

Apidologie

Pests, pathogens, and parasites of honey bees in Asia

--Manuscript Draft--

Manuscript Number:	APID-D-15-00082R2	
Full Title:	Pests, pathogens, and parasites of honey bees in Asia	
Article Type:	Review Article	
Keywords:	Asia; Bee virus; Tropilaelaps; Asian bee mites; honey bees; pathogen	
Corresponding Author:	Panuwan Chantawannakul, PhD Chiang Mai University A. Meung, Chiang Mai THAILAND	
Corresponding Author Secondary Information:		
Corresponding Author's Institution:	Chiang Mai University	
Corresponding Author's Secondary Institution:		
First Author:	Panuwan Chantawannakul, PhD	
First Author Secondary Information:		
Order of Authors:	Panuwan Chantawannakul, PhD Lilia I de Guzman, PhD Jilian Li, PhD Geoffrey R. Williams, PhD	
Order of Authors Secondary Information:		
Funding Information:	Thailand Research Fund (TH)	Dr Panuwan Chantawannakul
	National Research Council of Thailand (TH)	Dr Panuwan Chantawannakul
	Chiang Mai University (TH)	Dr Panuwan Chantawannakul
Abstract:	<p>Asia is home to at least nine honey bee species, including the introduced <i>Apis mellifera</i>. In addition to <i>A. mellifera</i> and <i>Apis cerana</i> being widely employed for commercial beekeeping, the remaining non-managed species also have important ecological and economic roles on the continent. Species distributions of most honey bee 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 honey bee populations is of great concern around the world, including in Asia. The global colony losses of <i>A. mellifera</i> are believed to be caused, in part, by pests, pathogens and parasites originating from Asia, such as the mite <i>Varroa destructor</i>, the microsporidian <i>Nosema ceranae</i>, and some bee viruses. This review discusses important pests, pathogens and parasites in both the introduced <i>A. mellifera</i> and native honey bees in Asia to provide an overall picture of honey bee health in the region and future threats to the apiculture industry.</p>	
Response to Reviewers:	<p>Dear Editor,</p> <p>All minor comments have been edited except: - line 364 & 383 , we have re checked the original article and the authors refer to '<i>Apis indica</i>'. Therefore, we did not change the species name to '<i>A. cerana</i>'.</p> <p>We have shorten the section 2 and 3 regarding to the editor 's suggestion.</p> <p>With my best regards Panuwan Chantawannakul</p>	

October 7th, 2015

Dear Editor,

Attached is the manuscript entitled “**Pests, pathogens, and parasites of honey bees in Asia**” This is a revised manuscript APID-D-15-00082R1, and in this version, the manuscript has been edited regarding to all your comments and suggestions. We have shorten the Section 2 &3 and the length of current version is 81,010 characters including 228 references. We also changed the previous title (Parasites and pests of honey bee in Asia) to cover all parts of our review. We hope that our review would benefit the readers of Apidologie (special issue) especially ones who are interested to gain bee health information in Asia.

We are looking forward to hearing from you. Thank you very much for handling our manuscript.

Sincerely yours,



Assoc. Prof. Dr. Panuwan Chantawannakul

Corresponding author

1 **Pests, pathogens, and parasites of honey bees in Asia**

2

3 Panuwan Chantawannakul^{1*}, Lilia I. de Guzman², Jilian Li³, Geoffrey R. Williams^{4,5}

4

5 ¹Bee Protection laboratory (BeeP), Department of Biology, Faculty of Science, Chiang Mai
6 University, 50200 Thailand

7 ²USDA-ARS, Honey Bee Breeding, Genetics and Physiology Laboratory, Baton Rouge,
8 Louisiana, 70820 USA

9 ³Institute of Apicultural Research, Chinese Academy of Agricultural Sciences, Beijing,
10 100093 China

11 ⁴Institute of Bee Health, Vetsuisse Faculty, University of Bern, Bern, 3003 Switzerland

12 ⁵Agroscope, Swiss Bee Research Centre, Bern, 3003 Switzerland

13

14 *Corresponding author: panuwan@gmail.com

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16

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

29

30 **Keywords:** Asia/ Bee virus/ *Tropilaelaps* / Asian bee mites/ honey bees/ pathogen

31

32

33 1. INTRODUCTION

34 The natural world is ripe with examples of species population dynamics driven by the
35 biotic environmental pressures such as parasites, predators, and pests. Honey bees (*Apis* spp.)
36 are no exception (Ellis and Munn 2005). In recent years both wild and managed honey bees
37 have experienced dramatic reductions in numbers in various regions of the world (Neumann
38 and Carreck 2010), which has led to a flurry of research into explanations for these
39 observations. The vast majority of these efforts have focused on the western honey bee (*Apis*
40 *mellifera*), which is unquestionably the single most globally ubiquitous and economically
41 important honey bee species (Crane 1999). The general consensus is that reductions in *A.*
42 *mellifera* colony numbers are primarily the consequences of multiple concomitant
43 environmental pressures, of which parasites and pests play an important role (e.g.
44 vanEngelsdorp and Meixner 2010; Williams et al. 2010; Neumann and Carreck 2010).
45 Relative to *A. mellifera*, investigations into the health of other honey bee species has taken a
46 backseat, despite their importance to economic and social systems around the world (Crane
47 1999).

48 In this review we focus on parasites and pests of honey bees in Asia. The region hosts
49 multiple species of native honey bees, as well as the introduced *A. mellifera*. Despite the
50 importance of these species as a source of bee products and pollination services (Oldroyd and
51 Wongsiri 2006; Sanpa et al. 2015; Pattamayutanon et al. *in press*), the health of native Asian
52 honey bees has been relatively less studied compared to that of *A. mellifera*. Furthermore,
53 comparative insights into parasites and pests of *A. mellifera* with native species in Asia
54 provides powerful insights into parasite-host responses among these organisms. This is
55 particularly important because several devastating parasites have host-jumped from native
56 Asian honey bees to *A. mellifera* to become of global concern (Rosenkranz et al. 2010; Fries
57 2010). First, we introduce honey bee species diversity in the region as well as the interactions
58 of these species with human. We then review pest, pathogen, and parasite interactions with

59 honey bees in Asia, and conclude by providing directions for further investigations that would
60 promote honey bee health in both Asia and abroad.

