthranon 2005). Ingestion of the fungus by honeybee larvae allows *A. apis* to germinate within the gut and eventually penetrate the body cavity, resulting in significant mechanical and enzymatic damage; dead, dried larvae, named Chalkbrood mummies, can be observed within uncapped brood cells (Heath 1982; Aronstein and Murray 2010). The fungus can

produce lytic enzymes (protease and beta-N-acetylglucosaminidase) that may be an important factor that assists fungal invasion in the bee larvae; the enzymatic patterns from Thai isolates were similar to the previous report of Spanish isolates (Theantana and Chantawannakul 2008). In *A. mellifera*, Chalkbrood disease can result in lowered colony productivity, but rarely results in colony death (Heath 1982; Aronstein and Murray 2010). It is also not considered to be a serious disease of honeybees in Asia, even though it has been reported more widespread than Stonebrood disease which is caused by fungi from the genus *Aspergillus* (Akratanakul 1990; Ra et al. 2012) (Figure 5c, d).

4.4. Bacteria

4.4.1. *Paenibacillus larvae*

P. larvae, the causative agent of a disease called American foulbrood (AFB), has a nearly ubiquitous distribution, including in Asia (Genersch 2010) (Figure 6a). The disease was found in *A. cerana* in India (Singh 1961) and *A. mellifera* in Taiwan (Yen and Chyn 1971). However, a survey conducted in 2003 in Thailand revealed that *A. mellifera* was free of this disease (National Bureau of Agricultural Commodity and Food Standards 2008). Bee larvae become infected when *P. larvae* spores are ingested; disease results in larvae that are brownish, semifluid, and glue-like, before drying to a hard scale on the lower cell wall (Genersch 2010). Scales are highly infective and contain millions of spores that may

be infective for several decades (Hasemann 1961). When artificially fed spores of *P. larvae*, *A. cerana* showed more resistance to infection than *A. mellifera* (Ho and Chen 2001).

4.4.2. *Melissococcus plutonius*

M. plutonius is a ubiquitously distributed bacterium of honeybees that has been detected throughout Asia, including in *A. mellifera* (Akratanakul 1990), *A. cerana* (Diwan et al. 1971; Bailey 1974; Zhou et al. 2000; Rana et al. 2012), *A. laboriosa* (Allen et al. 1990), and *A. florea* (Saraithong et al. 2015) (Figure 6b). *M. plutonius* primarily affects honeybee larvae, causing a disease known as European foulbrood (EFB) that is characterized by dead, twisted, brood within their cells. Infected colonies can be killed if a high proportion of larvae are infected (Bailey and Ball 1991). EFB was detected in *A. mellifera* beekeeping in China, Vietnam, Japan, and Thailand (Forsgren et al. 2015; Aronstein and Murray 2010; Budge et al. 2010). In Thailand, EFB is particularly prevalent during the wet season (Akratanakul 1990). It was also reported to cause serious damage to colonies of *A. cerana* in China between 1972 and 1976 (Yang 2005), Vietnam (Forsgren et al. 2015), and recently, in Japan (Arai et al. 2012; Takamatsu et al. 2014). A phenotypically and genetically distinct *M. plutonius* strain has been isolated from *A. cerana japonica*; it is frequently found and more virulent than the typical strain (Arai et al. 2014; Takamatsu et al. 2014).

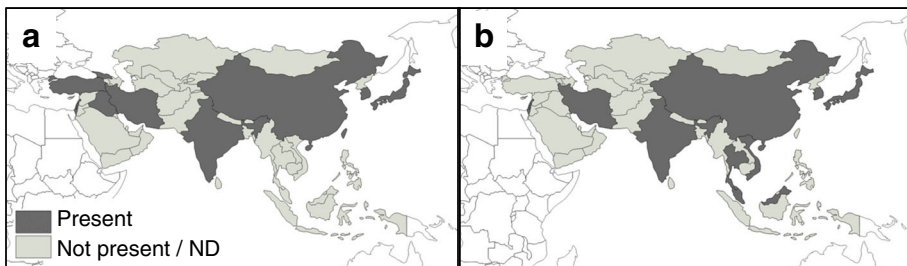


Figure 6. Distribution map of bacteria diseases. **a** American foulbrood and **b** European foulbrood in Asia. Dark gray indicates Asian countries where the parasite has been detected in at least one honeybee species; light gray indicates Asian countries where the parasite has not been detected or no data (ND) are available.

