Chapter

Pollinators: Their Relevance in Conservation and Sustainable Agro-Ecosystem

Mukesh Nitharwal, Rashmi Rolania, Hanuman Singh Jatav, Kailash Chandra, Mudassar Ahmed Khan, Subhita Kumawat, Sanjay Kumar Attar and Shish Ram Dhaka

Abstract

Survival and reproduction of several wild plants and crops is mostly by insects pollinator, their recognition and importance have been increased in this climatic changing scenario, which affects the various aspects of their life cycle. According to an estimate, approximately 30,000 species of bees are known in entomology, and about 190 species of bees have been reported to be associated with pollination. There can be an established link between seed production and pollinator diversity, for the plants with a generalist pollination system. The increasing of human habitation affects insect pollinators in various ways, i.e. of habitat destruction, results in low availability of food sources, nesting, oviposition, resting, and mating sites. Pollinator availability restricts the geographical distribution of plant species, i.e. to develop an ecological niche of certain plant species. Failure of pollinator-plant interaction mutualism results in lower seed production and sometimes extirpation of plant population has been recorded. The declining pollinators’ population strengthens existing plant-pollinator interaction or allows new plant-pollinator interaction to form. Maintaining the commercial and wild pollinator populations and preventing future shortages of pollination services, therefore, is extremely significant.

Keywords: agro-ecosystem, ecology, plant-pollinator interaction, pollinator, pollination, sustainable

1. Introduction

Plant and pollinator interaction results in the pollination of various plants that are self-incompatible. These pollinating agents are important for the existence and reproduction of about 87.5 percent of wild species of plants [1, 2]. Pollinators are important to increase agriculture production and in ecosystem functions to increase plant genetic diversity [3, 4]. The total annual economic value of crop pollination around the world has been estimated at about €153 billion [5]. Klein et al. [4], surveyed that more than 87 of the world’s leading food crops, representing 35 percent of global food production, depends upon animal pollinators, pollination by insect directly contributed about $20 billion and that of honey bee contribution was $14.6 billion in 2000 in the U.S [6]. The total economic value of insect pollination of
Chinese fruits and vegetables recorded about $52.2$ billion US dollars in 2008, which represented $25.5\%$ of the total production value of the $44$ crops produced in China [7]. The area among the pollinator-dependent crops has increased up to $300\%$ during the last $50$ years, both in temperate and tropical crops [8, 9]. Pollination is an essential prerequisite to seed and fruit development; it is a pivotal, keystone process and insects provide an important function in both natural and managed ecosystems [10, 11]. The mutual relationship has been found between insect pollinators and flowering plants, that in return nectar and pollen are major food rewards for pollinators.

Robbins et al. [12] reported that most accepted estimates indicate honeybees’ account for at least $80\%$ of all insect pollination. For decades the consequences of insect pollination have been documented in treaties by Free [13], McGregor [14], and Pesson and Louveaux [15]. In apiculture the most important species, *Apis mellifera* L. has been reported as the single most important pollinator [13, 14]. The pollinating potential of a single honeybee colony becomes evident when it is recognized that its bees make up to $4$ million trips per year and that during each trip an average of $100$ flowers are visited [16].

### 2. Pollinators diversity in agro-ecosystem

An enormous number of the world’s insect diversity visits flowers for nutrition, but all are not efficient pollinators. Among crop foods, fibers, edible oils, medicines, and other valuable products, a significant production occurs due to the vital role of insects and other animal pollinators. In all types of ecosystems, bees are recognized as the most valuable pollinators, but their precise roles in pollination are not well documented. According to estimation, approximately $30,000$ species of bees are known in entomology, and about $190$ species of bees have been reported to be associated with pollination in North America. Some of the other noteworthy contributors in pollination are; alkali bee (*Nomia melanderi* Cockerell) found as solitary bees to pollinator in alfalfa and alfalfa leaf cutting bee (*Megachile rotundata* Fabr.) also play its role in the pollination of this crop [17–20]. Through artificial mud nesting tunnels, orchard bees (*Osmia* spp.) can be managed in the field for pollination, as orchard bees are far much better for apple pollination than honeybees [21]. Another, bumblebees (*Bombus* spp.) are pollinators of red clover (*Trifolium pratense* L.) and cranberries (*Vaccinium macrocarpon* Ait.), but difficult to manage in field conditions [22]. Carpenter bees (*Xylocopa* spp.) are the outstanding pollinators of vine crops, especially of passion fruit (*Passiflora edulis* Sims), giant granadilla (*P. quadrangularis* L.), kiwi-fruit (*Actinidia deliciosa* (A.Chev.) C.F. Liang & A.E. Ferguson), various gourds, and winged beans (*Psophocarpus tetragonolobus* (L.)) but there is not much available data on these pollinators.