61

62 2. *APIS* SPECIES DIVERSITY

63 Asia hosts at least eight native honey bee species, with diversity highest in the tropics
64 (Crane 1999). Multi-comb-making cavity-nesting species, *Apis cerana*, *Apis koschevnikovi*,
65 *Apis nigrocincta*, and *Apis nuluensis* are particularly ubiquitous as a group and are classified
66 as medium-sized bees (Ruttner 1988; Otis 1996; Tingek et al. 1996; Hepburn et al. 2001;
67 Radloff et al. 2005a; Radloff et al. 2005b; Hepburn and Hepburn 2006; Takahashi et al. 2007;
68 Tan et al. 2008; Radloff et al. 2010). Residing in protective cavities such as tree hollows, they
69 are also well-known to nest in human-made structures throughout the region (Oldroyd and
70 Wongsiri 2006). Single-comb-making open- air- nesting honey bees include the dwarf (*Apis*
71 *floreana* and *Apis andreniformis*) and giant (*Apis dorsata* and *Apis laboriosa*) honey bees
72 (Sakagami et al. 1980; Otis 1996; Oldroyd and Wongsiri 2006; Hepburn and Radloff 2011).
73 This group is limited to sub-tropical and tropical areas likely due to inherent vulnerability to
74 the elements as a result of their open-nesting habits (Hepburn et al. 2005; Hepburn and
75 Hepburn 2005; Oldroyd and Wongsiri 2006). These species can be found nesting on branches,
76 cliff faces, and even under outcroppings of large urban structures (Crane 2003). Most
77 recently, two new species *Apis indica* in southern India and *Apis breviligula* in the Philippines
78 have been proposed (Lo et al. 2010). They were previously included with *A. cerana* and *A.*
79 *dorsata*, respectively. In addition to native species, the introduced *A. mellifera* is widespread
80 throughout the region (Wongsiri and Tangkanasing 1987; Crane 1999; Oldroyd and Wongsiri
81 2006).

82

83 3. INTERACTIONS WITH HUMANS

84 Asians have been associated with honey bees for thousands of years for food, medicinal
85 products, and trade (Crane 1999). Opportunistic honey bee hunting preceded ownership of
86 wild nests by individuals or communities (Oldroyd and Wongsiri 2006). The earliest evidence
87 of annual claims to *A. dorsata* nests occur on rock faces (e.g China between 265 and 290)
88 (Crane 1999). Managing honey bees in hives first developed using *A. cerana*, whereby hives
89 were fashioned using hollow logs, clay pots, or straw baskets. In western Asian countries like
90 Pakistan and Afghanistan, this management technique occurred as early as 300 BC. In the
91 east, hive beekeeping began in China circa 200. Adoption of beekeeping in other countries
92 was sporadic in history, with Malaysia being one of the last countries to adopt native honey
93 bee hive beekeeping in 1936 (Crane 1999). More recently, large scale commercial hive
94 beekeeping using *A. cerana* have been developed in temperate areas of China and India (Fig.
95 1A&B). The *A. cerana* subspecies native to these areas are more profitable because they are
96 less likely to abscond than other subspecies found in sub-tropical and tropical regions
97 (Oldroyd and Wongsiri 2006; Hepburn and Radloff 2011). Nevertheless, due to its relatively
98 greater potential for profitability compared to *A. cerana*, *A. mellifera* was widely imported
99 from Europe, North America, and Oceania starting first in Russia, east of the Urals in the late
100 1700s, followed by Japan, India, and Indonesia in the late 1800s. By the 1980s, nearly every
101 country in Asia accommodated the introduced *A. mellifera* (Crane 1999; Wu et al. 2006; Arai
102 et al. 2012; Sanpa and Chantawannakul 2009). Asia currently accommodates the largest
103 number of managed *A. mellifera* honey bee colonies in the world (FAO 2014). Organized
104 surveys of *A. mellifera* populations in Asia report lower losses of managed colonies compared
105 to Europe and North America (van der Zee et al. 2012). However, few work has focused on
106 populations of native species, particularly because their migratory nature makes their study
107 difficult. Anecdotal reports suggest *A. cerana* in China is under severe pressure from habitat

108 and forage plant losses, displacement by the introduced *A. mellifera*, as well as inter-specific
109 transfer of pathogens and parasites (Yang 2005; He and Liu 2011; Li et al. 2012).

110

111 4. HEALTH STRESSORS

112 4.1 Mites

113 Asian honey bees are indigenous hosts of several species of parasitic mites. The
114 sympatric existence of different species of honey bees and their associated parasitic mites in
115 Asia potentially promotes the exchange of parasites among them, as well as concurrent
116 infestations by multiple mite species at the colony or individual levels (Anderson 1994;
117 Anderson and Trueman 2000; Buawangpong et al. 2015).

118

119 *Varroa* spp.

120 Within the genus *Varroa*, four mite species are described, *Varroa jacobsoni*
121 (Oudemans 1904), *Varroa underwoodi* (Delfinado-Baker and Aggarwal 1987), *Varroa*
122 *rindereri* (de Guzman and Delfinado-Baker 1996), and *Varroa destructor* (Anderson and
123 Trueman 2000), all of which are known parasites of honey bees. First identified was *V.*
124 *jacobsoni* parasitizing *A. cerana* in Java (Oudemans 1904). However, subsequent
125 investigations in the region described additional species. *V. underwoodi* and *V. rindereri* were
126 observed parasitizing *A. cerana* in Nepal and *A. koschevnikovi* in Borneo, respectively
127 (Delfinado-Baker and Aggarwal 1987; de Guzman and Delfinado-Baker 1996). Reevaluation
128 of *V. jacobsoni* revealed an additional species, *V. destructor*, infecting *A. mellifera* (Anderson
129 and Trueman 2000). This redescription sent shock-waves throughout Asia and abroad, as it
130 became apparent that *V. destructor*, rather than *V. jacobsoni*, was the most prevalent *Varroa*
131 mite parasitizing honey bees around the world.

132 *Varroa* species nearly ubiquitously parasitize honey bees throughout Asia (Fig. 2).

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

141 The general morphology and chaetotaxy of the four *Varroa* species are similar.
142 However, several characters such as body size (Table 1) and shape, peritreme size, and length
143 and number of marginal setae can be used to distinguish them. A wide genetic variation
144 within and between *V. jacobsoni* and *V. destructor* populations exists in Asia, and may play
145 an important role in the pathogenicity of these parasites. Currently twenty-four haplogroups,
146 fifteen for *V. jacobsoni* and nine for *V. destructor*, are recognized (de Guzman and Rinderer
147 1998, 1999; de Guzman et al. 1997, 1998, 1999; Anderson and Trueman 2000; Fuchs et al.
148 2000; Zhou et al. 2004; Solignac et al. 2005; Warrit et al. 2006; Navajas et al. 2010), with the
149 Korean (K) and Japanese (J) haplotypes of *V. destructor* being the most successful parasites
150 of *A. mellifera* (Rosenkranze et al. 2010). Of these, the K haplotype is competitively superior
151 to J, and represents the most pathogenic *Varroa* mite haplotype in Asia and abroad. Virulent
152 parasites are generally more competitive than less virulent ones, and may possibly displace
153 them (Navajas et al. 2010). Failure to detect J haplotype mites in Thailand that were reported
154 earlier (de Guzman and Rinderer 1999; Anderson and Trueman 2000; Navajas et al. 2010)
155 may be a result of such a displacement event and not an erroneous finding as suggested by
156 Warrit et al. (2006). Recent genetic analysis of *Varroa* mites in Asia revealed new invasions
157 and hybridization between haplogroups (Navajas et al. 2010). The virulence of hybrid mites to
158 honey bees has yet to be established.