4.5. Pests

4.5.1. Vertebrates

Bee-eating birds. Bee-eating birds are also troublesome to *A. mellifera*; they include the little green bee eater (*Merops orientalis*), the chestnut headed bee eater (*Merops leschenaulti*), the swifts (*Crypsiurus balasiensis*, *Chaetura* spp.), the white-vented needletail (*Hirundapus cochinchinensis*), the wood peckers (*Picus* spp.), the honeyguides (Indicatoridae), the black drongo (*Dicrurus macrocercus*), the ashy drongo (*Dicrurus leucophaeus*), and the greater racket-tailed drongo (*Dicrurus paradiseus*) (Akratanakul 1990; Cervancia 1993; Wongsiri et al. 2005). In some cases, beekeepers will employ net-trapping to limit bird predation or relocate their colonies.

4.5.2. Invertebrates

Wax moths. Moth larvae attack the combs of honeybees worldwide. The greater wax moth, *Galleria mellonella*, and the lesser wax moth, *Achroia gisella*, are small nondescript moths that lay eggs in cracks and crevices of bee hives (Akratanakul 1990). Wax moths are a problem for unused or stored combs (Pernal and Clay 2013). Recently, larvae of *G. mellonella* attacking colonies of *A. cerana japonica* were collected in Japan. These samples also tested positive for IAPV and BQCV (Triyasut et al. 2015). The viruses were likely horizontally transmitted to the wax moth larvae by food or brood consumption within the colonies; however, viral replication in the wax moth larvae was not detected. Future work needs to clarify the possible role of bee viruses in moth larvae. In Southeast Asia, wax moths are a major pest of *A. cerana*, and causes them to abscond (Akratanakul 1990). Chemical controls are usually not applied for wax moth management. Instead, cultural measures such as removing hive debris, managing colonies to be strong, and removing or burning unused and infested combs are recommended.

Small hive beetle (*Aethina tumida*) *A. tumida* is now an emerging pest of honeybees in Asia since it was discovered in the region for the first time in the Philippines in 2014 (Brion 2015). Between June 2014 and April 2015, hundreds of *A. mellifera* colonies in Mindanao (southern Philippines) had been lost from SHB infestation. The beetle is an opportunistic scavenger (Neumann and Elzen 2004). Mild climates of southern Asia provide an exceptional environment for *A. tumida*; high temperatures shorten the development period of the beetle (de Guzman and Frake 2007), and year-round availability of food (brood, pollen, and honey) from multiple honeybee species promotes fecundity (de Guzman et al. 2015). Therefore, both native and introduced honeybee species, as well as stingless bees, are threatened by the beetle. Investigations are underway to adapt control measures employed in North America and Australia for the region.

Wasps (*Vespa* spp.). *Vespa* spp. are important predators of honeybees in Asia (Matsuura 1988). Entrances of honeybee colonies are often targeted, with one wasp capable of capturing seven bees in one attack (Cervancia 1993). Such a disturbance can result in *A. cerana* colonies to abscond. Furthermore, some species are known to predate on *A. cerana* drones at drone congregation areas (Koeniger et al. 1994). To deter predation, *A. cerana*, *A. nuluensis*, and *A. dorsata* perform body shaking as a defense mechanism (Koeniger et al. 1996; Kastberger et al. 1998; Tan et al. 2010; Khongphinitbunjong et al. 2012), and *A. cerana* and *A. mellifera* make tight balls that kill wasp intruders by heating (Ono et al. 1987; Tan et al. 2005). Beekeepers sometimes employ wasp traps or reduce the hive entrance and also frequently kill wasps by hitting them with slippers, pieces of wood, or badminton rackets (Cervancia 1993). Furthermore, toxic baits may be used to poison wasp nest mates.

