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A REVIEW OF POLLINATION BIOLOGY RESEARCH IN SELECTED ASIAN COUNTRIES

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ABSTRACT

The Asian region, with the southern part being mostly in the tropics, is high in pollinator diversity. Its rich vegetation and mild climate supports the population of pollinators. Solitary and social bees are among the important pollinator species. Other insect pollinators are butterflies, moths, beetles and flies. Birds and mammals pollinate bigger flowers. However, honey bees are the most widely studied species of pollinators. Of the 12 species of honeybees, 11 are native to Asia, namely: dwarf honey bees (*Apis andreniformis* and *Apis florea*), giant honey bees (*Apis dorsata, Apis laboriosa, Apis dorsata binghami,* and *Apis breviligula*) and cave nesting honey bees (*Apis koschevnikovi, Apis cerana, Apis nigrocincta, Apis nuluensis* and *Apis indica*). The European honey bee, *Apis mellifera,* is not native to Asia. Most pollination studies were focused on high value agricultural and plantation crops. Threats to pollinators are monoculture, pesticide use, pests and diseases, land use change, natural calamities and climate change. This review on the status of pollination research covers countries in Southeast Asia (Indonesia, Thailand, Vietnam, Singapore, Malaysia and Philippines), East Asia (China, Korea and Japan) and South Asia (Pakistan, India and Nepal).

Key words: *Apis* spp., bees, honey bees, pollination biology, pollinators

INTRODUCTION

Pollination is one key ecological phenomenon that has contributed to the survival of global diversity. This process is classically divided into two categories: allogamy (cross-pollination) and autogamy (self-pollination), which include cleistogamy and chasmogamy (Meeuse & Morris 1984). Throughout the evolutionary timeline of angiosperms, majority of the species developed pollination syndromes as a consequence of specialization on floral phenotypes (Ollerton et al. 2009). Pollination syndromes are an example of coevolution between the pollinated plant taxa and their pollinators. Moreover, this ecological phenomenon can be categorized into two forms: abiotic pollination syndromes (anemophily and hydrophily) (Du & Wang 2014, Friedman & Barrett 2011) and biotic pollination syndromes (melittophily, psychophily, phalaenophily, myophily, sapromyophily, ornithophily, chiropterophily, and cantharophily (Bernhardt 2000, Arathi & Kelly 2004, Tan et al. 2006, Dalsgaard et al. 2009, Fleming et al. 2009, Duara & Kalita 2014, Hahn & Brühl 2016).

Non-bee species are also important in pollination (Klein et al. 2016). Animal pollinators contribute largely to species richness in the tropics. Particularly with bee pollination, the probability of reproductive isolation between plant populations is greatly increased with resultant increase in speciation rates (Dressler 1968, Dodson et al. 1969). Increased speciation rates will produce greater species diversity in tropical regions where the proportion of animal-pollinated plants is highest (Price 1997). The proportion of animal-pollinated species rises from a mean of 78% in temperate-zone communities to 94% in tropical communities (Ollerton et al. 2011). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2016) assessed the values, status and trends in pollinators and pollination and drivers of change, risks and opportunities, and policy and management options for pollinator conservation. Pollinators are a key component of global biodiversity, providing vital ecosystem services to crops and wild plants (Potts et al. 2010). Klein et al. (2007) reported that 87 out of 115 global primary food crops require some level of animal pollination. Using the bioeconomic approach, Gallai et al. (2009) estimated the economic value of pollination worldwide to be €153 billion (ca. USD 175 B), which represented 9.5% of the value of the world agricultural production used for human food. Vegetables and fruits were the leading crop categories in value of insect pollination with about €50 billion (ca. USD 57.2 B) each, followed by edible oil crops, stimulants, nuts and spices. However, agriculture poses many threats to insect pollinators such as changes in land use, loss and fragmentation of habitat, introduction of exotic organisms, modern agricultural practices and pesticide use (Steffan-Dewenter et al. 2005). Agroecosystem diversity can be restored by maintaining weed populations that serve as alternate hosts for the pollinators, maintaining crop-weed balance, identifying beneficial weeds for pollinators, maintenance of hedgerows and management of non-cropped areas to encourage wild pollinators (Nicholls & Altieri 2012). The harmful effects of agricultural inputs especially insecticides on pollinators are well established (Schneider et al. 2012, Henry et al. 2012, Gill et al. 2012, Pilling et al. 2013, Goulson 2013, Rundlöf et al. 2015).

Rader et al. (2010) synthesized 39 field studies all over the continent that directly measured the crop pollination services provided by non-bees, honey bees and other bees to compare the relative contributions of these taxa. It was shown that insects other than bees provide 39% of visits to crop flowers. A shift in perspective from a bee-only focus is needed for assessments of crop pollinator biodiversity and the economic value of pollination. Further, studies should also consider the services provided by other types of insects, such as flies, wasps, beetles, and butterflies which are important pollinators that are currently overlooked.

