Chapter 6

Current Drivers of Taxonomic Biodiversity Loss in Asian and European Bees

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Introduction

Bees and their ancestors constitute a very old group- almost 120 million years old (Michener 2007, Michez et al. 2012, Danforth et al. 2013). Today over 16,000 species have been described worldwide, and undoubtedly they constitute a major part of the food chain, as well as the ecosystem's sensitive equilibrium through their service towards the pollination needs of the flowers, trees, and vegetables (Klein et al. 2007, Potts et al. 2016). However, this is a mutual relationship, as the bees rely on plants for their protein and carbohydrate nutrients, as well as on water and resins. The increasing human activity (habitat destruction, fragmentation, land use intensification, insecticides application), pathogens, and alien species threaten the diversity of life as a whole, and subsequently of bees around the world (Osborn et al. 1991, Banaszak 1995, Williams 1986, Steffan-Dewenter and Westphall 2008, Alaux et al. 2010a, Vidau et al. 2011) (Figs. 6.1 and 6.2).

Climate change also poses many risks for agricultural crops (Lobell et al. 2011, Rosenzweig et al. 2014), and eventually for pollinators (Freitas et al. 2009, Burkle et al. 2013, Vanbergen et al. 2013, Giannini et al. 2017). Hooper et al. (2012) suggested that species loss affects primary production and decomposition of plant

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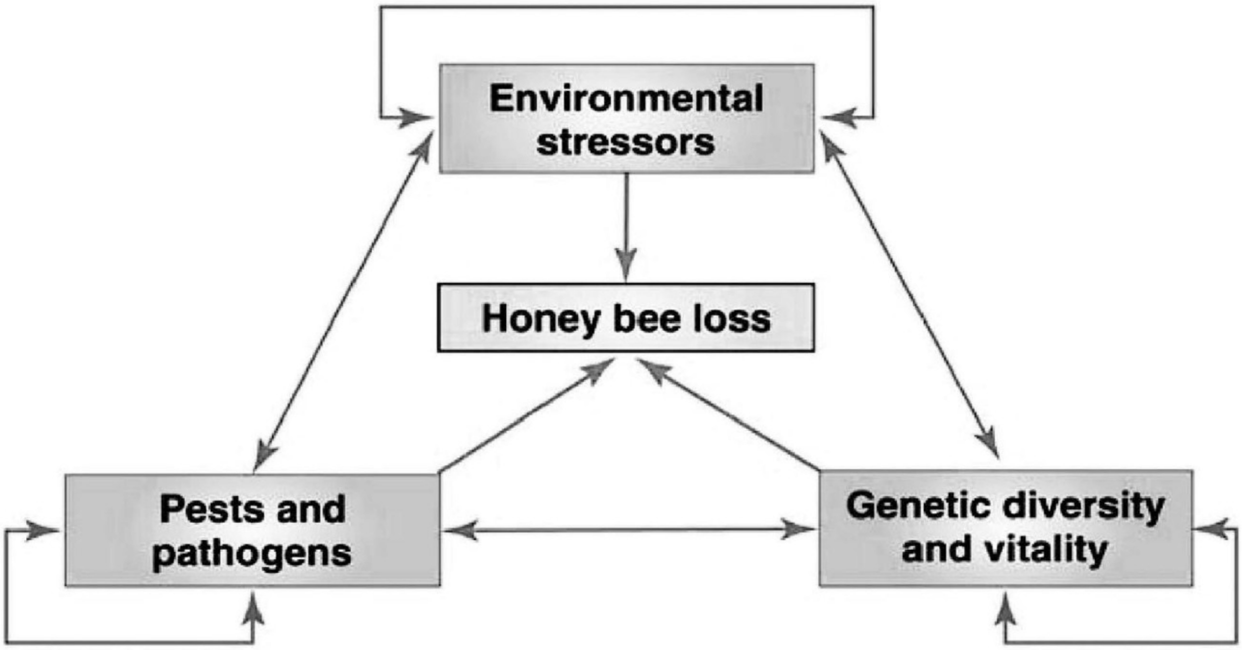

Figure 6.1: Interactions among multiple drivers of honey bee loss. Blue boxes represent the three main groups of drivers associated with honey bee loss; red arrows represent direct pressures on honey bees from drivers; green arrows represent interactions between drivers; black arrows represent interactions within drivers. (Retrieved from Potts et al. 2010b–TRENDS in Ecology and Evolution).

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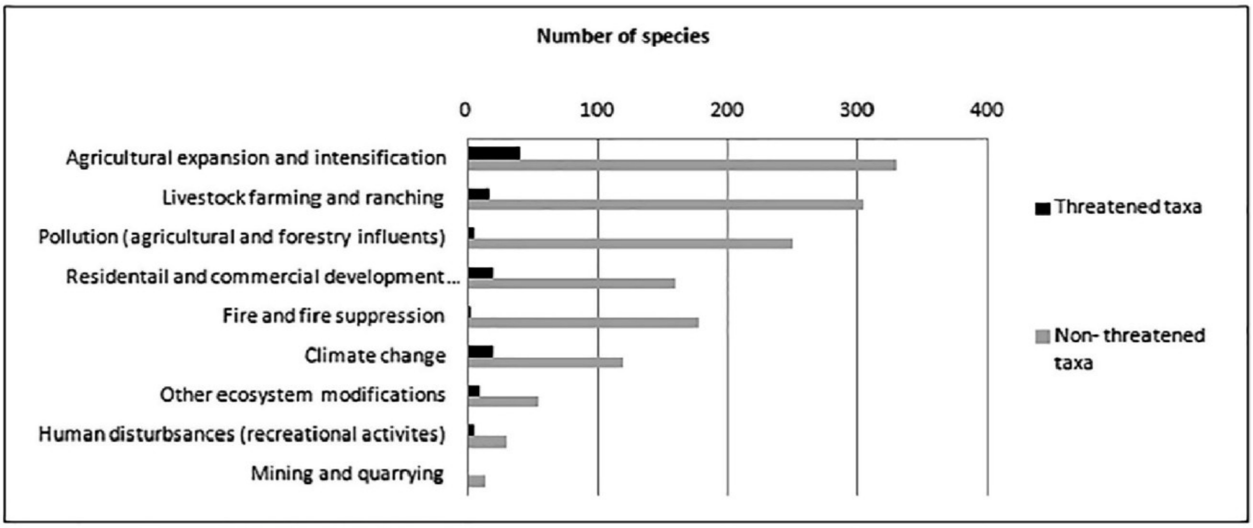

Figure 6.2: Drivers reducing biodiversity (Retrieved form Nieto et al. 2014).

species, and that biodiversity loss in the 21st century could be one of the major drivers of ecosystem change. The International Union for Conservation of Nature (IUCN) predicts a global loss of 20,000 flowering plant species within the next few decades; which will lead to the decline of dependent pollinators, such as honey bees (Heywood 1995). Also, the pollinator loss ultimately results in the decline of plant biodiversity (Thomas et al. 2004, Biesmeijer et al. 2006, Carvell et al. 2006, Pauw and Hawkins 2011).

Especially for the honey bees, there are reports of declines of their managed populations throughout the world (Potts et al. 2010b, vanEngelsdorp and Meixner 2010). Similarly, elevated colony losses have been reported from

Europe (Crailsheim et al. 2009, Potts et al. 2009), including countries, such as Austria (Brodschneider and Crailsheim 2010), Denmark (Vejsnaes et al. 2010), England (Aston 2010), France (Chauzat et al. 2010), Greece (Bacandritsos et al. 2010, Hatjina et al. 2010), Italy (Bortolotti et al. 2010), the Netherlands (van der Zee 2010), Norway (Dahle 2010), Poland (Topolska et al. 2010), Scotland (Gray et al. 2010), Bulgaria (Ivanova and Petrov 2010), Croatia (Gajger et al. 2010), Bosnia and Herzegovina (Santrac et al. 2010), Canada (Currie et al. 2010) and the USA (Ellis et al. 2010a, vanEnglesdorp and Meixner 2010), and the Middle East (Haddad et al. 2009a).