The interdependency of plants and pollinators vary in their degree, some plants species depend primarily on a single species of pollinator, which in turn has restricted sources of pollen or nectar. One example of a closely dependent association is the interaction between plant Yucca (Agavaceae) and its pollinators, yucca moth (*Tegeticula* spp.), having a mutualism estimated to be more than $40$ million years old [23]. Squash crops i.e. pumpkins and gourds are pollinated by specialized squash bees, *Peponapis* spp. and *Xenoglossa* spp., and are more manageable, they nest in underground burrows and become active at dawn, visiting cucurbit flowers until about midday when unisexual flowers close [24, 25]. There are many other pollinator native bees, which include sunflower bees (*Eumegachile pugnata* (Say) [26], blueberry bees (*Habropoda labiata* (Fabr.)) [27], and *Osmia ribiflorr*is Michener (Table 1) [28–30]. Oil palm weevil, *Elaeidobius kamerunicus* as the most
valuable in terms of the economic importance of this crop at the world trade level [31]. Non-biting midges, *Forcipomyia* spp., a specialty pollinator among the cocoa (*Theobromacacao* L.) crop, which breeds in rotting vegetation in its plantation [32] are a few of specific examples of pollination to produce the economic plants/crops that are in need of human beings.

Among the herbivorous insects, the interaction of butterflies and moths is found during both its larval and adult stages and the latter is involved in pollination (Table 2). Some of these are *Heliconius* butterfly [41, 42]; yucca moth [43], obligatory mutualisms are exceptional in order Lepidoptera of pollinators. Moths from the families Geometridae, Noctuidae, and Sphingidae are among the most studied moths to be known as pollinators, their pollinating activity takes place at night in many plants such as cacti, orchids, trees [44–47]). Many had also identified and reported thrips on flowers and they noticed that thrips feed on pollen so that they

| Common name          | Scientific name | Example of crop plants pollinated          |
|----------------------|-----------------|-------------------------------------------|
| Alkali bee           | *Nomia melanderi* | Alfalfa, clover, mint                      |
| Blueberry bee        | *Habropoda laboriosa* | Blueberry                                 |
| Carpenter bee        | *Xylocopa* spp. | Passion flower, eggplant, pepper           |
| Digger bee           | *Andrena*, *Colletes*, and *Melissods* spp. | Cotton, fruit trees                       |
| Alfalfa leafcutting bee | *Megachile rotundata* | Alfalfa                                    |
| Blue orchard bee (mason bee) | *Osmia lignaria* | Almond, apple, sweet cherry                |
| Squash and gourd bee | *Peponapis pruinosa* other *Peponapis* and *Xenoglossa* spp. | Squash, pumpkin, gourds                   |
| Sunflower bee        | *Eumegachile pugnata* | Sunflower                                  |

Table 1. Bees and specific plant fauna they visit and pollinate.

| Plant                   | Pollinator insect                  | References |
|-------------------------|------------------------------------|------------|
| Beetles                 |                                    |            |
| *Asimina*               | *Euphoria sepulchralis*             | [33, 34]   |
|                         | *Trichius* spp.                    |            |
|                         | *Trichotinus lunulatus*            |            |
| *Calycanthus*           | *Calopterus truncates*             | [35]       |
| *Calochortus*           | *Acanthoscelides* spp.             | [36]       |
| *Linanthus*             | *Trichochrous* sp.                 | [37]       |
| Butterflies             |                                    |            |
| Wild carnation, *Dianthus carthusianorum* | Butterfly species | [38]       |
| Native plants of North America | Checkerspot butterfly, *Euphydryas editha bayensis* | [39]       |
| Milkweed and other      | Monarch butterfly, *Danaus plexippus* | [40]       |

Table 2. Beetles, butterflies, and moths with specific plant fauna they visit and pollinate.
can be effective pollinators or minor or secondary pollinators of a wide variety of plants in agro-ecosystem or nature [48–52].