159 In the Philippines, the Papua New Guinea (=Java) *V. jacobsoni* haplotype parasitizes
160 *A. cerana* (de Guzman and Rinderer 1999), and three unresolved *V. destructor* haplotypes are
161 known to reproduce in *A. cerana* drone brood (Anderson 2004). In *A. mellifera* and *A. cerana*,
162 *V. jacobsoni* reproduces in drone brood only (Anderson 1994; Anderson and Sukarsih 1996;
163 Anderson and Fuchs 1998), whereas reproduction of *V. destructor* in *A. cerana* is likely
164 dependent on their haplotype or strain of the host bees (de Jong 1988). Inability of *V.*
165 *jacobsoni* to reproduce in worker brood of *A. cerana* and *A. mellifera* has most likely limited
166 its distribution and impact as drone brood is seasonally produced and relatively less crucial to
167 overall colony functioning (de Guzman and Rinderer 1999). Variations in mite infestation or
168 reproduction may be attributed to the combined effects of bee behavior, species and
169 haplogroup of mites. While grooming behavior removes mites from adult bees (Rinderer et al.
170 2010), hygienic behavior disrupts mite reproductive output when mites and infested
171 developing bees are removed from brood cells (Kirrane et al. 2011). *A. cerana* is particularly
172 well known for such behaviors (Peng et al. 1987a, 1987b).

173 Although *A. cerana* is the indigenous host of *V. jacobsoni* and *V. destructor*, much of
174 the life histories of the two are based on data using *A. mellifera* as the host. No biological
175 observations are available for either *V. rindereri* and *V. underwoodi*. In *A. mellifera*, *V.*
176 *destructor* reproduces in both worker and drone brood (Anderson and Trueman 2000;
177 Rosenkranz et al. 2010). Female *Varroa* mites enter brood cells before capping, with total
178 developmental time about six days (Ifantidis 1990). One female can produce an average of 1.8
179 and 3 mature daughters in worker and drone brood cells, respectively (Donzé et al. 1996).
180 Mating occurs within the capped brood cell; young mated adults subsequently leave the cell
181 with the emerging bee. Phoresy is a very important phase on the survival, dispersal, and even
182 reproductive success of *Varroa* mites. The phoretic stage lasts from 4 days to a few months,
183 depending on availability of brood (Martin 1998; Beetsma et al. 1999). While phoretic, mites

184 can feed on adult bees through soft membranes such as those between abdominal tergites (De
185 D'Aubeterre et al. 1999).

186 Similar to other regions of the world, parasitism by *Varroa* can have devastating
187 consequences for honey bees such as reduced longevity, immunosuppression, and increased
188 viral prevalence and intensity (Rosenkranz et al. 2010). However, pathogenicity is largely
189 specific to the particular mite and honey bee species considered, with natural parasite-host
190 associations typically less pathogenic. In *A. mellifera*, bee parasitic mite syndrome is a disease
191 complex of colonies simultaneously infested with *V. destructor* mites and infected with
192 viruses (Shimanuki et al. 1994). Detection of bee viruses in *Varroa* mites suggests that mites
193 are potential vectors that facilitate the horizontal transmission of bee viruses among honey
194 bees (Chen and Siede 2007). The co-existence of several bee viruses (Kashmir bee virus
195 (KBV), Acute bee paralysis virus (ABPV), Deformed wing virus (DWV), Sacbrood virus
196 (SBV), and Black queen cell virus (BQCV)) in a single mite suggests that *V. destructor* can
197 be responsible for multiple infections by viruses in apiaries in Thailand (Chantawannakul et
198 al. 2006). This combination of mite infestation and viruses likely aggravates the health of
199 colonies.

200

201 *Tropilaelaps* spp.

202 Four species of *Tropilaelaps* have been described in the mite family Laelapidae. First
203 identified, *Tropilaelaps clareae* was collected from dead *A. mellifera* bees and field rats near
204 beehives in the Philippines (Delfinado and Baker 1961). Twenty years later, *Tropilaelaps*
205 *koenigerum* was observed parasitizing *A. dorsata* in Sri Lanka (Delfinado-Baker and Baker
206 1982). More recently, Anderson and Morgan (2007) described two species, *Tropilaelaps*
207 *mercedesae* and *Tropilaelaps thaii* parasitizing *A. dorsata* and *A. mellifera* in mainland Asia
208 and *A. laboriosa* in the Himalayas, respectively. Similar to the reclassification of *V. jacobsoni*

209 and *V. destructor* (Anderson and Trueman 2000), *T. mercedesae* was initially described as *T.*
210 *clareae* (Anderson and Morgan 2007).

211 *Tropilaelaps* mites are believed to be indigenous parasites of the giant honey bees, *A.*
212 *dorsata*, *A. laboriosa*, and *A. breviligula* (Laigo and Morse 1968; Delfinado-Baker et al.
213 1985; Anderson and Morgan 2007). Since its discovery, all reports on *Tropilaelaps* are from
214 the distribution range of the giant honey bees, and therefore suggest co-evolution (Anderson
215 and Morgan 2007). *T. clareae* was first observed infesting *A. mellifera* in the Philippines, and
216 recently found parasitizing *A. breviligula* in the Philippines and Sulawesi Island in Indonesia
217 (Anderson and Morgan 2007). Reclassification of *T. mercedesae* by Anderson and Morgan
218 (2007) suggests that the mite parasitizes *A. dorsata* and *A. mellifera* throughout southern
219 mainland Asia and Indonesia, apart from Sulawesi Island, as well as *A. laboriosa* in the
220 Himalayas (Fig 3). Earlier studies classifying *T. mercedesae* as *T. clareae* (Delfinado-Baker
221 1982; Kapil and Aggarwal, 1987; Delfinado-Baker et al. 1989; Wongsiri et al. 1989; Abrol
222 and Putatunda 1995; Koeniger et al. 2002) need to be re-examined. *T. koenigerum* is a
223 parasite of *A. dorsata* in Sri Lanka, mainland Asia, and Indonesia apart from Sulawesi and
224 Borneo (Delfinado-Baker and Baker 1982; Anderson and Morgan 2007), and is known to co-
225 infest *A. dorsata* colonies in Borneo and Thailand with *T. mercedesae* (Delfinado-Baker et al.
226 1989; Koeniger et al. 2002). Reproduction by *T. koenigerum* on *A. cerana* brood was
227 observed in India (Abrol and Putatunda 1995) and by one adult *T. mercedesae* in Thailand
228 (Anderson and Morgan 2007). *T. koenigerum* has only been observed in *A. mellifera* debris in
229 Thailand (Kavinseksan, per. com.). Conversely, *T. thaii* has only been observed parasitizing
230 *A. laboriosa* in Vietnam (Anderson and Morgan 2007).

231 Molecular and morphological techniques can be used to identify *Tropilaelaps* and to
232 study their evolutionary history (Anderson and Morgan 2007). Morphologically, several
233 characters are used to distinguish them, including body size, apex of the epigynial plate, anal
234 plate shape, structure of the apical tooth of the chelicerae, and configuration of the apex of

235 male spermatodactyl. *T. mercedesae* is larger than *T. clareae* or *T. thaii*, with *T. koenigerum*
236 the smallest (Table 1). Molecularly, the most comprehensive survey of *Tropilaelaps* mites to
237 date by Anderson and Morgan (2007) using multiple gene sequences revealed that of 89
238 widespread isolates, 46 haplotypes fell into 4 lineages that can each be considered a separate
239 species. Genetic differences within species were also identified, but require further
240 investigation to better understand their intra-species phylogenetic relationships.