Ants. Many ant species can cause problems in commercial beekeeping. Most frequent recorded ant species are weaver ant (*Oecophylla smaragdina*), black ants (*Monomorium* spp.), fire ants (*Solenopsis* spp.), and *Formica* spp. (Akratanakul 1990).

Bee lice (*Braula coeca*) *B. coeca* wingless flies are not considered to be an important pest of honeybees (Pernal and Clay 2013). Larvae consume wax, pollen, and honey and tunnel through the combs. The adults eat nectar and pollen and steal food from the mouths of bees. Treatments for parasitic mites are also found effective against *B. coeca* (Kulincevic et al. 1991).

5. CONCLUSIONS AND FUTURE PERSPECTIVES

With the introduction of *A. mellifera* in the region, native Asian honeybees are also at a greater risk of pathogen and parasite infections from interspecies transmission routes. Likewise, *A. mellifera* could be susceptible to further pests and parasites from native honeybees, which was previously exemplified by infestation by *V. destructor* and *N. ceranae* (Fries 2010; Rosenkranz et al. 2010). The rich diversity of honeybees, pathogens, and parasites in Asia has attracted researchers around the world to better understand host-parasite evolution and to improve management of introduced exotic parasites of *A. mellifera* that have come from Asia by studying those parasites with their indigenous hosts. Many reports suggest that native Asian honeybees cope well with parasites that are currently devastating to *A. mellifera* using behavioral and immunological host defense mechanisms (Khongphinitbunjong et al. 2012; Chaimanee et al. 2010). The migratory nature of several species of native Asian honeybees may also affect susceptibility of infection or infestation (Kavinseksan et al. 2003). The resistance of Asian honeybees toward some bacterial pathogens may be due to their unique bacterial community structures inhibiting pathogen growth or infection. Studies have shown that gut bacteria in *A. mellifera*, *A. cerana*, *A. florea*, and *A. dorsata* differ, likely due to geographic location, life stage, and species of honeybees (Disayathanoowat et al. 2011; Saraithing et al. 2015a, b). Furthermore, some isolates of midgut bacteria inhibit growth of

American foulbrood causing *P. larvae* in vitro (Disayathanoowat et al. 2011, 2012). Honeybee hives also harbor actinomycetes, the main microbial groups that produce natural antibiotics (Promnuan et al. 2009, 2011), and hive components such as propolis and bee bread could also assist in safeguarding against some pests and parasites (Simone-Finstrom and Spivak 2012; Simone et al. 2009). Additionally, other nonbiological factors and management problems that plague not just honeybees, but other bees, could also result in decreased honeybee health in Asia. Increasing loss of foraging resources due to farming and urban encroachment may strain populations (Naug 2009). Pesticide exposure could also present high risks to honeybees, and a recent study revealed that organophosphates are highly toxic to *A. cerana* and *A. mellifera* (Stanley et al. 2015). The current policy of pollinator protection, especially honeybees, has not yet been successfully implemented in the region as honeybees are often undervalued or the value of honeybees is completely overlooked. Scientific information of honeybee pests and parasites in some regions are still lacking. In addition, standards and research on biomedical properties of bee products, such as honey (Wanjai et al. 2012) and propolis (Sanpa et al. 2015), are needed to promote beekeeping in Asia.

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Ravageurs, pathogènes et parasites des abeilles en Asie

Asie / virus / *Tropilaelaps* / Acari / abeilles asiatiques / santé des abeilles / agent pathogène

Schädlinge, Krankheiten und Parasiten von Honigbienen in Asien

Asien / Bienenviren / *Tropilaelaps* / Asiatische Bienenmilben / Honigbienen / Krankheitserreger

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