

Diversity of Insect Pollinators in Different Agricultural Crops and Wild Flowering Plants in Korea: Literature Review

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Abstract

Insect pollination is an important ecosystem process for increased agricultural crop yield as well as for enhancing ecosystem production. We analyzed insect pollinators visiting fruits and flowers in different orchards and wild fields across Korea during the last three decades, published in scientific journals in Korea. A total of 368 species in 115 families of 7 orders were recorded to serve as pollinators in 43 different agricultural crops and wild flowers. The most diverse insect pollinators were the species of Hymenoptera followed by Diptera and Coleoptera. The dominant insect pollinator was the honey bee (*Apis mellifera*) followed by *Eristalis cerealis*, *Tetralonia nipponensis*, *Xylocopa appendiculata*, *Eristalis tenax*, *Helophilus virgatus* and *Artogeia rapae*. Study methods employed for diversity of pollinators were mostly sweep netting, but trapping was mostly employed for bee diversity and direct observation for lepidopteran diversity. Bee diversity was higher in orchards while insect order level diversity was higher in wild plant pollinators, suggesting the important roles of wild flowers for conservation of insect pollinators.

Key words: *Apis mellifera*, *Eristalis cerealis*, *Tetralonia nipponensis*, *Xylocopa appendiculata*, *Eristalis tenax*, *Helophilus virgatus*, *Artogeia rapae*

INTRODUCTION

Animal-mediated pollination plays an important functional role in most terrestrial ecosystems and provides a key ecosystem service vital to the maintenance of both wild and agricultural plant communities as most angiosperms are pollen-limited and rely on animals for sexual reproduction (Potts *et al.*, 2010; Albrecht *et al.*, 2012). A large proportion of the human diet depends directly or indirectly on animal pollination (Klein *et al.*, 2007; Albrecht *et al.*, 2012; Garibaldi *et al.*, 2013).

Insects are the primary animal-mediated pollinators of 80% of all plant species in Europe, including most fruits, many vegetables and some biofuel crops and include

diverse species of Hymenoptera (bees, solitary species, bumblebees, pollen wasps and ants), Diptera (bee flies, houseflies, hoverflies), Lepidoptera (butterflies and moths), Coleoptera (flower beetles), and other insects. Although managed bee hives are increasing worldwide, insect pollinators are considered to be in a state of decline due to a range of recent and projected environmental changes, such as habitat loss and climate change, with unknown consequences for pollination service delivery (Potts *et al.*, 2010).

In Korea, Ko *et al.* (1977) first examined the diversity and frequency of insect pollinators visiting apple, pear and peach in Seoul and Suwon and reported 26 insect species in three orders and honey bee (*Apis mellifera*) was the most

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dominant species to visit fruits. Woo *et al.* (1986a, b) surveyed visiting insects to apple, pear and peach in 4 areas across Korea and reported different insect diversity depending on fruits: 12 families and 22 species of Hymenoptera and 10 families and 17 species of Diptera visited apple flowers; 13 families and 17 species of Hymenoptera and 10 families and 22 species of Diptera visited pear flowers; and 13 families and 19 species of Hymenoptera and 9 families and 16 species of Diptera visited peach flowers. Lee *et al.* (2000) reported 68 insect species in 27 families and 6 orders that visited apple flowers in Gyung-sangbuk-do province and the Hymenoptera comprised more than half (51.2%) of the total insects and honey bee was the dominant pollinator. Kim and Hwang (2009) recorded insect pollinators visiting peach and pear in Jeonju, Jeollabuk-do province: 11 species in 6 families and 4 orders visiting peach and 17 species in 11 families and 5 orders visiting pear and identified *Apis mellifera* as the major insect pollinator. Recently Kim *et al.* (2012, 2013) reported insect pollinator diversity visiting flowers of Asteraceae, Labiatae and Umbelliferae.

We reviewed insect pollinators visiting fruits and flowers in different orchards and wild fields across Korea during the last three decades. The purpose of the study was to see the pattern of diversity of insect pollinators and interactions between insects and plants. We hope that this review can be the baseline data to set up research plans on ecology and conservation of insect pollinators in Korea.

MATERIALS AND METHODS

We searched the literatures dealing with the diversity of insect pollinators in domesticated and wild plants in the

peer-reviewed scientific journals in Korea (Korean journal of Apiculture, Korean Journal of Environmental Ecology) published since 1977. We recorded the diversity of insect pollinators and their visiting fruits and flowers. Fourteen papers were retrieved mostly from fruit crops and horticultural crops (12) and wild plants (2), respectively (Hong *et al.*, 1989; Kang *et al.*, 2003; Kang *et al.*, 2009, Kim *et al.*, 2005; Kim *et al.*, 2009; Kim *et al.*, 2012, 2013; Ko *et al.*, 1977; Kwon *et al.*, 2011; Lee *et al.*, 2000; Lee *et al.*, 2007; Lee *et al.*, 2008; Woo *et al.*, 1986a, b). Fruit crops include apple, pear, peach, persimmon and wild berry, horticultural crops include strawberry, tomato and sunflower, while the wild plants include 30 wild flowers. Occurrence of each flower visiting insects on each crop was marked as record. Different sampling methods were employed but we grouped those into direct observation, sweep net collection and trapping with pollinator trap or water pan trap.