241 Much of the life cycle of *Tropilaelaps* is based on *T. mercedesae* infesting *A. mellifera*
242 colonies during a period when it was previously classified as *T. clareae*. Hence, re-
243 examinations are warranted. Like *Varroa* or *Euvarroa*, *Tropilaelaps* also enters brood cells
244 before they are sealed to complete their life cycle (Sammataro 2011). Foundress mites start to
245 lay eggs shortly before the brood cell is capped, which allows nearly all progeny to reach
246 adulthood before the adult bee emerges (Ritter and Schneider-Ritter 1988). The development
247 time for mites is estimated to be approximately 6 and 8.7 days *in vivo* (Woyke 1987c) and *in*
248 *vitro*, respectively (Kitprasert 1984), and a single foundress can produce up to four progeny
249 (Woyke 1987b). Unlike *Varroa* and *Euvarroa* in its indigenous host, *A. dorsata*, *Tropilaelaps*
250 appear to not show a gender preference between worker and drone brood (Koeniger et al.
251 2002; Buawangpong et al. 2013). The phoretic period of *Tropilaelaps* is short, surviving
252 approximately 1-3 days on adult bees *in vitro* (Kitprasert 1984; Woyke 1984; Koeniger and
253 Musaffar 1988; Rinderer et al. 1994). As a result, rapid oviposition, reduced life cycle period,
254 and reproduction in both worker and drone brood cells, contribute to relatively higher
255 populations of *Tropilaelaps* in colonies compared to *Varroa* or *Euvarroa* (Buawangpong et al.
256 2015). When both *T. mercedesae* and *V. destructor* are experimentally introduced into an
257 individual brood cell of *A. mellifera*, normal reproduction of both mites was observed
258 (Buawangpong et al. 2015). Natural co-infestation of *Varroa* and *Tropilaelaps* does occur in *A.*
259 *mellifera* brood; however, this is rare (<0.1 %) (Buawangpong et al. 2015). Additionally, *T.*

260 *koenigerum* and *T. mercedesae* have been found infesting the same *A. dorsata* colony, but not
261 the same brood cell (Delfinado-Baker et al. 1989; Koeniger et al. 2002).

262 Like *Varroa* and *Euvarroa*, pathogenicity of *Tropilaelaps* is believed to be closely tied
263 to specific parasite-host associations. Few studies have evaluated the effects of these mites on
264 honey bees, particularly their native hosts. Anecdotal reports suggest *T. mercedesae* and *T.*
265 *clareae* severely affect *A. mellifera* throughout the region whereas *T. koenigerum* and *T. thaii*
266 are believed to be harmless to *A. mellifera* (Burgett et al. 1983; Anderson and Morgan 2007).
267 By using artificial mite-inoculation in *A. mellifera* brood, the proportion of non-reproductive
268 *T. mercedesae* was found to be lower than that of *V. destructor*. Both mites produced similar
269 numbers of progeny. In natural infestations of *A. mellifera* in Thailand, the average worker
270 brood infestations of *T. mercedesae* (19.9 %) were significantly higher than that of *V.*
271 *destructor* (0.7 %). This higher prevalence and reproductive ability of *T. mercedesae* in
272 concurrently infested colonies reaffirm the competitive advantage of *T. mercedesae* over *V.*
273 *destructor*, and their reported negative impact to *A. mellifera* colonies (Buawangpong et al.
274 2015). Additionally, *T. mercedesae*-inoculated *A. mellifera* pupae showed higher levels and
275 incidence of DWV compared to uninfested pupae (Khongphinitbunjong et al. 2015). The mite
276 has been shown to promote wing deformation and reduce bee longevity in Thailand
277 (Khongphinitbunjong et al., submitted). Both surveys in China and Thailand suggest the mite
278 can vector DWV (Dainat et al. 2008; Forsgren et al. 2009; Khongphinitbunjong et al. 2015).
279 However, no other bee viruses could be found in *T. mercedesae* and suggest that the major
280 impact of mite infestation is caused by the mite itself (Khongphinitbunjong et al. 2015).

281 In contrary, *Tropilaelaps* populations are generally found to be low in their natural
282 giant honey bee hosts (Buawangpong et al. 2013). Likely the result of parasite-host co-
283 evolution, *A. dorsata* exhibits a high grooming behavior against *T. mercedesae* when
284 compared to *A. mellifera* (Büchler et al. 1992; Koeniger et al. 2002; Khongphinitbunjong et
285 al. 2012). Under artificial mite inoculation, *A. mellifera* removed brood infested with *T.*

286 *mercedesae* (52.6%) and peaked during the second and third days post inoculation
287 (Khongphinitbunjong et al. 2014). Information on hygienic behavior of giant honey bee
288 against *Tropilaelaps* is not available. However, frequent absconding, possibly triggered by
289 high mite infestation, or migration away from the nest, may also play important roles in the
290 suppression of *Tropilaelaps* populations (Koeniger et al. 2002), as would its inability to feed
291 on adult bees (Kitprasert 1984; Woyke 1984; Koeniger and Musaffar 1988; Rinderer et al.
292 1994; Kavinseksan et al. 2003).

293

294 Control of *Varroa* and *Tropilaelaps* mites

295 Numerous strategies for managing economically important mites of honey bees exist,
296 including the use of chemotherapy, physical, and cultural methods (Sammataro 2011). When
297 unmanaged, *Varroa* and *Tropilaelaps* are responsible for the rapid decline in colony health of
298 *A. mellifera* colonies in Asia (Wongsiri and Tangkanasing 1987; Buawangpong et al. 2015).
299 Although all Asian honey bees have mites associated with them, only *A. mellifera* colonies
300 are managed for mite control because of the relative ease of their management and because
301 the severe economic penalties this species faces when mites are not controlled (Wongsiri and
302 Tangkanasing 1987). Many acaricides used for *V. destructor* control also likely work for
303 *Tropilaelaps* (Sammataro 2011), including tau-fluvalinate, amitraz, formic acid, and thymol
304 for *T. clareae* on *A. mellifera* in Thailand (Wongsiri and Tangkanasing 1987; Burgett and
305 Kitprasert 1990), Vietnam (Woyke 1987a), and Pakistan (Raffique 2012), respectively.
306 Currently the use of fluvalinate and coumaphos is widespread throughout the region
307 (Wongsiri and Tangkanasing 1987; Akratanakul 1990). Due to the apparent short lifespan of
308 *Tropilaelaps* on adult bees, interrupting brood rearing by queen caging or by removing all
309 brood from colonies are effective to control *T. mercedesae* in Pakistan (Woyke 1984, 1985).
310 Furthermore, leaves of alagaw (*Premna odorata*) and lemon grass (*Andropogon citratus*) are
311 used to manage both mites with mixed success in the Philippines (Cervancia 1993; Booppha

312 et al. 2010). Breeding for *Varroa* or *Tropilaelaps* resistance has not gained much popularity
313 among Asian countries.

314

315 *Euvarroa* spp.