Environmental factors, such as weather conditions, availability of nesting sites, food sources, and chronic exposure to insecticides might cause CCD-like symptoms (Oldroyd 2007). Similarly, the pathogens and parasites which have been demonstrated to be involved in colony losses in different regions of the world, are considered current threats to honey bees and beekeeping (Genersch et al. 2010). In Fig. 6.2, we see the main drivers for bees decline, as reported by Nieto et al. (2014). Furthermore, in the most recently published review, we read "The main drivers of taxonomic insect biodiversity appear to be in the order of importance: (i) habitat loss and conversion to intensive agriculture and urbanization; (ii) pollution, mainly that by synthetic pesticides and fertilizers; (iii) biological factors, including pathogens and introduced species; and iv) climate change" (Sánchez-Bayo and Wyckhuys 2019). Concerning the bees (Apidae), the same authors report that almost 15% of bee species are extinct, 8% are threatened, and 42% are in a vulnerable condition.

Honey bee colony losses in general

Loss of taxonomic biodiversity of honey bees can partly be attributed to colony losses. Elevated losses of *Apis mellifera* colonies have been observed since over a decade now in numerous countries (Neumann and Carreck 2010). They were first observed in 2006 in North America (vanEngelsdorp et al. 2007, Ellis et al. 2010a), and were estimated to be 31.8 percent. Shortly after that, high loss was observed in Canada (36% and 35% in the respective winters of 2006/2007 and 2007/2008). Since then, many other countries started observing this trend, starting from the winter 2007/2008 (Brodschneider et al. 2010, Charriere and Neumann 2010, Gray et al. 2010, Hatjina et al. 2010, Ivanova and Petrov 2010, Vejsnæs et al. 2010, van der Zee 2010). In some regions of Italy, they reached 40% (Mutinelli et al. 2010), in Poland it was 15.3%, but it was still a big increase from 9.9% loss rate from the previous winter (Topolska et al. 2008, Topolska et al. 2010), which shows the scale of this phenomenon.

At some point, it became apparent, that individual countries are not going to solve this problem, so in 2008, an international network of honey bee experts-COLOSS—Prevention of Honey bee Colony Losses—was formed under COST funding (FA0803). Since then the network is working to identify the drivers of those elevated losses, as well as to estimate how high the losses were in different countries, and if there is any pattern to it. It has been observed, that the losses vary greatly across space and time. The "acceptable" loss level has been set at 10%, and anything that is higher than that indicates elevated colony losses.

A first comprehensive report from Europe was looking at the winter of 2008/2009, when the overall (for all participating countries) winter loss was 12.3%, which already exceeded the acceptable rate. Although looking at respective countries, the losses varied greatly, yet there were many, where the loss rate was almost double the acceptable limit (the Netherlands and Ireland 21.7%). The next winter (2009/2010) brought even bigger losses. For instance, in Italy, they were almost 30%, and in the Netherlands 29.3% (van der Zee et al. 2012). Since then, most countries still experience elevated colony losses (van der Zee et al. 2014, Brodschneider et al. 2016).

The most recent data shows an overall loss rate of 20.9% during the winter of 2016/2017 for Europe, yet, when looking at separate countries, the situation seems even worse. Overall losses noted in Spain were 27.6%, in Serbia 24.1%, Poland 21.8%, just to name the highest (Brodschneider et al. 2018).

In the US, the elevated losses still continued (and still do), and since 2008 they were reported to increase to 35.9% (vanEngelsdorp et al. 2008), and haven't gotten under the desired 10% since (Ellis et al. 2010b, Spleen et al. 2013, Steinhauer et al. 2014, Bruckner et al. 2018).

A report by FAO (2013) indicates that in the period between 1961 and 2007, the number of managed colonies decreased in Europe (26.5%), North America (49.5%), Asia (42.6%), Africa (13.0%), South America (86%), and Oceania (39%) (Fig. 6.3).

In Asia, colony losses of managed honey bees have raised a major concern, and surveys of colony losses were conducted around the globe to understand the apicultural situation. Till date, most studies have focused on the mortality of the western honey bee—*Apis mellifera*; however, little is known about the mortality of its eastern counterpart—*Apis cerana*. Here, we report the survey results of *A. cerana* colony losses in three consecutive years (2011–2012, 2012–2013, and 2013–2014) in China, which were 12.8%, 95%, and 11.9–13.7%, respectively, but varied among years, provinces, and types of apiaries (Chen et al. 2017).

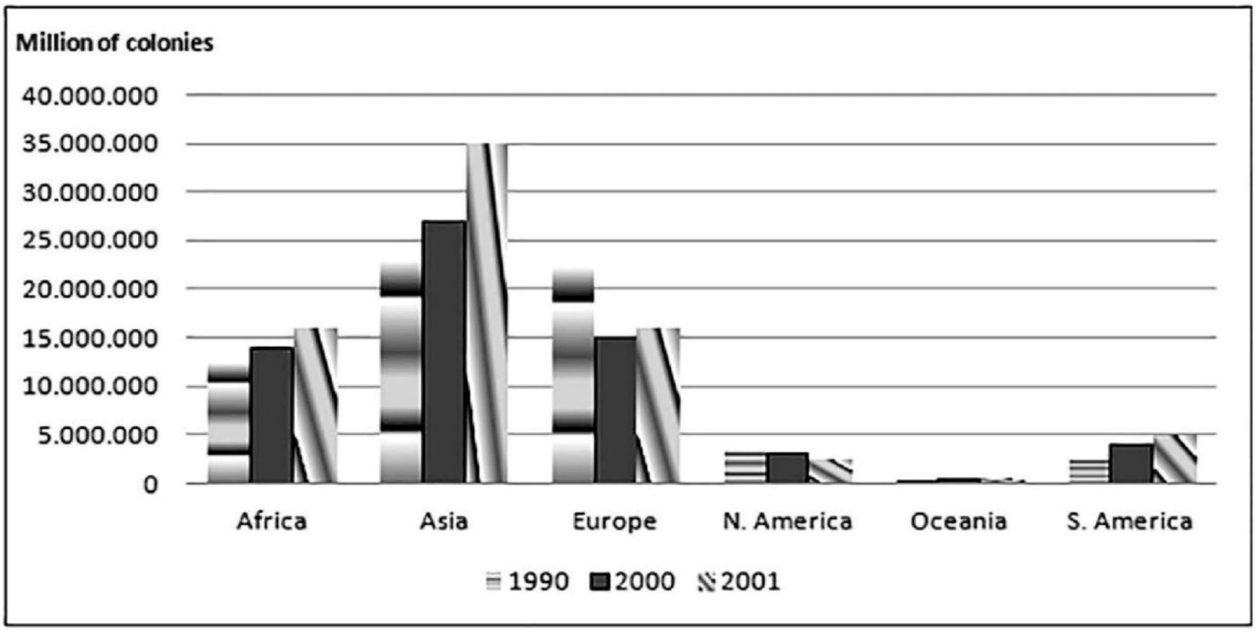

Figure 6.3: Honey bee colony declines over the years (Retrieved from FAO 2013).

Much thought and research has been given to determine the causes of those nearly catastrophic losses all over the world and it has been concluded that pathogens play a key role in this global decline. The intensity may vary between continents or countries, but *Varroa destructor* with viral infections that it vectors and activates has been unanimously named as the main cause of global colony losses (van der Zee et al. 2015). More recently, *Nosema ceranae* has been described as the second most important cause of mentioned losses (Higes et al. 2009).