Despite the importance of pollinators to agriculture, data regarding pollinators in the Asian region, including native bee species, have been scant and estimated using widely varying methods. In order to bridge this gap, it is necessary to survey the state of pollinators in the region (on a country-by-country basis), their diversity and relative abundance using harmonized method of assessment. This review will serve as reference in crafting the Asian Pollination Initiative (API). It should be noted that the Food and Agriculture Organization of the United Nations (FAO) established the International Pollination Initiative (IPI) that includes five participating regions: Europe, North America, Brazil, Africa and Oceania. This API is envisioned to be the starting point for a similar initiative for the Asian region, in order to narrow the gap in knowledge on global pollination.

This review covers pollination studies in Southeast Asia (Indonesia, Thailand, Vietnam, Singapore, Malaysia and the Philippines), East Asia (China, Korea, and Japan) and South Asia (Pakistan, India and Nepal).

SOUTHEAST ASIA

Indonesia

There are a total of five native honey bee species in Indonesia: *A. dorsata, A. nigrocincta, A. koschevnikovi, A. andreniformis* and *A. florea.* Engel (2012) devised taxonomic keys for both honey bees and tribes of corbiculate bees such as Bombini and Meliponini occurring across Indonesia. The impact of these bees in pollination has been evaluated in some valuable crops. Klein et al. (2002) conducted a study on pollination of *Coffea arabica* and *C. canephora* in Central Sulawesi, Indonesia. It was observed that bee pollination caused a 15.8% increase in fruit set compared to wind pollination and autogamy. Further, the results of the study indicated that cross pollination by bees causes significant increase of fruit set of not only self-sterile, but also the self-fertile coffee species. The economic evaluation of coffee pollination by bees was conducted by Olschewski et al. (2006) in a relatively undisturbed agroforest in Indonesia and a forest area of high human impact in Ecuador. In both regions, crop revenues exceeded coffee pollination values, generating incentives to convert forests, even if owners would be compensated for pollination services. They concluded that a comprehensive economic analysis is necessary to adequately evaluate rainforest preservation for the enhancement of ecosystem services, such as pollination.

Solanaceous crops such as tomato and pepper, which are known to be pollinated by bumble bees, are also major crops in Indonesia. However, bumble bee does not thrive well in a tropical climate, thus, Putra & Kinashi (2014) assessed the efficiency of *A. cerana* and stingless bee, *Trigona iridipennis* as pollinators. The fruit production per plant was higher in bee pollination (70-80) compared with the control (60). Using *A. cerana* and *Trigona laeviceps,* a similar trend was observed in pepper pollination (Putra et al. 2014) and zucchini, yielding 100% fruit set from bee pollination (Rosmiati et al. 2015).

Malaysia

The pollination biology of selected tree species (Sapindaceae and Bombacaceae) was studied in Malaysian rainforests in the 1980s by Sands et al. (1988). Cross-compatibility and outbreeding of the species indicated that these traits are important in the maintenance of species diversity in the lowland rainforest. In West Malesia, over 80% of the emergent and canopy tree forest species were observed to bloom in short periods (Ashton et al 1988, Appanah 1993). An extensive study on flowering plants and their floral visitors was conducted by Momose et al. (1998) from 1992-1996 in Sarawak and showed that the dominant pollinators were social bees (32%) and beetles (20%). Despite the diversity of the forest, long-distance specific pollinators were uncommon compared with the neotropics as observed by Bawa et al. (1985).

One of the approaches in the conservation of endangered species is understanding its reproductive biology. Chan & Saw (2011) investigated the floral phenology, floral visitors, pollen viability and stigma receptivity of an endangered and endemic Malaysian palm, *Johannesteijmannia lanceolata*. The observed pollinators were stingless bee, *Trigona* sp. and flies belonging to Phoridae and Cecidomyiidae. However, no empirical data to quantify the impact of the pollinators on seed set of the palm were reported. The species was observed to be self-compatible, indicating its ability to survive and persist in fragmented or isolated environment.

The oil palm, *Elaeis guineensis*, is an important economic crop in Malaysia. A total of 5.23 million hectares was planted to oil palm with a production of 0.43 million tons in 2013 (MPOC 2014). The plant requires outcrossing, since the male and female flowers are on separate inflorescences. Its native pollinators, *Thrips hawaiiensis* and *Pyroderces* sp. were found to be inefficient (Wahid & Kamarudin 1997), thus, hand pollination was necessary. Considering the results of the previous studies (Syed 1979, Syed et al. 1982), *Elaeidobius kamerunicus* was introduced to optimize the productivity of the palm. The introduction of the beetle to Malaysia increased the fruit seed and yield of the oil palm by 20% in Peninsular Malaysia and 53% in Sabah (Ponnamma 1999). However, it was observed that the pollination is now becoming insufficient (Teo 2015) and for long term solution, more studies on pollination ecology of the palm is necessary. In tropical America, the three species associated with oil palm inflorescence were reported to be *Elaeidobius kameronicus, E. subvittatus*, and *Mystrops costaricensis*. (Meléndez & Ponce 2016). Some plants are dependent on flies for pollination. This was studied in four Malaysian orchid species of *Bulbophyllum* spp. This plant species is fairly abundant in the Southeast Asian region (O'Byrne 2001). Flies, mainly the calliphorids and sarcophagids, were observed to visit and pollinate the cultivated *Bulbophyllum lassianthum, B. lobbii, B. subumbellatum* and *B. virescens* (Teck & Hong 2011).