316 To date, two species from the genus *Euvarroa* are believed to be associated with five
317 honey bee species in Asia: the open- air nesters *A. andreniformis*, *A. florea*, *A. dorsata*, as
318 well as the cavity- nesters *A. cerana* and *A. mellifera*. *Euvarroa sinhai* was first observed
319 from *A. florea* samples collected in 1971 in India (Delfinado and Baker 1974) and *E.*
320 *wongsirii* was first observed in *A. andreniformis* in Thailand (Lekprayoon and Tangkanasing
321 1991). These two *Euvarroa* species can be easily distinguished by the shape of their body
322 and number of marginal setae. *E. sinhai* is pear-shaped with 39-40 marginal setae whereas *E.*
323 *wongsirii* is triangular or wider posteriorly with 47-54 long setae (Delfinado and Baker 1974;
324 Lekprayoon and Tangkanasing 1991).

325 Infestations by *E. wongsirii* have only been reported in *A. andreniformis* in Thailand
326 and Malaysia (Lekprayoon and Tangkanasing 1991). *E. sinhai* has been reported in *A. florea*
327 in India, Iran, Sri Lanka and Thailand (Delfinado and Baker 1974; Koeniger et al. 1983;
328 Mossadegh 1991) and *A. andreniformis* in Thailand (Delfinado-Baker et al. 1989), *E.*
329 *wongsirii* has not been observed in *A. florea* nests. Nevertheless, both mites have been
330 collected from hive debris, with *E. sinhai* from *A. mellifera* colonies in India and Thailand
331 (Kapil and Aggarwal 1987; Lekprayoon and Tangkanasing 1991), and *E. wongsirii* from *A.*
332 *dorsata* in Borneo (Koeniger et al. 2002) (Fig. 4). *Euvarroa* infestations are generally low in
333 honey bee colonies, with decreased infestation likely due to host hygienic behavior of dwarf
334 honey bee workers removing dead brood together with their infesting mites (Kitprasert 1995).
335 Limited food supply of the single comb open air nesters, as well as reduced brood cell
336 diameter of dwarf honey bees, may also contribute to suppressed mite populations (Rinderer
337 et al. 1996). Drone reproduction is also seasonal and swarming further reduces *Euvarroa*

338 populations within colonies by disrupting bee brood, and hence mite reproduction (Kitprasert
339 1995).

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

354

355 *Acarapis* spp.

356 Three species of mites are known from the genus *Acarapis*; all are parasites of adult
357 honey bees. First classified was *Acarapis woodi* in the early 1900s in England's Isle of Wight
358 (Rennie 1921), followed by *Acarapis dorsalis* and *Acarapis externus* on several continents
359 (Morgenthaler 1934). All three species parasitize honey bees in Asia.

360 The distribution of the three *Acarapis* species in Asia is not well established. The first
361 report of *A. woodi* parasitizing honey bees in the region came from India (Michael 1957;
362 Milne 1957). The species has since been observed parasitizing *A. mellifera* in Egypt, Iran,

363 Israel, Jordan, Kuwait, Lebanon, Palestine and Syria (Matheson 1993; Rashad et al. 1985;
364 Gerson et al. 1994; Mossadegh and Bahreini 1994; Amr et al. 1998; OIE 2004), and *A. indica*
365 in India, Pakistan, Bangladesh, and China (Delfinado and Baker 1982). Recently, *A. woodi*
366 was observed in dead bees from collapsing colonies of *A. cerana japonica* in Japan (Kojima
367 et al. 2011). It was also detected in Bhutan, Nepal, Hong Kong and Thailand; however, the
368 honey bee host was not identified (Matheson 1993; Matheson 1995). Only in Iran has *A.*
369 *dorsalis* and *A. externus* been reported, in this case parasitizing *A. mellifera* colonies
370 (Mossadegh and Bahreini 1994).

371 The three *Acarapis* species are morphologically similar, and are usually identified by
372 the location where they are observed on a honey bee host, in addition to specific
373 morphological differences (Eckert 1961; Delfinado-Baker and Baker 1982). *A. externus* is the
374 largest (Table 1). Examination of the distal line of the sternal plates is the most definitive
375 defining feature of each species (Eckert 1961). Molecular tools have also been developed to
376 identify *Acarapis* species (Evans et al. 2007). The total developmental time for *A. woodi* is 11
377 days, whereas *A. dorsalis* and *A. externus* take 8-9 days (Royce et al. 1988; Ibay 1989; de
378 Guzman et al. 2001). Eckert (1961) claimed that a female *A. dorsalis* or *A. externus* can lay 2-
379 5 eggs compared an average of 6 eggs for *A. woodi* (Royce et al. 1988).

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

387

388 4.2 Viruses

389 Viruses of honey bees are nearly ubiquitously distributed throughout the world, with
390 more than 18 isolated to date (Bailey and Ball 1991; Allen and Ball 1996; Chen and Siede
391 2007). Among them, seven are common including Black queen cell virus (BQCV), Deformed
392 wing virus (DWV), Kashmir bee virus (KBV), Sacbrood virus (SBV), Acute bee paralysis
393 virus (ABPV), Chronic bee paralysis virus (CBPV), and Israeli acute paralysis virus (IAPV)
394 (Chen and Siede 2007). In Asia, these seven viruses have been reported to infect different
395 honey bee species throughout the region (Sanpa and Chantawannakul 2009; Ai et al. 2012;
396 Forsgren et al. 2015). Based on their genomic structures, SBV and DWV are classified under
397 Iflaviridae whereas BQCV, ABPV, KBV and IAPV belong to the Dicistroviridae.

398

399 Iflaviridae

400 Of the viruses, Sacbrood virus (SBV) is the first virus discovered in *A. mellifera*
401 (White 1913). Historical records from Asia showed that Sacbrood disease was first detected in
402 *A. cerana* from Thailand in 1976 (Bailey et al. 1982). It was named Thailand sacbrood virus
403 (TSBV, also known as Chinese sacbrood virus) since it was serologically related to SBV but
404 physiochemically distinct (Bailey et al. 1982). TSBV caused death of greater than 90% of
405 domesticated *A. cerana* populations in Kashmir (Abrol and Bhat 1990), and was also found in
406 *A. dorsata* and *A. florea* in India (Allen and Ball 1996). In *A. cerana* it was observed in India,
407 Thailand, South Korea, Japan, Nepal, China, and Vietnam (Shah and Shah 1988; Allen and
408 Ball 1996; Choi et al. 2010; Kojima et al. 2011; Grabensteiner et al. 2007; Ai et al. 2012;
409 Forsgren et al. 2015). SBV infection of *A. mellifera* colonies was detected in Thailand, South
410 Korea, Japan, China, and Vietnam (Sanpa and Chantawannakul 2009; Yoo and Yoon 2009;
411 Kojima et al. 2011; Ai et al. 2012; Forsgren et al. 2015).

412 DWV appears to be more prevalent than SBV in four honey bee hosts. In *A. mellifera*,
413 it was detected in Sri Lanka, Nepal, Thailand, Japan, China, and Vietnam (Berényi et al.
414 2007; Sanpa and Chantawannakul 2009; Kojima et al. 2011; Ai et al. 2012; Forsgren et al.
415 2015). DWV infections of *A. cerana* have been reported in China, South Korea, Japan, and
416 Vietnam, (Kojima et al. 2011; Ai et al. 2012; Li et al. 2012; Forsgren et al. 2015), and in *A.*
417 *florea* and *A. dorsata* in China (Zhang et al. 2012). The virus was detected in *V. destructor*
418 and *T. mercedesae* mites, and higher levels of DWV were detected in *A. mellifera* infested by
419 the mites in Thailand (Chantawannakul et al. 2006; Khongphinitbunjong et al. 2015).