Pathogens of honey bees

The drivers of colony losses (that add to the loss of taxonomic biodiversity of bees) are most often pests and pathogens, especially the (relatively) newly introduced ones. It is widely known, that an introduction (or invasion as a matter of fact) of an alien species into an ecosystem is one of the most important sources of biodiversity loss and may result in host eradication (Deredec and Courchamp 2003). Invasive alien species is an alien species whose introduction and/or spread threatens biological diversity. Introduced pathogens and parasites are often able to switch hosts, therefore posing new threats to native species which lack innate abilities to fight the infestation/ infection/invasion (Cuthbertson et al. 2013).

There is also the matter of biodiversity-disease relationship. There are many hypotheses on how these relations' dynamics work, but the most plausible is the "dilution effect" hypothesis, which puts weight on the fact that increased diversity will actually decrease the disease transmission, which means, that saving biodiversity of bees will help prevent diseases in the long perspective, as a sort of upward spiral.

Invasive alien honey bee pest and pathogen species are impacting global bee biodiversity, which is a major concern because biodiversity is essential in the functioning of healthy ecosystems. Those alien species are steadily increasing in numbers as a result of world trade expansion and improvement of transport. Also, global warming makes it possible for pests, which are native for tropics, to move, and settle in a more temperate climate. It is believed that wild populations are not normally threatened by the parasites and pathogens with which they co-evolved. However, adverse effects of pests and diseases may arise when wild populations are stressed by environmental degradation. Allen et al. (1990) found a Nepalese population of *A. laboriosa* that was severely infected with European foulbrood (*Mellisococcus plutonius*), which they attributed to environmental stress brought on by deforestation.

The *Varroa* mite

Regarding the honey bees, the most dangerous introduced pathogen is (still, after over 3 decades) *Varroa destructor* (Fig. 6.4 A).

Originally it was a parasite of *Apis cerana*, but due to the export/import of bees, which provided contact between Western and Eastern honey bee colonies, it had the opportunity to broaden its host range to *Apis mellifera*, which was far less resistant to the infestation and its consequences. As a result, the mite has spread almost worldwide. Till date, only Australia is free of this parasite (AQIS, Australian Government: http://www.daff.gov.au/aqis/quarantine/pests-diseases/honey bees).

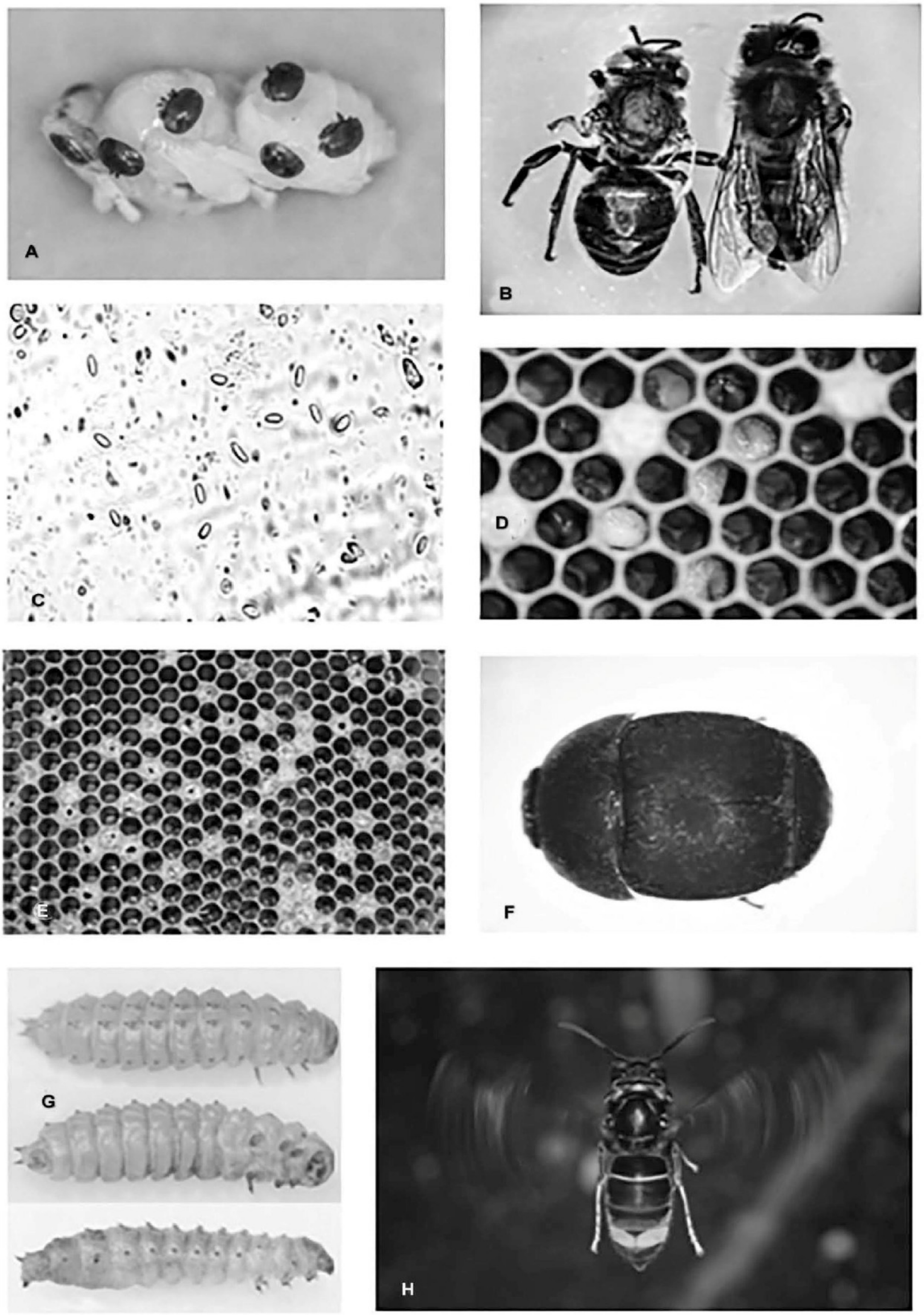

Figure 6.4: (A) The *Varroa* mite females feeding on a honey bee pupa. (B) A bee with deformed wings and shortened abdomen due to the DWV infection. (C) *Nosema ceranae* spores seen in 400x magnification. (D) A brood comb with twisted, diseased larvae attacked with *Melissococcus plutonius*. (E) a brood comb with brood cappings clearly punctured and scattered brood pattern. (F) The small hive beetle imago. (G) larva. (H) The yellow-legged hornet (Photos A, B, C, D, E, F, G: A. Gajda, Photo H: Per Kryger).

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V. destructor female feeds on the fat body and hemolymph by piercing the cuticle of brood and bees. With low and medium levels of colony infestation, the symptoms in individual bees are not visible, however, adult bees emerging from infected cells have lowered immunity and their life span is significantly shortened. Feeding females cause physical injuries to the bees and brood, which lowers their protein, fat, and carbohydrate levels, and interferes with organ development (Bowen-Walker and Gunn 2001).

The mite is also known to be a vector and activator for some bee viruses, such as Kashmir Bee Virus (KBV), Acute Bee Paralysis Virus (ABPV), Israeli Acute Paralysis Virus (IAPV), and Deformed Wing Virus (DWV) (Tentcheva et al. 2004, Boecking and Genersch 2008). Those viruses were long present before the occurrence of *V. destructor* in *A. mellifera*, but haven't been observed to cause major problems (Bailey and Ball 1991, Bowen-Walker et al. 1999). It is thought, that the direct injection of the virus to the hemolymph provokes typical disease symptoms. The most widely researched is DWV infection. It results in deformed wings (Fig. 6.4 B) and shortened abdomens in heavily infested honey bee colonies (Boecking and Genersch 2008, De Miranda and Genersch 2010).