RESULTS

A total of 368 identified species in 115 families of 7 orders were recorded to serve as pollinators in 43 different fruits and flowers in orchards and wild fields (Fig. 1, Appendix 1 include all listed species including unidentified species). The most diverse insect pollinators were the species of Hymenoptera (110 species, 373 records), followed by Diptera (104 species, 219 records), Coleoptera (88 species, 111 records) and Lepidoptera (47 species, 97 records). The dominant insect pollinator was the honey bee (*Apis mellifera*, 34 records) followed by *Eristalis cerealis* (Diptera, 26 records), *Tetralonia nipponensis* (Hymenoptera, 12 records), *Xylocopa appendiculata* (Hymenoptera, 12 records), *Eristalis tenax* (Diptera, 11 records), *Helophilus virgatus* (Diptera, 11 records), and *Artogeia rapae* (Lepidoptera, 10 records) (Table 1). Detailed lists were provided with Appendix 1 and 2. The main insect pollinators are bees (Hymenoptera) since bees spend most of their life in collecting pollen, a source of protein that they feed to their developing offspring and nectar, a concentrated energy source (Aizen and Harder, 2009). Honey bee is the best known and widely managed pollinator. In addition there are hundreds of other species

Table 1. Dominant flower visiting insect species

Species (Order)	Records
<i>Apis mellifera</i> (Hym)	34
<i>Eristalis cerealis</i> (Dip)	26
<i>Tetralonia nipponensis</i> (Hym)	12
<i>Xylocopa appendiculata</i> (Hym)	12
<i>Eristalis tenax</i> (Dip)	11
<i>Helophilus virgatus</i> (Dip)	11
<i>Artogeia rapae</i> (Lep)	10
<i>Bombus ignitus</i> (Hym)	9
<i>Allograpta balteata</i> (Dip)	9

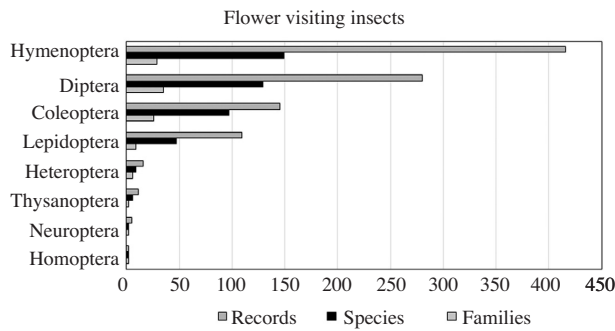


Fig. 1. Distribution of pollinating insect order in family, species (identified and unidentified species) and record levels from the literature review.

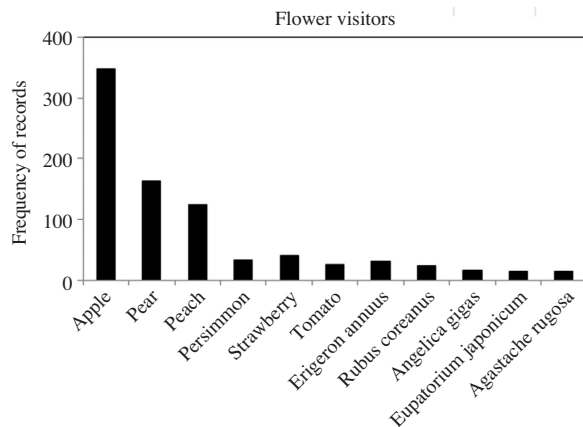


Fig. 2. Frequency distribution of flower visiting insects along with different crops and wild plants. Plants with lower frequency were excluded.

of bees, mostly solitary ground nesting species, that contribute some level of pollination services to crops and are very important in natural plant communities (Garibaldi *et al.*, 2013). Among bees, the diversity at the genus level showed that *Andrena* was the most diverse with more than 21 species, followed by 14 species of *Lasioglossum*, 8 *Bombus*, 6 *Nomada*, and 5 *Osmia* species.

Flies are considered to be the second most important insect order for both flower visiting and pollination (Larson *et al.*, 2001). A number of dipteran insects are used commercially around the world as pollinators for specific crops, including the use of *Eristalis* hoverflies on peppers, and calliphorid flies on canola, sunflower, buckwheat, garlic, lettuce and peppers, and other crops (Larson *et al.*, 2001; Defra, 2014). In Korea, the dominant dipteran genus was *Drosophila* with 5 species followed by 4 species of *Paragus* and 3 species of *Calliphora*, *Eristalis*, *Helophilus*,

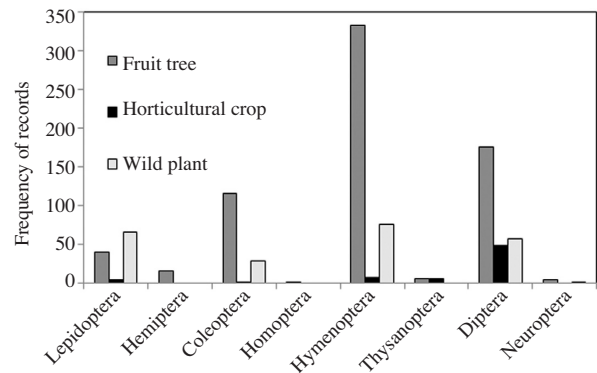


Fig. 3. Frequency distribution of insect orders on different types of plants: fruit tree, horticultural crops and wild plants.