420 Dicistroviridae

421 Black queen cell virus (BQCV) was first isolated from queen larvae and pupae of *A.*
422 *mellifera* found dead within their cells (Bailey and Woods 1977). The virus is highly
423 prevalent in *A. mellifera* in Thailand, South Korea, China, Japan, and Vietnam (Sanpa and
424 Chantawannakul 2009; Ai et al. 2012; Yang et al. 2013; Reddy et al. 2013; Kojima et al.
425 2011; Forsgren et al. 2015), in *A. cerana* in South Korea, China, Vietnam, Thailand, and
426 Japan (Li et al. 2012; Choe et al. 2012; Yang et al. 2013; Forsgren et al. 2015; Mookploy et
427 al. 2015), and in *A. florea* and *A. dorsata* from China and Thailand (Zhang et al. 2012;
428 Mookploy et al. 2015). Genetic variations of BQCV strains across four species of honey bees
429 have been studied. Based on the capsid coding region, the phylogenetic analysis revealed that
430 BQCV isolates from northern Thailand, China, South Korea, and Japan displayed a close
431 relationship within Asia and split separately from South Africa and European regions,
432 regardless of the host bee species from which the samples originated (Mookploy et al. 2015).
433 Similar findings were reported with the BQCV strains in Korea and Japan where the viral
434 isolates from the same country or continent showed high levels of similarity (Kojima et al.
435 2011; Noh et al. 2013). The role of BQCV in honey bee mortality is currently poorly

436 understood, particularly in association with other parasites such as the microsporidian *Nosema*
437 *apis* (Bailey et al. 1983).

438 ABPV, KBV and IAPV are part of a complex of related viruses (Chen and Siede
439 2007; de Miranda et al. 2010). KBV was first confirmed in *A. cerana* in India (Bailey and
440 Woods 1977), and subsequently in South Korea (Choe et al. 2012). Surveys of bee viruses in
441 *A. mellifera* colonies found KBV in Thailand (Sanpa and Chantawannakul 2009).
442 Interestingly, KBV was not found in China and Vietnam during the disease surveys in both *A.*
443 *cerana* and *A. mellifera* (Ai et al. 2012; Forsgren et al. 2015). ABPV has only been detected
444 in *A. cerana* (Choe et al. 2012), and in *A. mellifera* in China (Ai et al. 2012; Forsgren et al.
445 2015) and Thailand (Sanpa and Chantawannakul 2009). IAPV has been detected in both *A.*
446 *mellifera* and *A. cerana*, in *A. mellifera* in China (Ai et al. 2012), South Korea (Reddy et al.
447 2013), Japan (Morimoto et al. 2012) and Israel (Maori et al. 2007), and in *A. cerana* in China
448 (Ai et al. 2012) and Japan (Kojima et al. 2011).

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

453

454 4.3 Fungi

455 *Nosema* spp.

456 Two species of parasites belonging to this genus are known to infect honey bees, and
457 both occur in Asia (Klee et al. 2007). *N. apis*, first described in the early 1900s in Europe
458 (Zander 1909), is believed to historically parasitize *A. mellifera* (Fries 1993). *N. ceranae*

459 appears to have an Asian origin (Botías et al. 2012) since it was first detected in *A. cerana* in
460 China in the late 1990s (Fries et al. 1996).

461 Surveys have identified *N. apis* in *A. mellifera* (e.g. Klee et al. 2007) and *A. cerana*
462 (*Rice 2001*) only. In contrast, *N. ceranae* parasitizes a broader array of hosts such as *A.*
463 *mellifera*, *A. cerana*, *A. florea*, *A. dorsata*, and *A. koschevnikovi* (e.g. Klee et al. 2007;
464 Chaimanee et al. 2010; Botías et al. 2012). Although both parasites have been detected
465 throughout the region, *N. ceranae* appears to be more widespread (Fig. 5A&B). In *A.*
466 *mellifera*, *N. ceranae* was identified in Taiwan (Huang et al. 2007), Vietnam (Klee et al.
467 2007), China (Liu et al. 2008), Thailand (Chaimanee et al. 2010), Turkey (Whitaker et al.
468 2011), Indonesia (Botías et al. 2012), Solomon Islands (Botías et al. 2012), Japan
469 (Yoshiyama and Kimura 2011), and Jordan (Haddad 2014). *N. apis* was detected in Israel
470 (Gatehouse and Malone 1999), Indonesia (Rice 2001), and Turkey (Whitaker et al. 2011).
471 *A. mellifera* colonies in China (Liu et al. 2008), Thailand (Chaimanee et al. 2010) or Jordan
472 (Haddad 2014) were not infected with *N. apis*. Investigations of the incidence of *Nosema*
473 spp. on honey bees native to Asia have been less thorough. In *A. cerana*, *N. ceranae* was
474 identified in China, Vietnam, Indonesia, Solomon Islands, and Thailand (Fries et al. 1996;
475 Klee et al. 2007; Li et al. 2012; Forsgren et al. 2015; Botías et al. 2012; Chaimanee et al.
476 2010), and also detected in *A. florea* and *A. dorsata* in Thailand (Chaimanee et al. 2010).

477 Studies comparing the phylogenetic relationships among *N. ceranae* isolated from
478 four different honey bee species in Thailand using polar tube proteins, important for
479 microsporidian host invasion, showed three distinct clades (Chaimanee et al. 2011). *N.*
480 *ceranae* isolated from *A. mellifera* grouped into the same clade as *N. ceranae* isolated from
481 *A. cerana*, while *N. ceranae* isolated from *A. florea* and *A. dorsata* formed distinct clades. *A.*
482 *mellifera* and *A. cerana* are cavity-nesting honey bees, and are therefore more related to each
483 other than to open-air, single comb-nesting species such as *A. dorsata* and *A. florea*
484 (Alexander 1991). Therefore, the formation of a single clade for *N. ceranae* isolates from the

485 cavity-nesting species reflects the genetic lineage of *A. mellifera* and *A. cerana*, and
486 suggests ongoing co-evolution of this pathogen and its host. This is interesting considering
487 that the parasite supposedly came from *A. cerana*. In China however, studies using the 16 S
488 ribosomal RNA gene demonstrated that *N. ceranae* infecting *A. cerana* in the north and
489 south were distinct, and also different from *N. ceranae* circulating in *A. mellifera* worldwide.
490 Thai isolates fell into the same clade as those from southern China (Li et al. 2012).

491 Although *Nosema* are considered to be generalists, parasitizing a broad array of
492 honey bee hosts, their prevalence and intensity of infection are different for each species.
493 For *N. ceranae*, it appears that prevalence of infections in native honey bees is much lower
494 compared to *A. mellifera*, as colonies surveyed in Thailand revealed infection prevalences of
495 77.5 %, 22.2%, 45.4 %, and 37.5% for *A. mellifera*, *A. cerana*, *A. florea*, and *A. dorsata*,
496 respectively (Chaimanee et al. 2010). When infected with *N. ceranae* obtained from *A.*
497 *mellifera* from Thailand, all four honey bee species became infected. However, different
498 levels of intensity were observed. Infection rate of *A. dorsata* was similar to that found in *A.*
499 *mellifera*, but *A. florea* was lower and *A. ceranae* the lowest (Chaimanee et al. 2011).
500 Suwannapong et al. (2011) also observed that *N. ceranae* isolated from *A. florea* could infect
501 *A. ceranae* and affect hypopharyngeal protein production and shorten their lifespan.