However, palm oil plantation may have serious consequences for biodiversity, climate change and natural resources. Petrenko et al. (2016) analyzed the ecological impacts of palm oil expansion in Malaysia The clearing of the forest in favor of palm oil production reduces biodiversity. Deforestation decreases the diversity of pollinator species such as bees (Liow et al. 2001), butterflies (Sodhi et al. 2004), and moths (Beck et al. 2002). It is because plantations are less diverse than natural forests (Yaap et al. 2010). Moreover, Fitzherbert et al. (2008) found that oil palm supports fewer species than rubber, cocoa, or coffee plantation.

Mangrove is one of the diverse ecosystems in Peninsular Malaysia. Mohamed et al. (2016) reported that bats *(Eonycteris spelaea*) are the likely pollinators of two species of *Sonneratia* based on their foraging behavior. The bats visit the flowers frequently and deposit large quantities of conspecific pollen grains on the stigma. In Terengganu mangrove, Azmi et al. (2012) documented the foraging behavior of the carpenter bee*, Xylocopa varipuncta*. A total of 35 types of pollen were collected from the bodies of the bees, indicating the diverse number of plants they visited.

Stingless bee populations are diverse in Malaysia, comprising 33 species (Mohd Norowi et al. 2008). Through pollen analysis, Azmi et al. (2015) identified 11 types of pollen collected by *Lepidotrigona terminata* in Terengganu. In the lowland forest in Sabah, Eltz et al. (2003) identified the nesting sites and documented the nesting habit of stingless bees to assess the direct impact of logging operations on bee populations. Since tree harvesting damages the nesting sites, they recommended the retention of large hollow trees to preserve meliponine pollination in sustainable forest management.

Recently, Koeniger et al. (2010) published a scholarly book on honey bees of Borneo. It covers bee biology, behavior, management and conservation. A sourcebook for stingless bees authored by Jalil & Shuib (2014) is a practical guide in meliponiculture including the pollen and nectar sources of the bees, its potential for pollination, and component of landscape. This publication was inspired by the 11th Asian Apicultural Association Conference in Malaysia in 2012, where stingless bees and other native bee species were highlighted.

Philippines

The Philippines is home to diverse species of social and solitary bees. Of the nine species of honey bees in the world, five are native to the Philippines, namely: *Apis cerana, A. dorsata, A. breviligula, A. andreniformis,* and *A. nigrocincta.* (Cervancia 2018). Two species, *A. andreniformis* and *A. dorsata* are found only in the island of Palawan, while *A. nigrocincta* is observed in Mindanao (Damus & Otis 1997).

There are at least 260 identified pollinator species that belong to non-*Apis* group (Baltazar 1966). *A. mellifera* is used in commercial beekeeping and pollination of hybrid crops. However, being an exotic species, it is susceptible to diseases (American Foul Brood, European Foul Brood and Chalk Brood), mites (*Varroa* spp. and *Tropilaelaps* spp.), and bird predation (Cervancia, 1998) In 2014, small hive beetles entered Southern Philippines (Mindanao) and wiped out 80% of the *A. mellifera* colonies (Cervancia et al. 2016)

The major institution involved in bee research is the University of the Philippines Los Baños (UPLB). Its Bee Program is interdisciplinary, covering bee biology, genetics, pathology, chemistry, apitherapy and bio-mathematics. The major research thrust of this program is on native bee species. Tilde et al. (2003) identified at least four populations of *A. cerana* in the Philippines through morphometric analysis. This study is consistent with mtDNA analyses (Dela Rua et al. 2000, Smith et al. 2000). The technologies developed for the propagation of stingless bees for pollination and production of bee products are the milestones of this program (http:// teca.fao.org/technology). The Philippine National Standards for Honey and Code of Best Beekeeping Practices has been established by the Bureau of Agriculture and Fisheries and Standards of the Department of Agriculture.

Bee research started at the UPLB Department of Entomology in 1968 with the collaborative work of Dr. Roger A. Morse from Cornell University, USA and Dr. Francisco M. Laigo (Gabriel 1981). They published an Extension Bulletin on Beekeeping (1968a) and investigated the predatory birds (Morse & Laigo 1968b) and bee mites (Laigo & Morse 1968, 1969). The birds still remain as major predators of bees (Cervancia et al. 1999). Morse & Laigo (1969) also published a monograph on *A. dorsata,* which is now identified as *A. breviligula*. They mapped the distribution pattern of *A. breviligula* in Mt. Makiling. In 2004, the number of colonies was observed to decrease by 20% and the nests were concentrated at lower elevations of Mt. Makiling (Cervancia et al. 2011). Some aspects on the defensive behavior of *A. breviligula* were observed by Woyke et al. (2006) on their nest in Cavite City, Luzon Island. The flipping of the abdomen was correlated with the temperature of the nest curtain. This behavior was compared with *A. laboriosa* and *A. dorsata* in India (Woyke et al. 2007). During mating flights, it was established that the proportion of the workers accompanying the drones was higher. This is a strategy that could protect the drones from predators (Woyke et al. 2005).