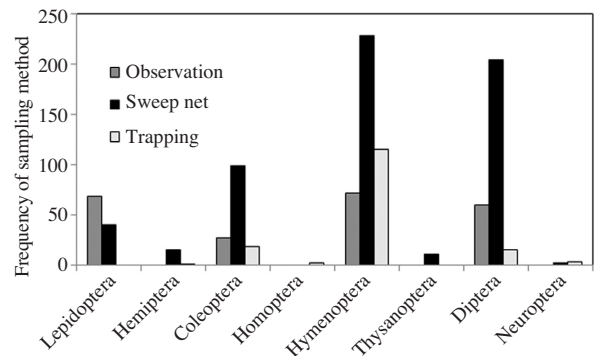


Fig. 4. Frequency distribution of sampling methods of each flower visiting insect order.

Pipiza, *Sphaerophoria*, and *Syrphus*, respectively. Drosophilidae have been associated with pollination of *Genoplesium* (Orchidaceae) in Australia (Bishop 1996; Larson *et al.*, 2001). In addition Drosophilidae and sympatric Nitidulidae (Coleoptera) are known to vector yeasts between flowers of many Convolvulaceae, Hibiscus, and other plants that possess campanulate flowers in the Nearctic, Neotropical, and Australo-Pacific regions (Lachance *et al.*, 2001; Larson *et al.*, 2001; Defra, 2014).

Beetles were the third diverse flower visiting insects group (Fig. 1). Beetles are the largest insect group and pollinate a wide range of plant species with various reproductive characters, pollinating 88% of the 240,000 flowering plants (Endress, 1994). In Australia, 23% of the beetle families (28 families) include the flower visiting insects, while 51% of the dipteran families (44 families) comprise the flower visiting insects (Armstrong, 1979). In Korea about 71 species in 27 families were identified as

Appendix 1. List of flower visiting insects of Hymenoptera and Diptera on different types of plants (F, H, and W denote fruit crop, horticultural crop and wild plants)

Hymenoptera				Diptera						
Family	Species	F	H	W	Family	Species	F	H	W	
Andrenidae	<i>Andrena benefica</i>	1	0	0	Agromyzidae	<i>Phytomyza horticola</i>	0	1	0	
	<i>Andrena benifca</i>	1	0	0	Anthomyiidae	<i>Anthomyiidae sp.</i>	1	0	0	
	<i>Andrena dentata</i>	6	0	0		<i>Helina uliginosa</i>	1	0	0	
	<i>Andrena fukuokensis</i>	1	0	0	Asilidae	<i>Neoitamus angusticornis</i>	1	1	0	
	<i>Andrena haemorrhoa japonibia</i>	1	0	0	Bibionidae	<i>Biblio pseudoclavipes</i>	1	0	0	
	<i>Andrena halictoides</i>	3	0	0		<i>Biblio rufiventris</i>	2	0	0	
	<i>Andrena hikosana</i>	2	0	0		<i>Bibionidae sp.</i>	1	0	0	
	<i>Andrena japonica</i>	0	1	0		<i>Penthetria japonica</i>	1	0	0	
	<i>Andrena kaguya</i>	2	0	0		<i>Bombyliidae</i>	5	0	0	
	<i>Andrena kunthi</i>	3	0	0		<i>Bombyliidae sp.</i>	1	0	0	
	<i>Andrena longitibialis</i>	2	0	0	Calliphoridae	<i>Bombylius shibakawae</i>	4	0	0	
	<i>Andrena mediocalensis</i>	1	0	0		<i>Aldrichina sp.</i>	1	0	0	
	<i>Andrena mikado</i>	2	0	0		<i>Calliphora lata</i>	1	0	0	
	<i>Andrena okinawana</i>	1	0	0		<i>Calliphora vicina</i>	1	0	0	
	<i>Andrena opacifovea</i>	1	0	0		<i>Calliphora vomitoria</i>	1	0	0	
	<i>Andrena prostomias</i>	0	1	0		<i>Hemipyrellia ligurriensis</i>	1	1	0	
	<i>Andrena pruniphora</i>	5	0	0		<i>Lucilia ampullacea</i>	1	0	0	
	<i>Andrena sp.</i>	2	0	1	Cecudimyidae	<i>Lucilia caesar</i>	7	1	0	
	<i>Andrena sp.</i>	6	1	11		<i>Diarthronomyia hypogaea</i>	0	1	0	
	<i>Andrena yamato</i>	1	0	0	Ceratopogonidae	<i>Culicoides amamiensis</i>	0	1	0	
	<i>Panurainus crawfordi</i>	1	0	0		<i>Dasyhelea scutellata</i>	0	2	0	
	<i>Andrena koma</i>	1	0	0		<i>Forcipomyia albiradialis</i>	0	1	0	
	<i>Andrena koreana</i>	1	0	0		<i>Microchrysa flaviventris</i>	0	1	0	
	<i>Andrena maetai</i>	1	0	0		<i>Palpomyia distincta</i>	0	1	0	
	Anthophoridae	<i>Amegilla florea</i>	3	0	0	Chironomidae	<i>Ptecticus matsumurae</i>	0	1	0
		<i>Amegilla quadrifasciata</i>	1	0	0		<i>Cricotopus metatibialis</i>	1	0	0
Apidae	<i>Anthophora florea</i>	3	0	0		<i>Cricotopus trifasciatus</i>	0	1	0	
	<i>Apis cerana</i>	2	0	2		<i>Tanypus punctipennis</i>	0	1	0	
	<i>Apis mellifera</i>	22	1	11	Conopidae	<i>Tanypus punctipennis</i>	0	1	0	
	<i>Apis sp.</i>	3	0	0		<i>Asiconops opinus</i>	2	0	0	
	<i>Bombus ardens</i>	6	0	2		<i>Mxopa testacea</i>	2	0	0	
	<i>Bombus ardens</i>	1	0	0		<i>Diptera sp.</i>	1	0	0	
	<i>Bombus consobrinus</i>	0	0	3	Dolichopodidae	<i>Dolichopus nitidus</i>	0	2	0	
	<i>Bombus hypocrita</i>	0	0	1	Drosophilidae	<i>Drosophila bifasciata</i>	0	1	0	
	<i>Bombus ignitus</i>	6	0	3		<i>Drosophila busckii</i>	0	2	0	
	<i>Bombus pascuorum flavobarbatus</i>	1	0	0		<i>Drosophila melanogaster</i>	0	1	0	
	<i>Bombus sp.</i>	1	0	1		<i>Drosophila quadrivittata</i>	3	0	0	
	<i>Bombus terrestris</i>	2	0	0		<i>Drosophila sp.</i>	1	0	0	
	<i>Bombus tersatus</i>	0	0	1		<i>Drosophila trilineata</i>	0	2	0	
	<i>Bombus ussuriensis</i>	2	0	6		<i>Drosophila trilineata</i>	0	2	0	
	<i>Ceratina flavipes</i>	2	0	0		<i>Leucophenga orientalis</i>	0	1	0	
	<i>Ceratina sp.</i>	1	0	0		<i>Lordiphosa clarofinis</i>	0	1	0	
	<i>Crocisa emarginata</i>	2	0	1	Dryomyzidae	<i>Mycodrosophila planipalpis</i>	0	2	0	
	<i>Eucera spuratipes</i>	2	0	1		<i>Scaptodrosophila coracina</i>	0	2	0	
						<i>Scaptomyza graminum</i>	0	1	0	
						<i>Stenodryomyza formosa</i>	1	0	0	
				Empididae	<i>Empididae sp.</i>	1	0	2		