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

508 In response to infection, *A. cerana* workers infected by *N. ceranae* tended to have
509 lower bacterial populations, particularly *Bifidobacterium* and Pasteurellaceae that produce
510 several antibiotic compounds important to host defense against parasites (Li et al. 2012). *N.*

511 *ceranae* may also promote the outbreak of other bee diseases, such as Chalkbrood (Hedtke
512 et al. 2011).

513 Both parasites can be managed by the fungicide fumagillin, but to varying degrees of
514 success that require further examination of timing and quantity of treatments (Akrotanakul
515 1990; Williams et al. 2008; Williams et al. 2011; Huang et al. 2013).

516

517 *Ascosphaera apis*

518 The fungus *Ascosphaera apis*, which causes Chalkbrood disease in honey bees, was
519 first described in the early 20th century in *A. mellifera* in Europe (Maassen 1913), and now is
520 found throughout the world. In Asia, incidence of Chalkbrood has been reported in China,
521 Israel, Japan, Korea, the Philippines, Russia, Thailand and Turkey (Figure 5C) (Oldroyd and
522 Wongsiri 2006; Aronstein and Murray 2010). In Turkey, it was believed to have been
523 introduced from contaminated beeswax which was imported to the country (Tutkun et al.,
524 1993). In the Philippines and Thailand, beekeepers often reported higher incidence of fungal
525 infection during the wet season (Cervancia 1993; Chantawannakul and Puchanichanthranon
526 2005). Ingestion of the fungus by honey bee larvae allows *A. apis* to germinate within the gut
527 and eventually penetrate the body cavity, resulting in significant mechanical and enzymatic
528 damage; dead, dried larvae, named Chalkbrood mummies, can be observed within uncapped
529 brood cells (Heath 1982; Aronstein and Murray 2010). The fungus can produce lytic enzymes
530 (protease and beta-N-acetylglucosaminidase) that may be an important factor that assists
531 fungal invasion in the bee larvae; the enzymatic patterns from Thai isolates were similar to the
532 previous report of Spanish isolates (Theantana and Chantawannakul 2008). In *A. mellifera*,
533 Chalkbrood disease can result in lowered colony productivity, but rarely results in colony
534 death (Heath 1982; Aronstein and Murray 2010). It is also not considered to be a serious
535 disease of honey bees in Asia, even though it has been reported more widespread than

536 Stonebrood disease which is caused by the fungi from genus *Aspergillus* (Akranakul 1990;
537 Ra et al. 2012) (Fig 5C and 5D).

538 4.4 Bacteria

539 *Paenibacillus larvae*

540 *Paenibacillus larvae*, the causative agent of a disease called American Foulbrood (AFB), has
541 a nearly ubiquitous distribution, including in Asia (Genersch 2010) (Fig 6 A). The disease
542 was found in *A. cerana* in India (Singh 1961) and *A. mellifera* in Taiwan (Yen and Chyn
543 1971). However, a survey conducted in 2003 in Thailand revealed that *A. mellifera* was free
544 of this disease (National Bureau of Agricultural Commodity and Food Standards 2008). Bee
545 larvae become infected when *P. larvae* spores are ingested; disease results in larvae that are
546 brownish, semi-fluid, and glue-like, before drying to a hard scale on the lower cell wall
547 (Genersch 2010). Scales are highly infective, and contain millions of spores that may be
548 infective for several decades (Hasemann 1961). When artificially fed spores of *P. larvae*, *A.*
549 *cerana* showed more resistance to infection than *A. mellifera* (Ho and Chen 2001).

550 *Melissococcus plutonius*

551 *Melissococcus plutonius* is a ubiquitously distributed bacterium of honey bees that has been
552 detected throughout Asia, including in *A. mellifera* (Akranakul 1990), *A. cerana* (Diwan et
553 al. 1971; Bailey 1974; Zhou et al. 2000; Rana et al. 2012), *A. laboriosa* (Allen et al. 1990),
554 and *A. florea* (Saraithong et al. 2015) (Fig. 6B). *M. plutonius* primarily affects honey bee
555 larvae, causing a disease known as European foulbrood (EFB) that is characterized by dead,
556 twisted, brood within their cells. Infected colonies can be killed if a high proportion of larvae
557 are infected (Bailey and Ball 1991). EFB was detected in *A. mellifera* beekeeping in China,
558 Vietnam, Japan and Thailand (Forsgren et al. 2015; Aronstein and Murray 2010; Budge et al.
559 2010). In Thailand, EFB is particularly prevalent during the wet season (Akranakul 1990). It
560 was also reported to cause serious damage to colonies of *A. cerana* in China between 1972-

561 1976 (Yang 2005), Vietnam (Chinh 1998; Forsgren et al. 2015), and recently in Japan (Arai et
562 al. 2012; Takamatsu et al. 2014). A phenotypically and genetically distinct *M. plutonius* strain
563 has been isolated from *A. cerana japonica*; it is frequently found and more virulent than the
564 typical strain (Arai et al. 2014; Takamatsu et al. 2014).

565 4.5 Pests

566

567 4.5.1 Vertebrates

568

569 Bee-eating birds

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

578

579 4.5.2 Invertebrates

580

581 Wax moths

582 Moth larvae attack the combs of honey bees worldwide. The greater wax moth,
583 *Galleria mellonella*, and the lesser wax moth, *Achroia gisella*, are small non-descript moths
584 that lay eggs in cracks and crevices of bee hives (Akranakul 1990). Wax moths are a
585 problem for unused or stored combs (Pernal and Clay 2013). Recently, larvae of *G. mellonella*
586 attacking colonies of *A. cerana japonica* were collected in Japan. These samples also tested
587 positive for IAPV and BQCV (Triyasut et al. *in press*). The viruses were likely horizontally

588 transmitted to the wax moth larvae by food or brood consumption within the colonies;
589 however, viral replication in the wax moth larvae was not detected. Future work needs to
590 clarify the possible role of bee viruses in moth larvae. In Southeast Asia, wax moths are a
591 major pest of *A. cerana*, and causes them to abscond (Akranakul 1990). Chemical controls
592 are usually not applied for wax moth management. Instead, cultural measures such as
593 removing hive debris, managing colonies to be strong, and removing or burning unused and
594 infested combs are recommended.