Initially, when the *Varroa* mite arrived in its non-native countries, it had a tremendous effect on wild bee populations (Kraus and Page 1995), and massive honey bee losses were documented, for example in Greece, where 20–25% losses were reported (Santas 1983). The parasite was "unknown" for the beekeepers, as there was negligible knowledge about its biology, its behavior, and there were no treatment methods. It took many years until beekeepers started to deal with this mite in a way that they could reduce the loss of their colonies and the reduction of their income (Emmanouel et al. 1984, Boecking and Genersch 2008). At the same time, beekeepers started to replace their lost colonies with populations from other places, from the same or different countries, resulting in introgressive hybridization of the native subspecies and ecotypes (Jensen et al. 2005, Ivanova et al. 2007, Soland-Reckeweg et al. 2009, Martimianakis et al. 2011), or they even stopped beekeeping completely.

An optimistic message has recently come from different parts of the world: there are many reports of colonies resistant to the mite infestation (Büchler et al. 2010, Danka et al. 2012, Locke et al. 2012, Kirrane et al. 2015), but with the current state of worldwide beekeeping, where many colonies have extremely high infestation levels due to poor treatment, the resistant colonies are simply attacked too strongly when introduced to an environment, and they automatically are in a losing position simply because they are "introduced" (Büchler et al. 2014). *Varroa* resistant colonies are, however, thought to be the best solution in eliminating the problem of colony losses due to this parasite, but it seems that global beekeeping and *Varroa* management need to be controlled and advised in a way that will allow for the resistant bees to thrive. This will, of course, mean further loss of diversity in favor of resistant genotypes, yet this seems to be the only plausible solution, allowing the end of the great colony losses observed due to this widespread and dangerous parasite. We also need to note that 30 years is simply not enough time for the host-parasite relationship to co-evolve in a way that would create some sort of homeostasis between them and allow them to co-exist, as it is observed in *A. cerana* colonies, for which the parasite doesn't pose such a big threat. Therefore, steps must be taken towards the most sustainable solution in saving honey bee diversity.

The Microsporidium *Nosema ceranae*

The second most dangerous pathogen causing colony losses is the Microsporidium *Nosema ceranae* (Fig. 6.4 C). Much like *V. destructor*, *N. ceranae* was previously parasitizing only *Apis cerana*. In 2005, it was found in *Apis mellifera* for the first time, but soon it turned out that it had made a host switch to *A. mellifera* at least 10 years before (Paxton et al. 2007, Chen et al. 2008, Topolska et al. 2008). By now, *N. ceranae* is spread worldwide, and causing major colony losses in many countries (Higes et al. 2006, Huang et al. 2007, Klee et al. 2007, Chen et al. 2008, Giersch et al. 2009, Higes et al. 2009, Invernizzi et al. 2009), including Canada and USA (Williams et al. 2008).

The microsporidia infect the epithelial cells of the midgut of adult bees, causing digestive disorders, which leads to a shorter life span. Just one infected cell is enough for the disease to develop, moreover, constant intake of spores is also not necessary (Meana 2009). The parasite damages not only the epithelial cells, but also the regenerative crypts of the midgut, which leads to irreversible damage (Kasprzak and Topolska 2007). The death of the bee is a result of a prolonged hunger state, which leads to energetic stress (Mayack and Naug 2009). This state of hunger is the reason bees are actively seeking others, who will potentially feed them (via trophallaxis), which leads to a rapid spread of the disease in the colony.

The threat of this disease is mostly attributed to the fact that it can kill quickly and there are no symptoms right until the moment when the level of infection is much too high to fight anymore. Beekeepers often find their colonies dead at the bottom board after the winter period, or "disappeared" if the infection level is already too high before the winter. In this case, it is thought that sick bees are leaving the hive to find food, and never come back due to energetic stress. As a consequence beekeepers will need to replace their lost stock with others, sometimes from foreign genotypes, resulting in an even higher dwindling of local biodiversity.

It seems that warmer climate favors the disease, while in colder regions of the world *N. ceranae* doesn't seem to be a problem (Forsgren and Fries 2013). In Kashmir, Dar and Ahmad (2013) also observed the highest infection rate of 41.1% in spring and 13.3% in summer, however, the infection rate was low to none in autumn. The mountainous climate of Kashmir with humid springs and summers favors *Nosema* spread. This usually leads to higher colony losses due to nosemosis in the warmer climate, meaning that the global diversity of honey bees is already dwindling, since the pathogen is wiping out bees in some parts of the world and beekeepers might seek "more resistant" bees from other countries. It is important to note here that even the scientific approach of seeking bee genotypes resistant to *Nosema* spp. (Chaimanee et al. 2012), might lead to a reduction of honey bee biodiversity.

Bacterial pathogens of honey bees

There are two main bacterial pathogens of honey bees, and both are pathogenic to larvae but not to adult bees: *Melissococcus plutonius*, causing European foulbrood (Bailey 1956, 1957) (Fig. 6.4 D) and *Paenibacillus larvae*, causing American foulbrood (Fig. 6.4 E) (Genersch et al. 2006, Genersch 2010). *P. larvae* is a spore-forming bacteria, which makes its control more difficult than *M. plutonius* (which does not form spores). The *M. plutonius* enters the larvae through ingestion and proliferates in the larval midgut, assimilating much of the larval food and the infected larvae die from starvation (Bailey 1983). There are few reports of colony losses due to bacterial pathogens around the world. Allen et al. (1990) found a Nepalese population of *A. laboriosa* that was severely infected with *M. plutonius*, which they attributed to environmental stress brought on by deforestation.

American foulbrood (AFB) is a notifiable disease in many countries. It is highly contagious, easily and rapidly spread within a colony and among colonies. Such colonies with AFB should be destroyed to prevent the disease from spreading further. AFB has had big impact on the beekeeping industry. In 2000, the annual economic loss attributed to AFB infection in the U.S. was $5 million (Eischen et al. 2005). It is considered to be more virulent than European foulbrood.

European foulbrood (EFB) has been reported from across every continent that honey bees inhabit (Matheson 1993), and currently appears particularly prevalent and dramatically increasing in the UK (Wilkins et al. 2007, Tomkies et al. 2009) and Switzerland (Belloy et al. 2007, Roetschi et al. 2008, Forsgren 2010), but EFB it is not believed to be a major factor to explain widespread colony losses.

The small hive beetle and the yellow-legged hornet

In recent years, two more invasive alien species were introduced to Europe, namely: small hive beetle *Aethina tumida* and the yellow-legged hornet *Vespa velutina*. The small hive beetle *A. tumida* is a parasitic pest and scavenger of social bee colonies (honey bees, bumble bees, stingless bees) in sub-Saharan Africa. In its original ecosystem, it rarely inflicts damage on colonies, which co-evolved with the pest and developed mechanisms to keep the invasion on non-threatening levels. However, *A. tumida* has since "escaped" from its native environment and has invaded North America and Australia, where it impacted the apiculture industry greatly. A decline in native bees due to infestation by small hive beetles will potentially have a negative impact on bee biodiversity (Cuthbertson and Brown 2009).

Adult small hive beetles (Fig. 6.4 F) measure on average 5.7 mm × 3.2 mm (Ellis et al. 2002). The size of beetles can vary due to food availability and variations in climate (Ellis 2004). They can fly several kilometers (Somerville 2003), which makes their spread fast and quite easy. But the real threat is the larvae (Fig. 6.4 G), which can destroy the honey bee nests nearly completely by feeding on brood, honey, and pollen, and destroying combs in the process. As it is a very new, and potentially big threat to European beekeeping, the infestation is compulsorily notifiable in the European Union. After a case is confirmed, Veterinary Services take necessary measures to stop its further spread. A decline in native bees due to infestation by small hive beetles will potentially have a negative impact on bee biodiversity (Cuthbertson and Brown 2009).