Appendix 1. Continued

Hymenoptera				Diptera					
Family	Species	F	H	W	Family	Species	F	H	W
	<i>Hylaeus sp.</i>	1	0	0		<i>Hybos japonicus</i>	2	0	0
	<i>Lassioglossum sp.</i>	1	0	0	Muscidae	<i>Fannia prisca</i>	1	0	0
	<i>Melecta sinensis</i>	1	0	0		<i>Musca domestica</i>	2	1	0
	<i>Nomada issikii</i>	1	0	0		<i>Muscidae sp.</i>	3	0	6
	<i>Nomada pyrifera</i>	1	0	0		<i>Muscina stabulans</i>	4	0	0
	<i>Nomada hakonensis</i>	2	0	0		<i>Ophyra leucostoma</i>	0	1	0
	<i>Nomada issikii</i>	2	0	0		<i>Orthellia coerulea</i>	0	1	0
	<i>Nomada japonica</i>	2	0	0		<i>Polietes lardaria</i>	0	1	0
	<i>Nomada pyrifera</i>	2	0	0		<i>Pyrellia vivida</i>	0	1	0
	<i>Nomada sp.</i>	0	0	1	Mycetophilidae	<i>Monoclona braueri</i>	0	1	0
	<i>Nomada sp. 1</i>	1	0	0		<i>Symmerus antennalis</i>	2	0	0
	<i>Nomada sp. 2</i>	1	0	0	Nemestrinidae	<i>Hirmoneura orientalis</i>	2	0	0
	<i>Nomada sp. 3</i>	1	0	0	Phoridae	<i>Phoridae sp.</i>	1	0	0
	<i>Nomada sp. 4</i>	1	0	0	Pipunculidae	<i>Pipunculus kumamotoensis</i>	0	1	0
	<i>Panurginus crawfordi</i>	1	0	0	Psychodidae	<i>Psychodidae sp.</i>	1	0	0
	<i>Panuriginus crawfordi</i>	5	1	0	Pyrgotidae	<i>Eupyrgota fusca</i>	1	0	0
	<i>Tetralonia nipponensis</i>	8	0	4	Sarcophagidae	<i>Helicophagella melanura</i>	0	0	1
	<i>Xylocopa appendiculata</i>	9	0	3		<i>Parasarcophaga albiceps</i>	3	0	0
Argidae	<i>Arge nipponica</i>	5	0	0		<i>Parasarcophaga harpax</i>	3	0	0
Braconidae	<i>Braconidae sp.</i>	1	0	0		<i>Pierretia josephi</i>	1	0	0
Callimonidae	<i>Callimonidae sp.</i>	1	0	0		<i>Ravinia striata</i>	5	0	0
Cerceridae	<i>Cerceris hortivaga</i>	1	0	0		<i>Sarcophagidae sp.</i>	1	0	0
Cimbicidae	<i>Orietabia sp.</i>	1	0	0	Sauxaniidae	<i>Sauxaniidae sp.</i>	1	0	0
Colletidae	<i>Hylaeus paradifformis</i>	1	0	0	Scathophagidae	<i>Scatophaga stercoraria</i>	1	0	0
Crabronidae	<i>Pemphredon sp.</i>	1	0	0	Sciaridae	<i>Sciaridae sp.</i>	1	0	0
	<i>Tachytea montiola</i>	2	0	0	Sepsidae	<i>Sepsidae sp.</i>	1	0	0
Cynipidae	<i>Cynipidae sp.</i>	2	0	0	Syrphidae	<i>Helophilus virgatus</i>	1	0	0
Eulophidae	<i>Eulophidae sp.</i>	1	0	0		<i>Syrphidae sp.</i>	89	9	42
Eumenidae	<i>Eumenidae sp.</i>	1	0	0		<i>Allograpta balteata</i>	3	1	6
	<i>Symmorphus captivus</i>	2	0	0		<i>Baccha maculata</i>	1	0	0
Formicidae	<i>Camponotus atrox</i>	0	0	1		<i>Cheilosia sp.</i>	1	0	0
	<i>Camponotus japonicus</i>	2	0	0		<i>Chrystoxum sp.</i>	1	0	0
	<i>Crematogaster osakensis</i>	2	0	0		<i>Dasysyrphus albobstriatus</i>	1	0	0
	<i>Formica japonica</i>	4	0	1		<i>Didea alneti</i>	1	0	0
	<i>Formicidae sp.</i>	1	0	0		<i>Eristalinus sepulchralis</i>	0	1	0
	<i>Lasius alienus</i>	0	0	3		<i>Eristalis arbustorum</i>	3	0	1
	<i>Lasius niger</i>	4	0	2		<i>Eristalis cerealis</i>	5	2	8
	<i>Myrmica sp.</i>	0	0	1		<i>Eristalis sp.</i>	0	0	1
	<i>Paratrechina flavipes</i>	1	0	1		<i>Eristalis tenax</i>	2	1	8
	<i>Polyrhachis sp.</i>	0	0	1		<i>Eupeodes frequens</i>	1	0	0
	<i>Tetramorium caespitum</i>	2	0	0		<i>Helophilus eristaloidea</i>	4	0	0
Halictidae	<i>Halictus aerarius</i>	8	0	0		<i>Helophilus sapporensis</i>	1	0	0
	<i>Lasioglossum amamiense</i>	2	0	0		<i>Helophilus sp.</i>	1	0	0
	<i>Lasioglossum apristum</i>	0	1	1		<i>Helophilus virgatus</i>	8	0	2
	<i>Lasioglossum calceatum</i>	2	0	0		<i>Lathyrophthalmus viridis</i>	3	0	0
	<i>Lasioglossum discrepans</i>	5	0	0		<i>Mallota tricolor</i>	0	0	1