595

596 Small hive beetle (*Aethina tumida*)

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

608

609 Wasps (*Vespa* spp.)

610 *Vespa* spp. are important predators of honey bees in Asia (Matsuura 1988). Entrances
611 of honey bee colonies are often targeted, with one wasp capable of capturing seven bees in
612 one attack (Cervancia 1993). Such a disturbance can result in *A. cerana* colonies to abscond.
613 Furthermore, some species are known to predate on *A. cerana* drones at drone congregation

614 areas (Koeniger et al. 1994). To deter predation, *A. cerana*, *A. nuluensis*, and *A. dorsata*
615 perform body shaking as a defense mechanism (Koeniger et al. 1996; Kastberger et al. 1998;
616 Tan et al. 2010; Khongphinitbunjong et al. 2012), and *A. cerana* and *A. mellifera* make tight
617 balls that kill wasp intruders by heating (Ono et al. 1987; Tan et al. 2005). Beekeepers
618 sometimes employ wasp traps or reduce the hive entrance, and also frequently kill wasps by
619 hitting them with slippers, pieces of wood, or badminton rackets (Cervancia 1993).
620 Furthermore, toxic baits may be used to poison wasp nest mates.

621 Ants

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

625

626 Bee lice (*Braula coeca*)

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

631

632 5. CONCLUSIONS & FUTURE PERSPECTIVES

633 With the introduction of *A. mellifera* in the region, native Asian honey bees are also
634 at a greater risk of pathogen and parasite infections from inter-species transmission routes.
635 Likewise, *A. mellifera* could be susceptible to further pests and parasites from native honey
636 bees, which was previously exemplified by infestation by *V. destructor* and *N. ceranae* (Fries
637 2010; Rosenkranz et al. 2010). The rich diversity of honey bees, pathogens and parasites in

638 Asia has attracted researchers around the world to better understand host-parasite evolution
639 and to improve management of introduced exotic parasites of *A. mellifera* that have come
640 from Asia by studying those parasites with their indigenous hosts. Many reports suggest that
641 native Asian honey bees cope well with parasites that are currently devastating to *A. mellifera*
642 using behavioural and immunological host defense mechanisms (Khonphinitbunjong et al.
643 2012; Chaimanee et al. 2010). The migratory nature of several species of native Asian honey
644 bees may also affect susceptibility of infection or infestation (Kavinseksan et al. 2003). The
645 resistance of Asian honey bees towards some bacterial pathogens may be due to their unique
646 bacterial community structures inhibiting pathogen growth or infection. Studies have shown
647 that gut bacteria in *A. mellifera*, *A. cerana*, *A. florea*, and *A. dorsata* differ, likely due to
648 geographic location, life stage, and species of honey bees (Disayathanoowat et al. 2011,
649 Saraithing et al. 2015, *in press*). Furthermore, some isolates of midgut bacteria inhibit growth
650 of American foulbrood causing *P. larvae in vitro* (Disayathanoowat et al. 2011, 2012). Honey
651 bee hives also harbor actinomycetes, the main microbial groups that produce natural
652 antibiotics (Promnuan et al. 2009, 2011), and hive components such as propolis and bee bread
653 could also assist in safeguarding against some pests and parasites (Simone-Finstrom and
654 Spivak 2012; Simone et al. 2009). Additionally, other non-biological factors and management
655 problems that plague not just honey bees, but other bees, could also result in decreased honey
656 bee health in Asia. Increasing loss of foraging resources due to farming and urban
657 encroachment may strain populations (Naug 2009). Pesticide exposure could also present high
658 risks to honey bees, and a recent study revealed that organophosphates are highly toxic to *A.*
659 *cerana* and *A. mellifera* (Stanley et al. 2015). The current policy of pollinator protection,
660 especially honey bees, has not yet been successfully implemented in the region as honey bees
661 are often undervalued or the value of honey bees is completely overlooked. Scientific
662 information of honey bee pests and parasites in some regions are still lacking. In addition,

663 standards and research on biomedical properties of bee products, such as honey (Wanjai et al.
664 2012) and propolis (Sanpa et al. 2015), are needed to promote beekeeping in Asia.

665 **Acknowledgement**

666 P.C. would like to thank the Thailand Research Fund, National Research Council of Thailand
667 and Chiang Mai University fund. G.R.W. thanks the Vinetum Foundation.

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1266 Figure legends

1267 Figure 1 *Apis cerana* beekeeping in China A) Traditional hive (Hubei) B) Modern box

1268 (Chongqing)

1269 Figure 2 Distribution map of *Varroa* spp. in Asia. A) *Varroa destructor*, B) *Varroa*

1270 *jacobsoni*, C) *Varroa rindereri*, D) *Varroa underwoodi*. Dark grey indicates Asian

1271 countries where the parasite has been detected in at least one honey bee species; light

1272 grey indicates Asian countries where the parasite has not been detected or no data

1273 (ND) are available.

1274 Figure 3 Distribution map of *Tropilaelaps* spp. in Asia. A) *Tropilaelaps clareae*, B)

1275 *Tropilaelaps koenigerum*, C) *Tropilaelaps mercedesae*, D) *Tropilaelaps thaii*. Dark

1276 grey indicates Asian countries where the parasite has been detected in at least one

1277 honey bee species; light grey indicates Asian countries where the parasite has not been

1278 detected or no data (ND) are available.

1279 Figure 4 Distribution map of *Euvarroa* spp. in Asia. A) *Euvarroa sinhai*, B) *Euvarroa*

1280 *wongsirii*. Dark grey indicates Asian countries where the parasite has been detected in

1281 at least one honey bee species; light grey indicates Asian countries where the parasite

1282 has not been detected or no data (ND) are available.

1283 Figure 5 Distribution map of fungal pathogens and diseases in Asia. A) *Nosema apis*, B)

1284 *Nosema ceranae*, C) Chalkbrood and D) Stonebrood. Dark grey indicates Asian

1285 countries where the parasite has been detected in at least one honey bee species; light

1286 grey indicates Asian countries where the parasite has not been detected or no data
1287 (ND) are available.

1288 Figure 6 Distribution map of bacteria diseases A) American foulbrood and B) European
1289 foulbrood in Asia. Dark grey indicates Asian countries where the parasite has been
1290 detected in at least one honey bee species; light grey indicates Asian countries where
1291 the parasite has not been detected or no data (ND) are available.

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- 1 Table 1. Differences in body size for all parasitic mites of honey bees in Asia. Aa - *A.*
 2 *andreniformis*, Ac - *A. cerana*, Ad - *A. dorsata*, Adbi - *A. d. binghami*, Adbr - *A. d. briviligula*,
 3 Af - *A. florea*, Ak - *A. koschevnikovi*, Al - *A. laboriosa*, Am - *A. mellifera*, Ani - *A. nigrocincta*,
 4 Anu - *A. nuluensis*.

Mite Species	Bee Host	Length (um)	Width (um)	Reference
Family Varroidae				
<i>Varroa jacobsoni</i>	Ac	1,063-1077	1,507-1596	Anderson and Trueman 2000, de Guzman and Delfinado-Baker 1996
<i>Varroa destructor</i>	Am, Ac	1,167	1,709	Anderson and Trueman 2000
<i>Varroa rindereri</i>	Ak	1,180	1,698	de Guzman and Delfinado-Baker 1996
<i>Varroa underwoodi</i>	Ac, Ani, Anu, Am	690-820	1,050-1,360	Delfinado-Baker and Aggarwal 1987, Anderson et al. 1997, de Guzman and Rinderer 1999
<i>Euvarroa sinhai</i>	Af	1,040	1,000	Delfinado and Baker 1974
<i>Euvarroa wongsirii</i>	Aa	1,000	1,125	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