The invasive yellow-legged hornet (*V. velutina*) is a predator of honey bees introduced into Europe from Asia (Fig. 6.4 H). It poses an additional threat to honey bees and other pollinators in light of current, already high, colony (and generally pollinator) losses. It was first observed in France in 2004 (Rortais et al. 2010), and has rapidly spread to Spain, Italy, Belgium, Portugal, Germany, and Great Britain. Other areas of introduction are South Korea and Japan. The diet of *V. velutina* may be comprised of honey bees and other Apoidea in 70 percent. Besides honey bees, *V. velutina* preys on other Hymenoptera, including various species of wild bees, but also preys on Vespidae, Diptera, and other insects. Therefore, the hornet might have a negative effect on insect communities, reducing biodiversity.

All the above mentioned invasive species have a great (but not only) impact on the honey bee biodiversity, as they are adding to the colony losses that are already high in recent years. However, research shows that certain genotypes of bees may be resistant, while others remain susceptible to different pathogens or pest invasions. Studies show that no matter the disease/invasion, locally adapted bees will always do better when exposed to certain pests and pathogens in their own environment, than the introduced ones (Meixner et al. 2015), which gives a strong hint as to how to manage bee populations.

Interestingly, many microparasites, including *Nosema*, viruses, and fungi which affect honey bees were detected also in solitary bees in the vicinity of the apiaries, suggesting "that beehives represent a putative source of pathogens for other pollinators. Similarly, solitary bees may act as a reservoir of honey bee pathogens" (Ravoet et al. 2014).

Agricultural intensification and pesticides

Land Use. As already mentioned in the Introduction, intensification of agriculture has a number of impacts on the availability of resources for wild and managed bees at a landscape scale (Feon et al. 2010), and is widely regarded as the primary driver of bee declines across Europe (Kuldna et al. 2009). Discussing about bee losses, we do not refer only to actual number of insects or honey bee colonies (Aizen and Harder 2009, Le Conte et al. 2010, Neumann and Carreck 2010, van der Zee et al. 2012, van der Zee et al. 2014, Brodschneider et al. 2016), but also to the loss of bee biodiversity, loss of taxa, loss of honey bee subspecies, and other pollinators (Biesmeijer et al. 2006, Moritz et al. 2007, Goulson et al. 2008, Williams and Osborne 2009, Settele et al. 2008, Meixner et al. 2010). The European Red List of Bees provided information on the status of nearly 2,000 species of bees in Europe, including *A. mellifera*. According to the Red List of Bees 7.7% (150 species) of European bees have declining populations, while 9% of bees in Europe are threatened with extinction, mainly due to habitat loss as a result of agriculture intensification (Nieto et al. 2014).

Deforestation during the last 25 years (Sodhi et al. 2004) and an extremely high human population density in some countries, such as Pakistan, Nepal, and Bangladesh inevitably causes increased pressures on natural ecosystems. Broad-scale conversion of primary forest to short-cycle forestry, rubber and oil palm plantation, agriculture, and urban areas (Kevan and Viana 2003, Sodhi et al. 2004) are a major concern for honey bee conservation. Sodhi et al. (2004) outline the depressing reality of deforestation in Southeast Asia. This region has the highest rate of tropical deforestation in the world, and is predicted to lose three-quarters of its original forest and 42% of its biodiversity in the next hundred years.

In most industrialized countries, intense land use has led to a progressive reduction of habitats suitable for honey bees with a negative impact on feral and wild populations (Biesmeijer et al. 2006, Kremen et al. 2007, Flynn et al. 2009). Agricultural intensification and forestry have been shown to reduce the diversity and abundance of native bees in the US, diminishing their pollination services by 3 to 6-fold (Kremen et al. 2007). In Europe, commonly practiced intense land use is likely to reduce not only the availability of floral resources, but also nesting sites suitable for honey bees (Biesmeijer et al. 2006, Murray et al. 2009). According to Nieto et al. (2014), "Europe seems to have the most highly fragmented landscapes of all continents, and only a tiny fraction of its land surface can be considered as wilderness".

In areas of intense land use, facilitating the establishment of native honey bees in nature reserves may be a strategy to reestablish wild populations. Many European governments (e.g., Belgium, Netherlands, and the UK) however, have implemented national policies to warrant the legal exclusion of managed pollinators from Protected Areas (Sections 14 and 16 of the UK's Wildlife and Countryside Act 1981), based on questionable evidence on competition between honey bees and other native pollinators (Huryn 1997, Paini 2004). Based on the same evidence, other countries, such as Germany and Austria, permit apiculture within designated Protected Areas.

Fragmentation of habitats is responsible for changing pollinator populations (Thomas et al. 2004); it causes genetic erosion by reducing gene flow and increases the chance of extinction of populations and species (Barrett and Kohn 1991), as well as decreasing food and nesting resources (Hines and Hendrix 2005, Potts et al. 2005). Habitat loss might be one of the biggest factors impacting honey bee decline and the agricultural landscape changes after the Second World War (Winfree et al. 2009).

Use of Pesticides. During the last 5 years, an exponential increase in the interest of scientists to determine the effects of all types of pesticides on bees' behavior, immunity, biodiversity, and general well-being is observed. It is due to a massive expansion in the use of chemicals active at very low doses, which do not really kill the individuals, but they jeopardize their well-being. According to the European Environment Agency, the agricultural sector is one of the mainland users in Europe. Farming systems in Europe, as well as around the world have been strongly intensified over the past 50 years, and have led to the homogenization of agrosystems. Eventually, higher amounts and new chemical compounds are used every year to protect the crops (Fig. 6.5).