Appendix 1. Continued

Hymenoptera				Diptera					
Family	Species	F	H	W	Family	Species	F	H	W
	<i>Lasioglossum duplex</i>	4	0	0		<i>Melangyna compositarum</i>	1	0	0
	<i>Lasioglossum exiliceps</i>	2	0	0		<i>Melanostoma scalare</i>	6	2	0
	<i>Lasioglossum japonicum</i>	2	0	0		<i>Merodon sp.</i>	1	0	0
	<i>Lasioglossum laeiventre</i>	1	0	0		<i>Mesembrius flaviceps</i>	0	1	0
	<i>Lasioglossum mutillum</i>	1	0	1		<i>Metasyrphus corollae</i>	1	0	0
	<i>Lasioglossum occidens</i>	0	0	1		<i>Metasyrphus frequens</i>	4	0	2
	<i>Lasioglossum proximatium</i>	2	0	0		<i>Microdon caeruleus</i>	2	0	0
	<i>Lasioglossum scitulum</i>	1	0	0		<i>Monoceromyia pleuralis</i>	0	0	3
	<i>Lasioglossum sp.</i>	2	0	2		<i>Paragus coreanus</i>	0	0	1
	<i>Lasioglossum taeniolellum</i>	2	0	0		<i>Paragus joznus</i>	1	0	0
	<i>Lasioglossum transpositum</i>	2	0	0		<i>Paragus tibialis</i>	2	0	0
	<i>Sphecodes sp.</i>	2	0	0		<i>Paraus politus</i>	0	1	0
Ichneumonidae	<i>Coccygomimus luctuosa</i>	1	0	0		<i>Phytomia zonata</i>	1	0	0
	<i>Coccygomimus nipponicus</i>	1	0	0		<i>Pipiza austriaca</i>	1	0	0
	<i>Ichneumonidae sp.</i>	6	0	1		<i>Pipiza flavimaculata</i>	3	0	0
Megachilidae	<i>Megachile humilis</i>	4	0	0		<i>Pipiza inornata</i>	2	0	0
	<i>Megachile nipponica</i>	3	0	1		<i>Sphaerophoria cylindrica</i>	1	0	0
	<i>Megachile rixator</i>	1	0	0		<i>Sphaerophoria javana</i>	2	0	0
	<i>Megachile sp.</i>	2	0	0		<i>Sphaerophoria menthastri</i>	6	0	0
	<i>Megachile sp.</i>	1	0	0		<i>Sphaerophoria sp.</i>	0	0	1
	<i>Megachile spissula</i>	2	0	0		<i>Syritta pipiens</i>	0	0	1
	<i>Megachile sp.</i>	2	0	0		<i>Syrphidae sp.</i>	0	0	1
	<i>Osmia cornifrons</i>	7	1	0		<i>Syrphidae sp.</i>	1	0	3
	<i>Osmia imaii</i>	1	0	0		<i>Syrphus serarius</i>	2	0	0
	<i>Osmia orientalis</i>	1	0	0		<i>Syrphus torvus</i>	2	0	0
	<i>Osmia pedicornis</i>	7	0	0		<i>Syrphus vitripennis</i>	4	0	0
	<i>Osmia sp.</i>	1	0	0		<i>Volucella jeddona</i>	0	0	1
	<i>Osmia taurus</i>	2	0	0		<i>Volucella pellucens</i>	0	0	1
Pamphiliidae	<i>Pamphiliidae sp.</i>	1	0	0		<i>Volucella sp.</i>	0	0	1
Pompilidae	<i>Anoplius samariensis</i>	1	0	0	Tabanidae	<i>Tabanus chrysurus</i>	1	0	0
Pteromalidae	<i>Pteromalidae sp.</i>	2	0	0	Tachinidae	<i>Dexia flavipes</i>	1	0	0
Scolidae	<i>Campsomeris annulata</i>	1	0	0		<i>Tachina luteola</i>	0	0	4
Scoliidae	<i>Campsomeris annulata</i>	5	0	1		<i>Tachinidae sp.</i>	1	0	0
	<i>Scolia oculata</i>	2	0	0	Tephritidae	<i>Bactrocera dorsalis</i>	0	1	0
Scollidae	<i>Campsomeris prismatica</i>	1	0	0		<i>Dacus depressus</i>	0	2	0
Sphecidae	<i>Ammophila sabulosa</i>	1	0	1		<i>Ensina sonchi</i>	2	1	0
	<i>Crossocerus sp.</i>	1	0	0		<i>Tephritidae sp.</i>	1	0	0
	<i>Passaloecus monilicornis</i>	3	0	0	Therevidae	<i>Dialineura albata</i>	1	0	0
	<i>Sphecidae sp.</i>	5	0	0	Tipulidae	<i>Tipula nova</i>	1	0	0
	<i>Sphecodes sp.</i>	2	0	0		<i>Tipula patagiata</i>	1	1	0
Tenthredinidae	<i>Tenthredo analis</i>	2	0	0					
Tenthredinidae	<i>Aglaostigma nebulosa</i>	1	0	0					
	<i>Athalia lugens</i>	1	1	0					
	<i>Athalia proxima</i>	2	0	0					
	<i>Athalia rosae</i>	3	0	0					
	<i>Dolerus ephippiatus</i>	1	0	0					