3. Pollinators and plant interaction

In an ecosystem, the interaction between the organisms favors co-evolution and it gradually helps to evolve together for some betterment or for existence in nature. Those plants having a generalist pollination system, have a link between pollinator diversity and seed production can also be established [53]. Pollination biology (Figure 1) draws attention to both evolutionary and ecological approaches i.e. the link between pollinator behavior and plant mating patterns, generalization, and specialization in a pollination system [24, 54, 55].

There are many reasons for which pollinators visit flowers, including feeding, pollen collection, warmth in some cases, oils and resins, as well as for shelter and mating rendezvous sites [56]. These plant and pollinator interactions as mutualisms sustain not only plant diversity, but also the diversity of an estimated 350,000 animal species, including insects, birds, and mammals [57–59]. Ratto et al. [60] reported an average 63% loss of fruit or seed production when vertebrate pollinators are excluded from the flowering plants’ ecology they visit. These results often reported experimentally that selective exclusion of a single group of an effective pollinators from plant-pollinator interaction can result in the failure of plants to produce fruits or seeds.

Diversity of pollinators in habitat can compete for floral resources [61], the declining pollinators population strengthens existing plant-pollinator interaction or allow new plant-pollinator interaction to form [62, 63]. The diverse pollen feeding behavior by bee species is due to digestibility and nutritional content requirement fulfillment [64]. There are specialized flower plant-pollinator relationships like certain solitary bees species [65], reduction of these flower plants from habitat often results in the elimination of their specialist plant-pollinator populations. Viana et al. [66] evaluated more than 250 studies that showed the impact of landscape and pollinators interactions. The forage bees’ ability to assess the nutritional value of pollen sources before establishing plant-pollinator interaction is valuable [67, 68]. A recent study by Armbruster [69] on pollination ecology mainly emphasizes three aspects, first ecological (pollination involving one or few kinds of plant and animals), second phenotypic (having specialized flowers or morphologies) and third is evolutionary (showing transitions towards increased specialization).

![Conceptual representation of the interplay between ecology and evolution in the study of plant-pollinator interactions.](image-url)
4. Declining pollinator, a potential threat

It is difficult to determine as less surveys are organized to record whether pollinator species are declining around the world. If we study the literature many explanations have been invoked to account for declines in pollinator population around the globe [70–74]. There are a few of these reasons such as exposure to pathogens, parasites, and pesticides; habitat fragmentation and loss; climate change; market forces; intra and inter specific competition with native and invasive species; and genetic alterations. Reduction in pollinator diversity or abundance may influence the amount and source of pollen deposited on the reproductive part of flower or stigma [75].

The western honeybee, *Apis mellifera*, colony losses are elucidated in many literatures with attack of different honey pests i.e. parasites, pathogens [76], mostly predominately identified parasitic mites *Varroa destructor* and *Acarapis woodi*, the pathogen *Paenibacillus larvae* (American foulbrood) and the invasive Africanized honey bee [77–82].

The application of pesticides, especially insecticides in crops, vegetable, and orchards to control pests, kills or weakens thousands of honey bee colonies and affect their foraging and nesting behaviors that prevent plant pollination [83–86]. The basic behind pesticides to kill or weaken the colony is the result of accidents, careless application, or failure to adhere to label recommendations and warnings. Some of the advance studies showed that transgenic crops developed to reduce the unintended effects of pesticides have shown that there are direct effects on non-target species, including some pollinators [87–89]. Transgenic crops that express transgene with varied expression levels have not been yet reported effects on honeybee [90].

There are degradations reported around the globe in habitat i.e. alternations, fragmentation, and loss cause major problems for populations of many organisms, and pollinator populations are also one of them [1, 91]. Insect pollinator’s i.e. bees and others require nesting sites (suitable soil, dead wood, abandoned mouse nests, and burrows) and floral resources (nectar and pollen) to exist. These habitat resources are at extinction through the disruption caused by row crop agriculture, grazing, and fragmentation of habitat into patches, which are small enough for the survival of diverse communities of pollinators [92]. Some other reported causes of decline in pollinators’ population are monoculture, the lower density of weed flora, declining pastures, loss of flower-rich grasslands, and overgrazing can disrupt the nesting of bees [93–96].