In the 1980s, a noted botanist, Dr. Pacifico C. Payawal, started melissopalynological studies. This led to the identification of pollen sources for *A. mellifera* such as *Cocos nucifera*, *Mimosa* sp., undetermined Asteraceae and plants that provide secondary pollen (Payawal 1984a & b, Payawal et al. 1986, Payawal et al. 1991a & b, Tilde & Payawal 1987, 1992a & b), *A. cerana* (Tilde et al. 2003), and *A. dorsata* (Manila-Fajardo & Gonzales 2010). Pollination studies progressed, with consideration of pollinator-plant interactions. These include pollination of mango (Fajardo et al. 2008), bitter gourd (Deyto & Cervancia (2009), cucumber (Bergonia & Cervancia 1992, Cervancia & Forbes 1993), passion fruit (Rodriguez & Cervancia 1999), Chinese mustard (Rubin-Reyes & Cervancia 1999), calamondin (Manila-Fajardo et al. 2003), coffee (Manila-Fajardo 2011), reforestation species (Escobin et al. 1999, Escobin et al. 2004), and mangroves (Almazol & Cervancia 2013 & 2014, Cervancia & Almazol 2014, Almazol et al. 2014). A variation in the foraging patterns among bee species was observed (Cervancia et al. 1994, Barile & Cervancia 1995, Forbes & Cervancia 1993). The colony establishment is also dependent on the type of ecosystem. Fajardo & Cervancia (2003) compared the population growth of *A. mellifera* colonies in three locations: agricultural farm, forest, and industrial site, and found that *A. mellifera* did not survive the predation pressure in the forest, but were able to establish well in agroecosystem and industrial areas with lots of trees in the vicinity. However, trace amounts of heavy metals were detected in honey from colonies in the industrial site.

With the problems associated with *A. mellifera* in the Philippines like mites (Beaurepaire et al. 2015, Anderson et al. 2004, Cervancia & Fajardo 2002), American foul brood disease (Cervancia et al. 2013, Montecillo et al. 2014), and most recently, the small hive beetles (Cervancia et al. 2016), the country has focused more on conservation and harnessing of the potential of native bees for pollination (http://teca.fao.org/technology). Stingless bees are used for large scale mango pollination, and observed to be more effective pollinators than honey bees, syrphids or blow flies in mango orchards (Cervancia & Fajardo 2018). To facilitate decision-making in utilizing bees for pollination, mathematical models were devised for foraging behavior and determining the optimal location of bee hives in a farm requiring pollination services (Rabajante et al. 2009, Esteves et al. 2010, Tambaoan et al. 2011, Ciar et al. 2013, Gavina et al. 2014, Jatulan et al. 2015, Real et al. 2016).

In response to the need to derive empirical data on the status of pollinators especially in Asia, Rabajante & Tubay (2017) developed a protocol to assess the pollinator population in managed, natural, and disaster-hit ecosystems. The proposed protocol was slightly modified from the handbook of Vaissiere et al. (2011). The three important steps in this protocol are - planning, implementation and computation of diversity indices.

Singapore

Singapore's geographical location and its tropical climate support lush natural vegetation. Despite having lost more than 90% of its original forest cover, it is still home to huge diversity of plants and animals (Chin 2008). The diversity of tree species is high despite the habitat loss (0.2% of the total primary forest) based on the estimated genetic diversity index of the present forest (Noreen & Webb 2013). The diverse forest supports the population of natural pollinators, especially the leaf cutter bees (Ascher et al. 2016). An annotated list of leaf-cutter and resin bees *Megachile* **sensu lato** from Singapore by Ascher et al. (2016) included *Megachile (Aethomegachile) borneana, M. (A.)* nr. *borneana, M. (A.)* sp. (*fusciventris* group), *M. (Alococanthedon) indonesica, M. (Callomegachile) ornata, M. (C.) stulta, M. (C.)* sp. 1 (nr. *stulta*), *M. (C.)* sp. (*biroi* group), *M. (Chelostomoda) moera, M. (Eutricharaea)* sp., and *M. (Paracella) tricincta.* Additional species under the tribe Anthidiini were described by Soh et al. (2016). However, a decline in the number of species of stingless bees was observed (Xiong 2015). Out of 11 recorded species, only seven were observed in the forest which was attributed to reduction of nesting sites.

Thailand

In the Southeast Asian region, durian (*Durio zibethinus* L.) is one of the high value export crops, with Thailand as its major producer followed by Malaysia and Indonesia (Bais 2016). Most durian trees are observed to be self-incompatible and require outcrossing. Among the volant mammal pollinators, the dawn bat, *Eonycteris spelaea,* is known to be the principal pollinator to most chiropterophilous plant taxa in Southeast Asia (Acharya et al. 2015). In Southern Thailand, durian flowers open fully at 1600h-1630h with anther dehiscence at 1930-2000 when the stigmata are most receptive. *E. spelaea* collect nectar during this period, and as they transfer from one flower to another, pollination is effected (Bumrungsri et al. 2008). Other studies on the floral biology, visitors and pollination of durian by bats, birds, and other animal pollinators were those of Boonkird (1992), Gould (1977, 1978), Honsho et al. (2004a & b, 2007a & b), Lim & Luders (1998), and Salakpetch et al. (1992). The food resources of the nectar-feeding bats pollinating other tropical tree species were identified by Srithongchuay et al. (2008) and the mutualism between bats and the flowers they pollinate was fully elucidated by Stewart & Dudash (2016). The foraging behavior of the bats matches with the floral traits of the nocturnal flowers.