Appendix 1. Continued

Hymenoptera				
Family	Species	F	H	W
	<i>Dolerus sp.</i>	2	0	0
	<i>Hoplocampa coreana</i>	2	0	0
	<i>Strongylogaster filicis</i>	2	0	0
	<i>Strongylogaster secundus</i>	1	0	0
	<i>Tenthredinidae sp.</i>	3	0	1
	<i>Tenthredo analis</i>	4	0	0
	<i>Tenthredo mortivaga</i>	1	0	0
Tiphiidae	<i>Tiphiidae sp.</i>	2	0	0
Trypoxtlidae	<i>Pison punctifrons</i>	1	0	0
Vespidae	<i>Dolichovespula media</i>	1	1	0
	<i>Polistes jadwigae</i>	1	0	0
	<i>Polistes mandarinus</i>	2	0	1
	<i>Vespa analis parallela</i>	2	0	0
	<i>Vespa crabro flavofasciata</i>	3	0	1
	<i>Vespa mandarinia</i>	1	0	0
	<i>Vespula flaviceps lewisii</i>	1	0	0
Xyelidae	<i>Xyelidae sp.</i>	2	0	0
Xylocopidae	<i>Xylocopa amamensis</i>	4	0	0

Appendix 2 List of flower visiting insects of Lepidoptera, Coleoptera and other orders on different types of plants (F, H, and W denote fruit crop, horticultural crop and wild plants)

Lepidoptera					Coleoptera				
Family	Species	F	H	W	Family	Species	F	H	W
Adelidae	<i>Nemophora staududingerella</i>	0	0	2	Anthribidae	<i>Gibber nodulosus</i>	1	0	0
Geometridae	<i>Baptria tibiale</i>	0	0	1	Attelabidae	<i>Rhynchites heros</i>	1	0	0
	<i>Obeidia tigrata</i>	0	0	1	Buprestidae	<i>Agrilus asiaticus</i>	1	0	0
Hesperiidae	<i>Bibasis aquilina</i>	0	0	1		<i>Agrilus cyaneoniger melanopterus</i>	1	0	0
	<i>Hesperia florinda</i>	0	0	1		<i>Agrilus pilosovittatus</i>	1	0	0
	<i>Lobocla bifasciata</i>	0	0	4		<i>Agrilus rotundicollis</i>	3	0	0
	<i>Ochlodes venatus</i>	0	0	2		<i>Agrilus sp.</i>	1	0	0
	<i>Thymelicus leoninus</i>	0	0	3		<i>Anthaxia reticulata</i>	1	0	0
Lycaenidae	<i>Celastrina argiolus</i>	2	0	0		<i>Anthoxia proteus psiittacina</i>	1	0	0
	<i>Japonica lutea</i>	2	0	0	Cantharidae	<i>Athemellus oedemeroides</i>	1	0	0
	<i>Lycaeides argyronomon</i>	4	0	0		<i>Athemus suturellus suturellus</i>	1	0	0
	<i>Lycaena phlaeas</i>	0	0	1		<i>Athemus vitellinus</i>	2	0	0
	<i>Maculinea teleus</i>	1	0	0		<i>Cantharis pallida</i>	1	0	0
	<i>Pseudozizeeria maha</i>	1	0	0		<i>Podabrus temporalis</i>	2	0	0
	<i>Rapala caerulea</i>	1	0	1		<i>Wittmercantharis vulcana</i>	1	0	0
Nymphalidae	<i>Araschnia burejana</i>	0	0	5	Cephaloidae	<i>Cephaloon pallens</i>	1	0	0
	<i>Argynnis paphia</i>	0	0	7	Cerambycidae	<i>Carilia virginea</i>	1	0	0
	<i>Argyronome rustlana</i>	0	0	2		<i>Chlorophorus motschulskyi</i>	0	0	1
	<i>Brenthis ino</i>	0	0	3		<i>Chlorophorus yedoensis</i>	1	0	0
	<i>Clossiana selene</i>	0	0	2		<i>Corymbia rubra</i>	0	0	4
	<i>Cyntia cardui</i>	0	0	1		<i>Demonax transilis</i>	1	0	0
	<i>Fabriciana pallescens</i>	0	0	4		<i>Dere thoracica</i>	1	0	0