Industrial development around the global, regional and local climate changes can alter or disrupt plant-pollinator relationships. Many studies and reports show the climate change forecast is shifted in temperature [97] and precipitation, concentrations of carbon dioxide [98] and ozone, and ultraviolet levels [99, 100] effects pollinators in many ways. There is evidence that the latitudinal and altitudinal ranges of some plants and pollinators have changed in the past 30 years, presumably in response to global warming [101–103].

5. Management and restoration of pollinators

Information on the status of most of the pollinators is incomplete around the world, and it is in a natal stage in developing countries [90]. Much can be done to maintain commercial and wild pollinator populations and to prevent future shortages of pollination services. Indigenous communities have an important role in the conservation of habitats through customary laws/rules, these areas are important
biodiversity refuges providing valuable ecosystem services including pollination, which improved crop pollination in adjacent farming landscape [104–107]. An agri-environment scheme, on farmlands, has been proactively practiced in European Union countries through incentives to support biodiversity [108]. The US Farm bill (2008) had made specific economic provisions for pollinator conservation when it was further ratified in the 2014 Farm bill. The potential of conserving non-cropped land as a model in agro-ecosystem can be proved vital, through these agri-environment scheme models of conservation pollinators in the agriculture landscape can go a long way to inoculate pollinators naturally [109]. Mostly, pollinators are transported over long distances for the purpose of pollination [110]. They are also transported outside of their natural distribution range (e.g. African honey bees into Brazil, European bumble bees into Australia, Asia, and South America) [111].

Best management practices (BMP), similar to Good Agricultural Practice (GAP) should be promoted by the FAO in apiaries that need to be developed that respect local differences in beekeeping and hive management at the country level. There should be non-compulsive suggestions have been put forward overall lacking international harmonization [112]. In this perspective resistant stock of bees against parasitic mites is to be developed, identify the locally adapted stock of bees, instrumental insemination in bees, selection and managing miticide resistance in bees, etc.

Through collective approaches either for native and introduced bee species, whether solitary or social, requires the correct balance of water, flora hosts that offer sufficient pollen and nectar of the correct types [113], nest building materials (leaves, resin, sap, gums, floral oils, essential oils, bark, plant trichomes, old mouse nests, snail shells, mud, sand, pebbles), and nesting substrates [114] to survive as adults and rear their larval broods (Table 3) [115].

### Table 3. Pollinators and resource requirements

| S. no. | Pollinator group | Resource function | Resource |
|--------|------------------|-------------------|----------|
| 1. | Honey bees, bumble bees | Nesting, roosting sites, or substrates | Cavities (underground, hollow trees) |
| 2. | Nonsocial bees, wasps | Nesting sites or substrates | Bare ground, vertical cliffs or ditch bank, adobe walls |
| 3. | Bumble bees | Nesting sites | Rodent, mouse nests |
| 4. | Flies | Adult food | Pollen, nectar |
| 5. | Leafcutter bees, mason bees | Building materials | Leaves cut into pieces or masticated |
| 6. | Orchid bees | Pheromones | Essential oils, such as monoterpenoids collected by males |
| 7. | Ants | Adult, larval food | Nectar, honeydew, insect prey |

### 6. Limitations that restrict the pollinator-plant interaction

Deforestation and habitat changes have shown an adverse effect on insect pollinators, seed predators, decomposers, and parasitoids, which are highly susceptible to these changes. The success of plant reproduction may be sensitive to the loss of pollinators [74, 116, 117]. Some the evidence suggests that pollinator populations are declining worldwide [74]. These changes result in the destruction...
of food sources, nesting, oviposition, resting, and mating sites [95]. The increase in population pressure and urbanization of wild and agricultural lands has disrupted the habitat of wild pollinators viz., moths [118], butterflies [119], and bees [70, 71, 120, 121] and managed pollinators experienced sudden colony losses [122]. With the increased demand for food crops and higher productivity by use of either plant production or plant protection chemicals has killed the pollinators directly, and eradicated alternative pollen sources from their natural forage species [123, 124]. The pollination host range of honeybees is wide, but they do not pollinate all types of the crop with equal efficiency, are not active under all climatic conditions [125]. Whereas, some of the bees have the ability to pollinate some crops at a higher level of efficiency, with their lower population densities, and with greater independence of climatic conditions [21, 126].