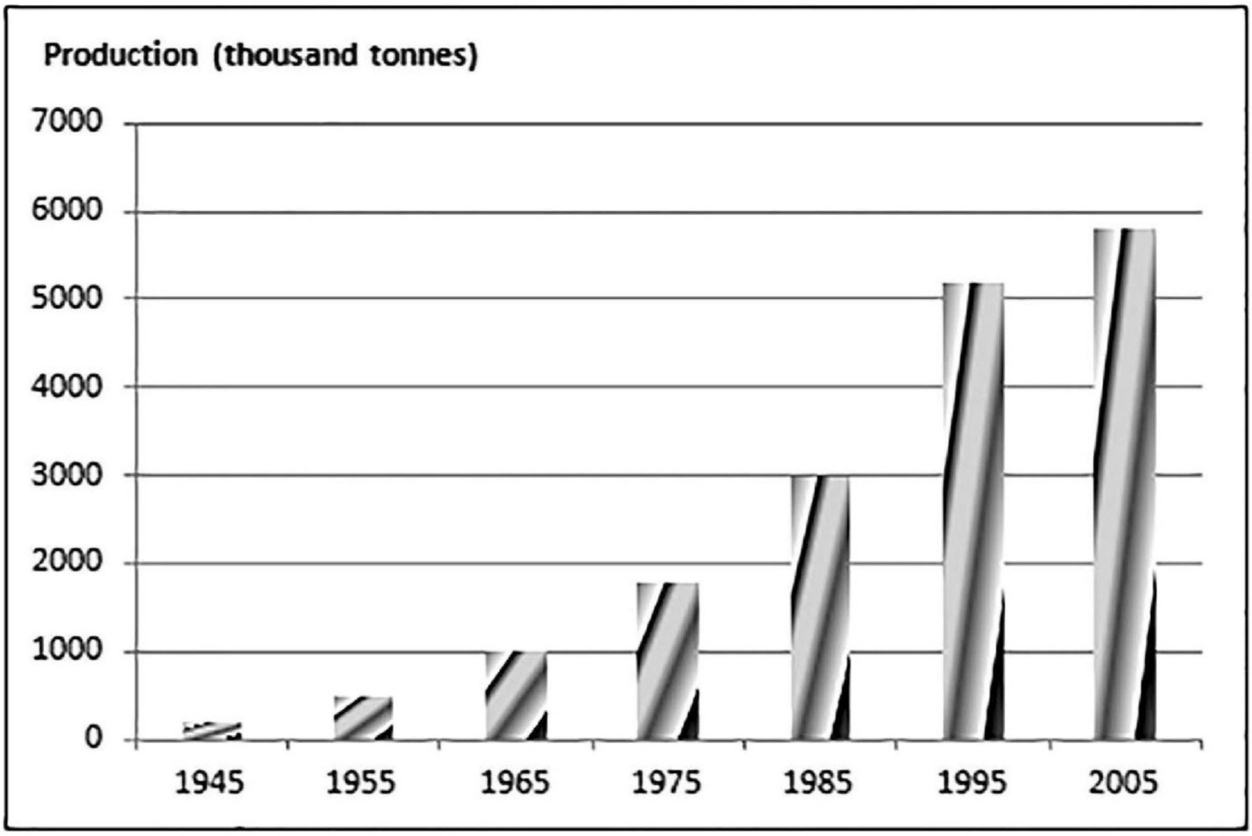

Figure 6.5: World production of pesticides. (Retrieved from Agrochemical Service 2000 in Carvalho 2006).

A recent update from the Worldwide Integrated Assessment on the Impact of Systemic Pesticides on Biodiversity and Ecosystems has evaluated 500 scientific evidence published since 2014 and confirms the high risk posed by these substances not only to insects but also to vertebrates and wildlife in general. Almost 90% of these publications demonstrate the devastating effects of pesticides on biodiversity of bees around the world. The reduction is referring to species richness as well as to population numbers of all: solitary bees, bumble bees, and honey bees (Simon-Delso et al. 2014, Goulson et al. 2015, Raine and Gill 2015, Van der Sluijs et al. 2015, Kerr 2017, Lundgren 2017, Rortais et al. 2017).

Honey bees and non-*Apis* bees may differ in their susceptibility and exposure to pesticides because they differ significantly in terms of morphology, physiology, life cycle, survival needs, and behavior (Arena and Sgolastra 2014, Heard et al. 2017). Moreover, non-*Apis* bees may also experience higher pesticide exposure than honey bees due to their life cycle, which makes them more susceptible (Arena and Sgolastra 2014, Heard et al. 2017, Gradish et al. 2019).

When the effect of pesticides is high, for example when there is direct oral or contact exposure to high concentrations, the population numbers of all species are affected. However, when the exposure is through a continuous low concentration poisoning, then the behavior and the immune system is altered, and the effect could even be on a species level, as most of the species are oligolectic and have a short lifespan (Arena and Sgolastra 2014). Pesticides, therefore, could be regarded as the number one stressor on species decline of European and World bees, although this might not apply to honey bees. Nonetheless, the synergistic or combination effect of pesticides together with honey bee diseases (e.g., nosemosis) should not be overlooked, as it can wipe out vast numbers of managed bees (Vidau et al. 2011, Pettis et al. 2012).

Hunting pressure of honey bees (Asia). Asian people have been hunting honey bees for more than 40,000 years (Crane 1999), and bee hunting is still widely practiced throughout the continent. To take an A. florea or *A. andreniformis* colony, the hunter merely shakes the bees off, snips the branch holding the colony, and carries the comb home. It is assumed that provided there is plenty of food available, the colony recovers from the theft of its comb more often than not. Hunting *A. dorsata* and *A. laboriosa* is much more brutal and often involves burning the bees with a smoldering torch of the tightly-bound brush (Valli and Summers 1988, Lahjie and Seibert 1990, Nath et al. 1994, Crane 1999, Tsing 2003). Some harvested colonies may be able to regroup, especially if the hunt occurs in daylight. Often, however, the hunt is conducted in the darkness. The hunter bangs his torch on the branch supporting the colony to create a shower of sparks. The bemused bees follow the sparks to the forest floor (Tsing 2003) where they crawl, often with burned wings. Many queens are lost during these harvests, and their colonies perish along with them. Night hunting is preferred by many hunters because it reduces the number of stings received. This method of hunting kills many, if not most, colonies.

The level of hunting pressure is most likely increasing in many areas. Even the poorest communities (who are more likely to engage in hunting than landowners) have increasing access to motorized transport so that they can access nests over a broad area. Conversion from a barter/subsistence economy to a cash-based economy increases the incentive to produce a high value, an easily-transported product like honey (Nath et al. 1994, Tsing 2003, Nath and Sharma 2007). Increasing population in the cities and rural towns may increase the demand for wild honey, which is perceived as being more natural, pesticide-free, more healing and delicious than honey produced from domestic colonies. Finally, decreasing areas of forested land increase the hunting pressure on the remaining forested pockets (Nath et al. 1994). Consequently, hunting pressure might lead to the extinction of local species across extensive areas of Asia, although a complete extinction of any honey bee species is unlikely to occur.

Beekeeping practice, breeding, and hybridization

Europe. Fifteen (15) subspecies of *A. mellifera* are recognized today in Europe (Ruttner 1988, Garnery et al. 1992, De la Rúa et al. 2004, De la Rúa et al. 2009, Meixner et al. 2013), and it seems that species richness for both *Apis* and non-*Apis* bees is increasing from the North to the South of Europe. According to Ruttner (1988), the present distribution of European honey bee subspecies has been influenced by the Last Glacial Maximum (LGM), when the mountain chains of the Pyrenees, the Alps, and the Balkans acted as geographic barriers in maintaining the European populations in isolation (Fig. 6.6).

As can be seen in Fig. 6.6, the subspecies with the largest natural area of distribution is *A. m. mellifera* and the ones with the smallest are *A. m. siciliana*,