Appendix 2 Continued

Lepidoptera				Coleoptera					
Family	Species	F	H	W	Family	Species	F	H	W
	<i>Kaniska canace</i>	1	0	0		<i>Leptura arcuata</i>	0	0	2
	<i>Limenitis camilla</i>	1	0	2		<i>Moechotypa diphysis</i>	1	0	0
	<i>Melanargia epimede</i>	0	0	1		<i>Oedemera lurida</i>	0	0	1
	<i>Mimathyma schrenckii</i>	0	0	1		<i>Phytoecia rufiventris</i>	1	0	0
	<i>Neptis sappho</i>	0	0	2		<i>Pidonia gibbicolis</i>	0	0	4
	<i>Parantica sita</i>	0	0	1		<i>Pidonia puziloi</i>	0	0	1
	<i>Polygonia c-aureum</i>	5	1	1		<i>Purpuricenus lituratus</i>	2	0	0
	<i>Ypthima argus</i>	0	0	1	Cetoniidae	<i>Gametis jucunda</i>	1	0	2
	<i>Ypthima motschulskyi</i>	0	0	1		<i>Nipponovalgus angusticollis</i>	1	0	0
	<i>Ypthima amphithea</i>	0	0	1		<i>Trichius succinctus</i>	0	0	8
Papilionidae	<i>Atrophaneura alcinous</i>	0	0	1	Chrysomelidae	<i>Agelasa nigriceps</i>	1	0	0
	<i>Papilio maackii</i>	0	0	2		<i>Chrysolina aunchalcea</i>	1	0	0
	<i>Papilio macilentus</i>	2	0	0		<i>Phratora inhonesta</i>	2	0	0
	<i>Papilio xuthus</i>	4	1	0		<i>Chrysomelidae</i>	1	0	1
Pieridae	<i>Anthocharis scolymus</i>	1	0	0		<i>Nonarthra cyanea</i>	0	0	1
	<i>Artogeia canidia</i>	0	0	1		<i>Paropsides duodecimpustulata</i>	1	0	0
	<i>Artogeia melete</i>	3	0	1	Cleridae	<i>Thanassimus lewisi</i>	1	0	0
	<i>Artogeia napi</i>	0	1	2		<i>Coccinellidae</i>	17	0	0
	<i>Artogeia rapae</i>	8	1	1		<i>Aiolocaria hexaspilota</i>	2	0	0
	<i>Colias erate</i>	2	0	0		<i>chilocorus kuwanae</i>	1	0	0
	<i>Eurema laeta</i>	1	0	0		<i>Coccinella septempunctat</i>	1	0	0
	<i>Gonepteryx aspasia</i>	0	0	2		<i>Harmonia axyridis</i>	3	0	0
	<i>Gonepteryx rhamni</i>	0	0	1		<i>Henosepilachna</i>			
	<i>Leptidea amurensis</i>	1	0	1		<i>vigintioctomaculata</i>	2	0	0
Zygaenidae	<i>Alataea octomaculata</i>	0	0	1		<i>Hyperaspis asiatica</i>	1	0	0
Hemiptera						<i>Hyperaspis sp</i>	3	0	0
Cydnidae	<i>Chilocoris confusus</i>	1	0	0		<i>Prophylea</i>			
Lygaeidae	<i>Arocatus melanostomus</i>	1	0	0		<i>quatuordecimpunctata</i>	4	0	0
	<i>Nyslus plebejus</i>	1	0	0	Curculionidae	<i>Baris dispilota</i>	1	0	0
	<i>Paradieuches dissimilis</i>	1	0	0		<i>Lixus impressiventris</i>	1	0	0
Pentatomidae	<i>Dolycoris baccarum</i>	5	0	0		<i>Otiorthynchinae sp.</i>	1	0	0
Rhopalidae	<i>Liorhyssus hyalinus</i>	1	0	0		<i>Dermestidae</i>	1	0	0
	<i>Rhopalus maculatus</i>	2	0	0		<i>Anthrenus pimpinellae</i>	1	0	0
Tingidae	<i>Stephanitis nashi nashi</i>	3	0	0	Elateridae	<i>Ampedus carbunculus</i>	1	0	0
Urostylidae	<i>Urochela quadrinotata</i>	1	0	0		<i>Ampedus puniceus</i>	1	0	0
Homoptera						<i>Melanotus cribricollis</i>	1	0	0
Aphrophoridae	<i>Aphrophoridae sp.</i>	1	0	0		<i>Paracardiophorus pullatus</i>	3	0	0
Cicadellidae	<i>Bothrogonia japonica</i>	1	0	0	Harpalidae	<i>Chlaenius naeviger</i>	1	0	0
Thysanoptera						<i>Cyrtototus giganteus</i>	1	0	0
Phlaeothripidae	<i>Haplothrips chinensis</i>	1	2	0		<i>Harpalidae sp.</i>	1	0	0
Thripidae	<i>Frankliniella intonsa</i>	2	0	0		<i>Parena nigrolineata nipponensis</i>	1	0	0
	<i>Megalurothrips distalis</i>	1	0	0		<i>Laemophloeidae</i>	1	0	0
	<i>Microcephalothrips abdominalis</i>	1	1	0		<i>Leptophloeus convexiusculus</i>	1	0	0
	<i>Thrips hawaiiensis</i>	1	1	0	Lagriidae	<i>Luprops orientalis</i>	1	0	0
	<i>Thrips tabaci</i>	0	1	0	Lycidae	<i>Calochromus rubrovestitus</i>	1	0	0
Chrysopidae	<i>Chrysopa intima</i>	0	0	1		<i>Dictyopterus aurora</i>	0	1	0
	<i>Chrysopa sp.</i>	1	0	0		<i>Lyponia delicatula</i>	1	0	0