Chiropterophilous pollination is also observed in some tree species in a rainforest, like *Parkia* spp. The species known of medicinal value are *P. speciosa* (Kamisah et al. 2013) and *P. timoriana* (Doley 2014). The species are self-incompatible and cross-pollination by *E. spelaea* is crucial in fruit and seed production (Bumrungsri et al. 2008). Dipterocarps such as *Dipterocarpus obtusifolius* are abundant in a tropical forest and the pollination biology of *D. obtusifolius* was studied by Ghazoul (1997). The plant produces a few, large flowers that are obligately pollinated by moths. Anthesis starts at dusk and flowers remain open for 24–36h. Nectar secretion occurs at flower opening and continues through the next day. Pollen is maximally available at night but much pollen remains available to daytime visitors.

The diversity of bee species and pollen sources of Apidae (Hymenoptera) in four forest types in lower northern Thailand were studied by Jongjitvimol & Petohsri (2015) from 2011 to 2012. The results from biodiversity indices such as species diversity (H'), species evenness (J'), similarity habitat (Ss), and species richness (D), indicated that this area has relatively high species diversity. In addition, the dwarf honey bees, *A. florea* were shown to be the main pollinator at this study site with the highest number of pollinated plant species (46 species). Thus, this bee could be used as a biological indicator for future studies. In addition, wild non-*Apis* species are valuable crop pollinators as well. Hongjamrassilp & Warrit (2014) described the nesting behavior of a carpenter bee, *Xylocopa (Biluna) nasalis,* by measuring the size of the nest, counting the number of bees per nest and identifying their pollen stores. This information is needed in utilizing bees for pollination.

In general, the pollination of tropical forest trees is affected by logged and fragmented habitats (Ghazoul & Mcleish 2001). In logged areas where tree densities are reduced, the longer foraging period of pollinators has been observed. Moreover, small bees rarely move between forest fragments resulting in low genetic variability of the tree species, as observed in Thailand and Costa Rica. The intensive agriculture production system in Northern Thailand may eventually result in pollinator decline and eventually production outputs. Thus, farmers such as longan farmers are willing to pay for conservation measures such as bee-friendly pest management, improving the habitat of native bees and fostering the husbandry of native bees (Narjes & Lippert 2016)

Vietnam

Vietnam has six honey bee species (*Apis cerana*, *A. dorsata*, *A. laboriosa, A. mellifera, A. andreniformis* and *A. florea*), eight stingless bees and two bumble bee species (Thai & Van Toan 2018). Being in a tropical country, Pham & Otis (2010) observed that bee forage is available whole year round and crops are dependent on natural pollinators, thus, commercial pollination services are not practiced. In terms of honey production, Vietnam is one of the major exporters of honey to the United States constituting 17.8% of the total honey importation (Flottum 2017).

Unlike other countries experiencing forest loss due to deforestation and conversion, Vietnam's forest cover has been dramatically increasing for the past 20 years (http://theredddesk.org/countries/vietnam). *Melaleuca cajuputi* and *Nypa fruticans* are two prominent plants in the forest of Vietnam that help in the regulation of climate and protection of wildlife. These two species were reported to provide nectar to pollinators such as *A. dorsata* and *A. florea* (Nguyen 2008).

Pham (2012) reviewed the pollination requirements for 39 Vietnamese crops and found that most benefited from honey bee pollination. He also studied the floral biology and pollinators of longan (*Dimocarpus longan*) and jujube (*Ziziphus mauritiana)*. Like the majority of the crops reviewed, the native honey bee, *A. cerana*, was found to be the major pollinator of the crops. Stingless bee management is not yet popular in Vietnam. The presence of two genera, *Lisotrigona* and *Trigona,* was reported by Chinh (2004) while their nesting behavior and colony characteristics were described by Chinh et al. (2005).