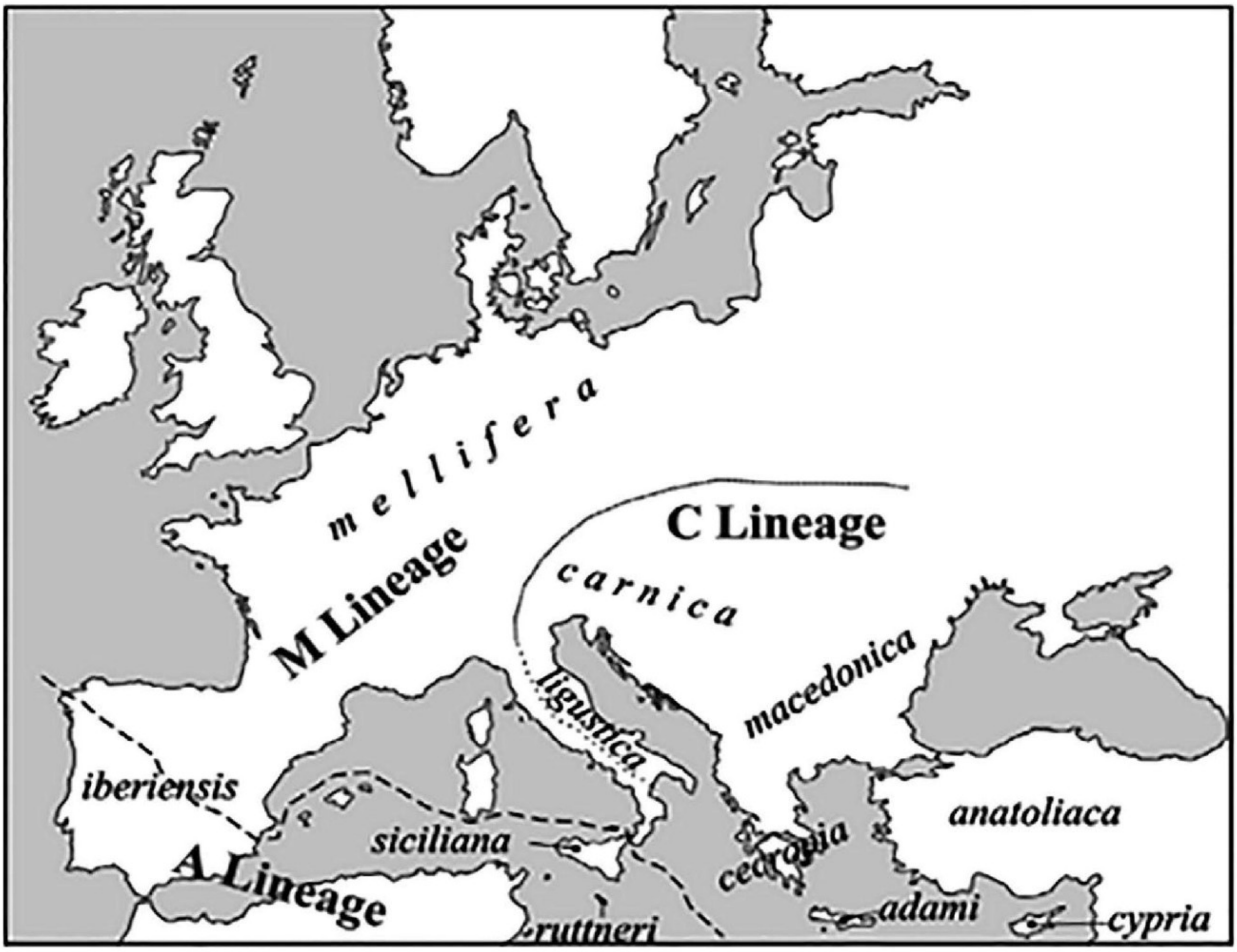

Figure 6.6: Approximate distribution of the *Apis mellifera* evolutionary lineages and subspecies in Europe (Source: De la Rúa et al. 2009).

A. m. ruttneri, and *A. m. adami*. Therefore, it is not surprising that the species with the smallest distribution suffers the most effects of all threats discussed in this chapter (Fontana et al. 2018).

The Italian bee (*A. m. ligustica*), the Carniolan bee (*A. m. carnica*), and the Caucasian bee (*A. m. caucasica*) are regarded as the "favorite" subspecies kept by many beekeepers around the world. The breeding activities and intense dissemination of these particularly docile and productive "superior" honey bees throughout the European continent have resulted in introgressive hybridization of the native subspecies and ecotypes (Jensen et al. 2005, Ivanova et al. 2007, Soland-Reckeweg et al. 2009, Martimianakis et al. 2011). In other areas, a complete replacement of the local subspecies has occurred. For example, the *A. m. mellifera* in central European countries, such as Germany. As a result of beekeeping activities, the distribution map described originally by Ruttner (1988), as shown in Fig. 6.6, has been changed. In other words, the "introduction" of the "superior" subspecies outside their natural range, and in regions where other subspecies of *A. mellifera* are endemic (Europe, Africa, and western Asia) or where *Apis* species are not endemic (America, Australia), could be regarded as an invasion, and all "invasion" types have resulted in loss of biodiversity (Moritz et al. 2005).

It has also been claimed that the consequence of the introduction of particular *A. mellifera* subspecies in a certain region is the extinction of its native honey bees

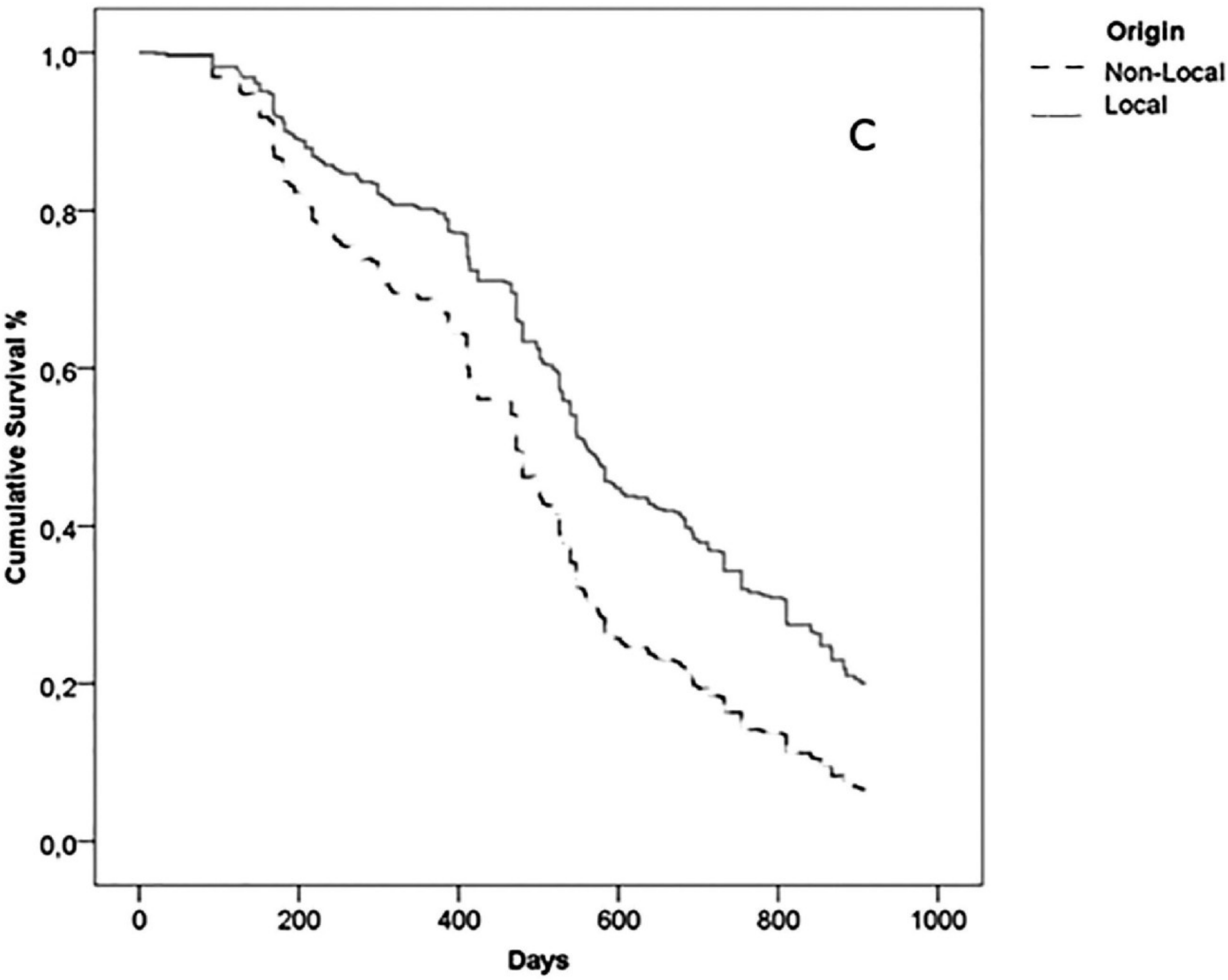

Figure 6.7: Colony survival in relation to the origin of the queens (Source: Büchler et al. 2014).