Appendix 2 Continued

Lepidoptera				Coleoptera					
Family	Species	F	H	W	Family	Species	F	H	W
Corydalidae	<i>Neutroptera sp.</i>	1	0	0	Melyridae	<i>Attalus sp.</i>	2	0	0
						<i>Mordellidae</i>	5	0	2
						<i>Mordella aculeata</i>	1	0	0
						<i>Mordella brachyura</i>	1	0	1
						<i>Mordella holomelaena</i>	1	0	0
						<i>Mordella truncatoptera</i>	1	0	0
						<i>Mordellidae sp.</i>	0	0	1
						<i>Mordellistena comes</i>	1	0	0
					Nitidulidae	<i>Bpuraea paulula</i>	1	0	0
						<i>Epuraea parlis</i>	2	0	0
					Oedemeridae	<i>Ditylus laevis</i>	1	0	0
						<i>Eobia cinereipennis cinereipennis</i>	1	0	0
						<i>Icschnomera subrugosa</i>	1	0	0
						<i>Oedemeridae sp.</i>	1	0	0
						<i>Oedemerina robusta</i>	0	0	1
						<i>Oedemeronia testaceithorax</i>	2	0	0
					Pyrochroidae	<i>Pseudopyrochroa rubricollis</i>	1	0	0
						<i>Pseudopyrochroa rufula</i>	5	0	0
					Rutelidae	<i>Anomala cpustulata</i>	1	0	0
						<i>Anomala octiescostata</i>	1	0	0
						<i>Anomala rufocuprea</i>	1	0	0
						<i>Anomala sieversi</i>	1	0	0
						<i>Blitopertha conspurcata</i>	1	0	0
						<i>Oxycetonia jucunda</i>	5	0	0
						<i>Popillia flavosellata</i>	0	0	1
						<i>Proagopertha pubicollis</i>	5	0	0
					Scolytidae	<i>Xyleborinus saxeseni</i>	1	0	0
						<i>xyleborus apicalis</i>	1	0	0
						<i>xyleborus validus</i>	1	0	0
						<i>Xylosandrus germanus</i>	1	0	0
					Staphylinidae	<i>Staphylinidae sp.</i>	1	0	0
					Tenebrionidae	<i>Tarpela cordicollis</i>	1	0	0
						<i>Trachyscelis sabuleti</i>	1	0	0

the flower visiting beetle species.

In the present review 43 butterflies visited flowers of diverse crops and wild plants. In addition only four species of moths (Adelidae, Geometridae and Zygaenidae) were recorded (Appendix 1). Many sphingid and noctuid moths that visit flowers of wild plants during daytime were, however not included in the studies that we surveyed.

Among the plants, most pollinators were observed as visiting major fruits such as apple, pear, and peach, followed by some horticultural crops (Fig. 2). Meanwhile

the insect pollinators on wildflowers were relatively uncommon, except an exotic herb, *Erigeron annuus* (Fig. 2). This does not exactly reflect the field condition, but more the study intensity because this review was confined to the record counting rather than density estimation. Based on plant types, record frequency of Hymenoptera was highest in fruit crops (Fig. 3) indicating that diversity of bee pollinators on fruit crops is higher than horticultural crops or wild plants. From wild plants, higher frequencies of Hymenoptera, Diptera, and Lepidoptera as well as

Coleopteran insects were relatively higher (Fig. 3). This is the important finding in terms of pollinator conservation because diverse plant flower morphology and nutritional availability provoke the wild pollinator diversity. In contrast, pollinator diversity from horticultural crops were low (Fig. 3), partially because of the nature of cultivation of those crops inside the greenhouse.

There are basically three types of sampling; direct observation, sweep net collection and trapping with pollinator trap or water pan trap (Fig. 4). Depending on the insect order, different methodologies were employed. For lepidopteran insects, visual observation was dominant, while the other taxa were collected by sweep netting. It is interesting to see that trapping with water pan or pollinator trap was mostly employed to study bee diversity (Fig. 4).

The role of insect pollinators in diverse ecological systems including agriculture is important (Garibaldi *et al.*, 2013). About 75% of global food crops are at least partially dependent on animal pollinators and majority of them are insects. Here we reviewed the diversity of insect pollinators, and found that bees, bumblebees and syrphid flies are most important pollinator groups. However, we found that wild plants harbored low frequency of insect pollinators but, with high taxonomic diversity, which may imply some important context for conservation and enhancement of wild pollinators. Further, we need more detailed research on diversity of pollinators and biological interactions between plants and pollinators in diverse ecosystems.

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