EAST ASIA

China

China is one of the world's major centers of biodiversity because of its mountainous terrain, topography, and share of the tropical and sub-tropical climate (Harkness 1988). The environment supports diverse populations of both wild and managed honey bee species (Hepburn & Radloff 2011). There are around six species of honey bees, namely: *A. andreniformis, A. florea, A. dorsata, A. cerana, A. laboriosa,* and the introduced *A. mellifera* (Oldroyd & Wongsiri 2006), but only *A. mellifera* and *A. cerana* are used for honey production (Zheng et al. 2011, Jiang 2013). The number of apiaries is continuously expanding (Chen & Wang 2012, An & Chen 2011). With the abundant pollen and nectar sources for the bees, China's annual honey harvest (400,000 metric tons) is highest in the world (FAOSTAT 2012). From 1985 to 2013, the density of managed bee colonies per area of bee pollinated crops did not vary significantly. From 1985 to 2013, the density of managed bee colonies density per area of bee pollinated crops did not vary significantly. Today, China is one of the most significant providers of pollination ecosystem services globally with more than eight million managed bee colonies (Teichroew et al. 2016). Bumble bees are also managed for the pollination of peach and were found to be more effective than honey bees (Zhang et al. 2015). The same result was obtained by Sung & Chiang (2014) in tomato pollination. While both bee types successfully pollinated tomato, bumble bee pollination resulted in higher percentage of well-formed fruits and higher number of seeds. The observed decline in the population of bees (Ren et al. 2014, Lui & Tan 2012), bumble bee (Xie & An 2014) and some species of solitary bees (Xie et al. 2013) in some regions may negatively impact pollination. However, bumble bees can be reared artificially in order to sustain the pollination services. Chiang et al. (2009) cultured *B. eximius* and *B. sonani* and the results showed no differences between the two species in the queen nesting, successful colonization, successful mating, and egg laying rates of laboratory-reared queens. They strongly suggest that *B. eximius* has great merit for pollination programs of commercial utilization, while *B. sonani* can only serve as a substitute species for pollination in Taiwan.

Pests and diseases are one of the causes of colony loss. Li et al. (2012) conducted a nationwide survey on parasites and diseases of native *A. cerana*. It was observed that *A. cerana* was infected by deformed wing virus (DWV), black queen cell virus (BQCV), *Nosema ceranae*, and *Crithidia bombi* that have been linked to the decline in population of *A. mellifera* and bumble bees. However, the prevalence of DWV, a virus that causes widespread infection in *A. mellifera*, was low, arguably a result of the greater ability of *A. cerana* to resist the ectoparasitic mite *Varroa destructor*, an efficient vector of DWV. Another virus disease posing threat to bee colonies is Sacbrood virus (Liu et al. 2010, Ai et al. 2012). The introduction of *A. mellifera* negatively impacted the population of local bees (He & Liu 2011, Yang 2005).

Earlier researches on plant reproductive biology in China were focused on crop breeding. However, in year 2000, interest in ecology and pollination biology started (Barret 2015). Some of these studies were on floral biology of *Alpinia* (Li et al. 2001) and *Caulokaemferia* (Wang et al. 2004), pollination mechanism in *Impatiens reptans* (Tian et al. 2004), sex allocation in *Aquilegia* (Huang et al. 2004), pollination of *Tacca* (Zhang et al. 2005), and soybean (Zhou et al. 2015), anheterodichogamy in *Juglans* (Bai et al. 2007), and reproductive biology of Iridaceae (Xiao 2010), and *Jatropha curcas* (Wang & Ding 2012)

The floral visitors and pollination of other plant species were documented, but the impact of pollinators on plant yield was not measured. The plants observed were *Cypripedium flavum* (Zheng et al. 2011), *Musella* (Liu et al. 2002), orchids (Yu et al. 2008, Zheng et al. 2011, Tang et al. 2014), desert plant, *Eremosparton songoricum* (Shi et al. 2010), oil palm (Yue et al. 2015), and *Rhododendron floccigerum* (Georgian 2015).

The mutualism between figs and their wasp pollinators is an interesting model of coevolution between plants and pollinators (Janzen 1979). In Taiwan, Tzeng et al. (2006) investigated the pollination of *Ficus erecta* by its obligate wasp pollinator *Blastophaga nipponica* where the flowering phenology of *F. erecta* synchronized with the development and behavior of *B. nipponica*. The fig trees could control the developmental period of wasp-producing syconia during pollination. The pollination mechanism in other fig species such as *F. microcarpa* (Chen 1994), *F. irisana* (Chen 1998), and *F. ampelas* (Chang 2003) were also undertaken.

While pollinator diversity is still high in China, this country also faces the same threats to diversity that are now observed globally (Teichroew et al. 2016) However, China has an advantage over Europe and U.S. in terms of pollinator conservation because of key conditions such as diverse endemic pollinator species and low levels of managed bees.

Japan

Japan is home to two honey bee species, *A. cerana japonica* and *A. mellifera.* The exotic *A. mellifera* has been observed in Japan since 1877 (Sakai & Okada 1973). Between the two species, *A. c. japonica* is valued as major pollinator of crops and wild plants (Yokoi 2015) even if both share common pollen sources at primary beech forest in Kyoto (Nagamitsu & Inoue 1997). Compared with *A. mellifera,* Sugahara et al. (2012) observed that *A. c. japonica* is more resistant to diseases, gentle and has innate defense against predatory hornets by forming a "bee ball" that suffocates the hornets. In the report of Kohsaka et al. (2017) on the status of beekeeping and honey production in Japan, they emphasized that native beekeeping is necessary to ensure sustainable forestry and conserve biodiversity. The decline in the number of beekeepers and bee colonies resulted in dependence on importation of honey and shortage of pollinators in agriculture.

Among the non-*Apis* species widely studied are the bumble bees and carpenter bees. Inari et al. (2012) observed that the foraging activity of *Bombus ardens* and *B. hypocrita* on tree canopies was positively related with floral resources. The link between floral resources or the trees, bumble bee abundance and seed production of understory plants was demonstrated in the study.