(Ruttner 1969, Ruttner 1988). However, recent studies fail to document a complete extinction, and autochthonous subspecies or genotypes can still be identified (De la Rúa et al. 2004, Martimianakis et al. 2011). Certainly, a racial admixture has occurred and valuable characteristics might have been lost.

Commercial breeding activities often overlook the importance of local adaptation. The long coexistence and adaptation of honey bees with plants and the environment, in general, is recognized by distinct genotype-environment interactions (GEI), and is expressed through the degree to which different genotypes are affected by the environmental conditions (Falconer and Mackay 1996). It has well been documented through a recent Genotype-Environment Interaction experimentation, that local populations/subspecies/genotypes are better adapted, longer survived, and more productive (Fig. 6.7) (Büchler et al. 2014, Hatjina et al. 2014, Meixner et al. 2014, Uzunov et al. 2014b, Meixner et al. 2015).

Asia. East Asia is home to at least 9 indigenous species of honey bees. Furthermore, the Asian honey bee *A. cerana* has been raised in indigenous cultures across the Asian continent for around two thousand years (Crane 1995). At the beginning of the 20th century, however, beekeepers across Asia began to import the European honey bee, *A. mellifera*, a species that lives in significantly larger colonies (30,000–50,000 vs. 2,000–20,000 in *A. cerana*). For example, some of the first European honey bees

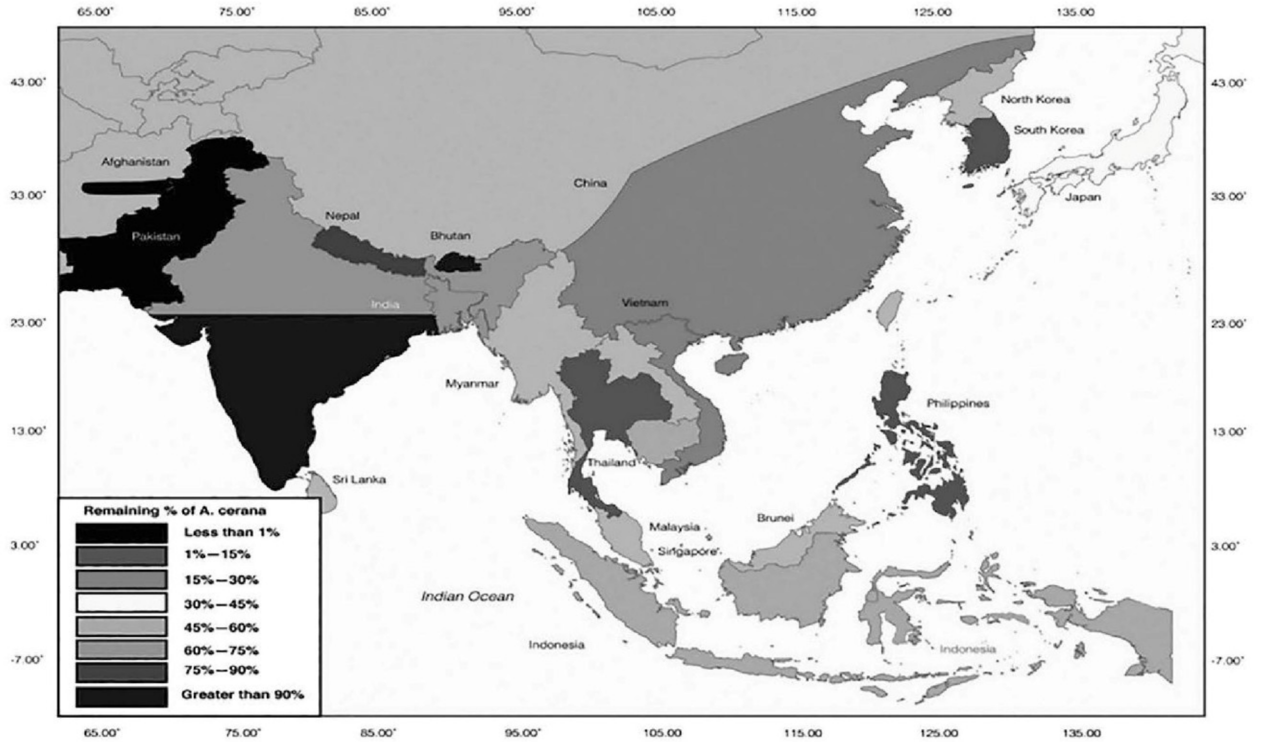

Figure 6.8: Map of the estimated remaining percentage of *A. cerana* compared with *A. mellifera* based on 2014–15 of 31 apiculturists in 16 Asian countries. Due to lack of data about wild honey bee species, only the commercially kept species (*A. cerana* + *A. mellifera*) could be taken into account. The sum of both species represents 100%, while the map details the proportion of *A. cerana* still extant (Source: Jones and Bienefeld 2016).

Color version at the end of the book

arrived in India in 1880 and were firmly established by 1960 (Abrol 2013, Crane 1995).

A. cerana was established in Vietnam in the 1960s (Tan and Binh 1993), and in Pakistan by the late 1970s (Sivaram 2012), but only reached Nepal and Bangladesh in 1990 and 1995, respectively (Sivaram 2012). *A. mellifera* is considered to be more productive than its Asian counterpart, and therefore more suitable for commercial beekeeping (Abrol 2013, Atwal 2000). Whether or not *A. mellifera* is profitable, its introduction into the native range of *A. cerana* is often problematic, for a myriad of reasons, i.e., competition for floral resources, interference with *A. cerana* mating by *A. mellifera* drones, who will pursue *A. cerana* queens, the introduction and exchange of pests and diseases. All this has contributed to a drastic decline in *A. cerana* health and numbers (Fig. 6.8).

The decline of *A. cerana* was observed in Afghanistan, Bhutan, China, India, Japan, South Korea, Myanmar, Pakistan (Verma 1998, Abrol 2013), the Philippines (Mojica 2011, Wendorf 2002), Taiwan, and Vietnam (Koetz 2013a) on an average of about 55 percent (Jones and Bienefeld 2016). It is now a reality across all of Asia. The essential drivers of this decline are lower productivity per hive, the impact of habitat destruction, alien species invasion, monoculture, chemical use, and the management challenges of absconding behavior (Akratanakul et al. 1990, Abrol 2013, Koetz 2013b).

China has six million bee colonies, About 200,000 beekeepers in this region raise Western honey bees (*A. mellifera*) and Eastern honey bees (*A. cerana*). In recent years, Chinese beekeepers have faced several complex symptoms of colony losses in both *Apis* species. Certain losses are known to be caused by *Varroa* mites (*A. mellifera*), Sacbrood virus (*A. cerana*), and *Tropilaelaps* mites (both species). However, other factors and mechanisms are being investigated, although no data has been published till date (UNEP 2010).

The red dwarf honey bee, A. florea, in the Asian subcontinent is actually expanding its range into the Middle East (Mossagegh 1993), and the Eastern honey bee, *A. cerana*, into New Guinea (Anderson 1994). In Hong Kong, one of the most urbanized and altered landscapes on the planet, *A. cerana*, remains common and is an important pollinator of remnant vegetation (Corlett 2001).

Nonetheless, there are obvious signs of threatening processes at work in some species in some areas, and it is suspected that these processes either have or soon will drive local extinctions. Perhaps this has already occurred in the dwarf bees on the island of Hong Kong, where they are apparently absent (Corlett 2001). The red honey bee, *A. koschevnikovi*, is now extremely rare on peninsular Malaysia and the south of Thailand (Otis 1996).

Take home message. The loss of taxonomic biodiversity in honey bees could somehow be controlled by breeding of local bee strains rather than imported ones. At the same time, conservation efforts also need to be reinforced and increased, ensuring that endangered populations will be protected from uncontrolled introgression of imported strains, and genetic richness will be available for the future generations.

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