The pollination biology of buckwheat was elucidated by Namai (1990, 1991) and bumble bees are recognized as major pollinators (Sasaki & Wagatsuma 2007). Their abundance is dependent on the distance of the field from the managed hives, the area of the forest cover within a 3-km radius and the area of forest and grassland cover within a 100-m radius, respectively (Taki et al. 2010).

Flower constancy is an important trait that enhances pollinator efficiency. Kobayashi-Kidokoro & Higashi (2010) documented the foraging behavior of *Ceratina flaviceps* which is known to be a generalist species. However, based on the analysis of pollen, the bees have constant flower preferences like a specialist pollinator. In an apple orchard, *Osmia cornifrons* also showed strong floral constancy during one pollen-nectar foraging trip (Matsumoto et al. 2009). Under greenhouse conditions, *Anthophora plumipes* effectively pollinated strawberry flowers in the greenhouse and could be developed as an alternative pollinator for this crop (Adhikari & Miyanaga 2016).

The use of stingless bees for crop pollination has been practiced in Japan (Amano 1997 & 2004, Amano & Boongrid 1997, Amano et al. 2000). Under greenhouse conditions, *Tetragonula carbonaria* and *Scaptotrigona bipunctata* were observed to be the potential pollinators.

The accident at the Fukushima Daiichi nuclear plant in 2011 adversely affected the population of pollinators. Yoshioka et al. (2015) observed that

Xylocopa appendiculata decreased, and suggested the need to monitor the insect population to evaluate the long-term effects of the accident. Application of pesticides has direct negative impact to bee colonies. Massive bee deaths due to agrochemicals applied to rice fields were observed by Kimura et al. (2014). Pollen and honey samples were found to contain measurable concentrations of the pesticides applied in the field.

Korea

In Korea, beekeepers manage native *A. cerana* and exotic *A. mellifera* for honey production. *A. mellifera* is believed to be introduced in early 1900 (Jung 2014). The number of bee hives is approximately 2,000,000 and honey production ranges between 20,000 and 27,000 tons (Lee et al. 2010, Jung 2014). Jung & Cho (2015) established the positive relationship between honey bee population and production. Patterns of national honey production were reflected by the hive population reaching 28,000 tons in 2009.

Pests and diseases were major problems in beekeeping (Yoo & Yoon 2009, Kang et al. 2012). Among the prevalent diseases observed were Sacbrood (Kim et al. 2008, Choi et al. 2010), nosema and viruses (Choi et al. 2008, Hong et al. 2011), American Foul Brood (Lee et al. 2004), deformed wing virus (Lee et al. 2005), chalk brood (Lee et al. 2006), and Kashmir Bee Virus. In Incheon area, Ra et al. (2012) detected 13 honeybee diseases including seven viral, two each of bacterial, fungal, and parasitic diseases which were detected by preliminary inspections and PCR. Lee (2012) reported for the first time the occurrence of kakugo virus (KV) in Korea. Kakugo virus, first described in Japan by Fujiyuki et al. (2004) is a picorna-like virus that was originally identified in the brains of aggressive but apparently healthy worker honey bees (Fujiyuki et al. 2005). The species of bee mites detected in surveyed apiaries were *Varroa jacobsoni*, *Tropilaelaps clareae* (Woo & Lee 1997) and *Acarapis* spp. (Ahn et al. 2015).

The economic value of pollination service provided by honey bees was estimated on major fruit and vegetable crops in Korea. The annual production for selected crops was estimated at USD 12 billion. Approximately 50% of the annual production was the honey bee pollination service, amounting to USD 5.8 billion. This is 18 times more than the annual primary production of Korean beekeeping (USD350 million) (Jung 2008). Choi & Jung (2015) listed a total of 368 insect species visiting 43 crops and wild flowers. The most diverse insect pollinators were the Hymenoptera followed by Diptera and Coleoptera. The pollinator species were *A. mellifera, Eristalis cerealis, Tetralonia nipponensis*, *Xylocopa appendiculata*, *E. tenax, Helophilus virgatus,* and *Artogeia rapae.* While natural pollinators are available, large commercial fields, gardens and greenhouses use managed colonies of bumble bees, honey bees and mason bees (Yoon et al. 2011). One of the problems encountered by the industry was the insufficient supply of the mason bees (Lee et al. 2010).

SOUTH ASIA

India

The shift of Northern India from traditional farming system to commercial cultivation would require increase in pollinator diversity to optimize crop yield (Sharmah et al. 2015). One crop that is extensively cultivated in Northern India is apple which occupies 48% of area under fruits and 78% of total fruit production (Singh et al. 2012). Mattu & Nirala (2013) observed that among the floral visitors of apple, *A. cerana* was the most abundant and observed to be the primary pollinators of apple. Pollinators are also important in mango with pollinator contribution estimated to be 53%. In a study by Munj et al. (2017), stingless bees (*Tetragonula* sp.) were the predominant pollinators of mango, followed by blow fly (*Chrysomya* sp.), honey bee (*A. indica*), syrphid fly (*Syrphus* sp.) and giant honey bee (*A. dorsata*). The number of flower visits of *Tetragonula* sp. was high (11.50/hour) followed by *A. indica* (6.40/panicle/ hour) and *Chrysomya* sp. (5.85/panicle/hour).

The effect of pollinators were also evaluated on other crops such as *Luffa cylindrica* (Bhattacharyya & Chakraborty 2014), bitter gourd (Subhakar et al. 2011), peach, plum, citrus and kiwi (Gupta et al. 2000), strawberry (Partap 2000, Partap et al. 2000), apple (Dulta & Verma 1987), and cannabis (Rana & Choudhary 2010). Seed production in cabbage, cauliflower, radish, broad leaf mustard and lettuce increased when adequately pollinated by honey bees (Partap 1998, Partap et al. 2000 & 2001). Aware of the importance of dwarf bee, *A. florea* in pollination, Shwetha et al. (2012) studied the floral sources of the bees and were able to identify 147 plant species that provided either nectar or pollen. The impact of pollinators to the country's economic growth in terms of food production was reported by Partap et al. (2012).

Nepal

Beekeeping has been a component of "Mountain Agriculture" in the Hindu Kush Himalayas (HKH). The native bee species in the HKH are *A. laboriosa, A. cerana, A. dorsata,* bumble bees, stingless bees and solitary bees. Bee products are source of cash incomes, nutrition and medicine (Joshi et al. 2002). Several studies on pollination in the area revealed that bees significantly increased yield of cultivated crops (Thapa 2006 & 2015, Aryal et al. 2014, Pudasaini et al. 2015). The annual economic value of insect pollinators to agricultural productivity for the major crops cultivated in HKH region was estimated at USD 2.7B (Partap et al. 2012). Over 50 species of insects were observed visiting 17 different crop species during flowering periods contributing around 80% of the total pollination activities (Thapa 2006). In an economic study of beekeeping in Nepal, Devkota et al. (2016) obtained a high cost benefit ratio (1.8) from honey production. While there was an observed increase in the yield of mustard due to the presence of bees, the effect was not quantified. The observed threats to beekeeping are farm practices like monoculture, pesticide use, and introduction of *A. mellifera*. Bee mites, *Varroa destructor* and *Tropilaelaps clareae* were also identified as major pests (Neupane 2015).

Due to deforestation, and over-harvesting, the cliff-nesting bees, *A. laboriosa* is in an alarming decline (Thapa et al. 2018)

Pakistan

The production value of pollination-dependent crops in Pakistan is estimated to be USD 1.59 billion. These are fruits (USD 0.98 billion), vegetables (USD 0.32 billion), nuts (USD 0.15 billion), oilseed (USD 0.13 billion), and spices (USD 0.004 billion) (Irshad & Stephen 2014). In the Himalayan region of Pakistan, Partap et al. (2012) reported that the economic value of pollinators was USD 954.59 million. Rafique et al. (2016) studied the pollination of mango which showed that fruit weight and fruit quality is enhanced with increasing number of visitors per panicle. *Ceratina binghami, A. andreniformis,* and *Episyrphus balteatus* were observed to be the dominant pollinators.

In spite of the government's aim to achieve sustainable agricultural development to ensure food security and produce surplus for export, there is a decline in fruit production especially apple and pear, due to lack of pollinators and pesticide application (Ahmad et al. 2004, Partap & Partap 2002). Using bagging techniques, it was demonstrated that pollinators can increase the yield of loquat (Khan et al. 1986), orange (Haq et al. 1978), cucumber (Ahmad 1991), radish and cauliflower (Gondal & Haq 1973), and *Brassica campestris* (Latif et al. 1965). It was also observed that linseed pollinated by honey bees had higher germination rate (Sabir et al. 1999). A total of 20 insect species under 16 genera belonging to eight families are known to be insect pollinators of litchi (*Litchi chinensis*). Among the prominent families include Calliphoridae, Muscidae, Sarcophagidae, Syrphidae, Andrenidae, Apidae, Halictidae and Vespidae (Ali et al. 2013).

CONCLUSION AND RECOMMENDATION

Asia is home to diverse bee species. Wild pollinators such as bats, beetles, and solitary bees contribute largely to the productivity of the forest and agroecosystem. Managed colonies of *Apis mellifera* and *A. cerana* are commonly used in commercial orchards, plantation crops and vegetable farms for pollination services. In the Philippines, the stingless bee, *Tetragonula biroi*, is extensively used for mango pollination. Bats and beetles are essential in the pollination of durian. In Asia, the most significant threat to local honey bee populations are deforestation, excessive hunting pressure, loss of nest sites, parasites and pathogens, climate change, forest fire, pesticides, street lighting, competition with introduced *A. mellifera,* anthropogenic movement and tourism (Oldroyd & Nanork 2009). However, despite the importance of pollinators to agriculture, scientific data regarding the pollinators in the region, including native bee species has been limited and were generated using widely varying methods. It is necessary to develop a harmonized method to survey the state of pollinators in the region (on a country-by-country basis), their relative density and relative abundance and health. The initiative would seek to identify the most vulnerable scenarios, determine causes and provide mitigation methods in order to protect the pollinators.

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