Database of wild pollinator populations and communities is one of severe lack of long term planning and evaluation of their valuation in much of the world, especially for invertebrate pollinators [127–129]. Such as European red List of bees, 57% of the European bee species were categorized as “data deficient”; butterflies and moths from parts of Africa that are described at threatened status also reported in the literature [130–132].

Emerging risks such as diseases, invasive alien species, pathogens, etc., threaten the pollinators, there should be phytosanitary and preventive measures that could be accompanied for the effective response to these emerging risks. Few regions in the world (parts of Australia, Seychelles), that are not affected by the ectoparasitic mite, Varroa destructor, the most detrimental honey bee pest [82, 133, 134]. These mites also act as a vector for a number of bee viruses, which might spill over to wild bee species [135].

7. Conclusion and future prospect of pollinators

Sustainable agriculture requires reliable pollinators, but a shortage of pollinators could not be strongly evidenced for food crisis or pollination crisis. Long-term data deficient on the pollinators’ population should be noted and there is no evidence of their decline over time, neither there is a framed definition to label pollinator crisis universally on that frame. The honeybee is a valuable pollinator to perform an important pollination function in the ecosystem. The decline in a number of managed pollinators in the system is due to some of the reasons such as introduced parasites and pathogens. There is a need for time to be compatible with and comprehensive management strategy of crop pollination for sustainable agriculture. Pollinators require to be managed through augmentation or conservation as needed to study their biology and ecology. Several studies that show the declining bee population poses a threat to global food security. Nesting habitat must be provided whether as a soil bed of a more or less special nature, or as stumps of trees and logs, or as rodent burrows for bumbles. Conservation of native pollinator habitat can be enhanced by changes in land use management strategies viz., non-cultivated patches of ground, setting up parks or protected areas for wildlife, flora, and fauna both at public and private areas. There should be a policy for arable, non-arable, and along with the roadside land that could facilitate the planting of wild plant flora which encourages pollinator populations. There should be judicious and timely use of pesticides that should ensure the protection of pollinators. There should be a crop pollination plan for all pollinator-dependent crops that must be included in the national or state crop production strategies. Farmer’s awareness camps should be organized in the rural areas about crop pollination and the role of pollinators should be described, so that there may be a change in plant protection chemicals patterns.
Author details

Mukesh Nitharwal¹*, Rashmi Rolania², Hanuman Singh Jatav¹, Kailash Chandra¹, Mudassar Ahmed Khan¹, Subhita Kumawat¹, Sanjay Kumar Attar¹ and Shish Ram Dhaka¹

1 S.K.N. Agriculture University, Jobner, India
2 University of Rajasthan, Jaipur, India

*Address all correspondence to: mnitharwal14@gamil.com

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References

[1] Kearns CA, Inouye DW. Pollinators, flowering plants, and conservation biology. Bioscience. 1997;47:297-307

[2] Ollerton J et al. How many flowering plants are pollinated by animals? Oikos. 2011;120:321-326

[3] Cox PA, Elmqvist T. Pollinator extinction in the Pacific Islands. Conservation Biology. 2000;14:1237-1239

[4] Klein A-M, Vaissière B, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, et al. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B. 2007;274:303-313

[5] Gallai N, Salles JM, Settele J, Vaissiere BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics. 2009;68:810-821

[6] Barfield A, Bergstrom J, Ferreira S. An Economic Valuation of Pollination Services in Georgia. Birmingham: Southern Agricultural Economics Association; 2012

[7] Jian D, Chen WF. Economic value of insect pollination for fruits and vegetables in China. Acta Entomologica Sinica. 2011;54(4):443-450

[8] Aizen MA, Morales CL, Morales JM. Invasive mutualists erode native pollination Webs. PLoS Biology. 2008;6(2):e31. DOI: 10.1371/journal.pbio.0060031

[9] Aizen MA, Harder LD. The Global stock of domesticated honey bees is growing slower than agricultural demand for pollination. Current Biology. 2009;19:1-4

[10] Kevan PG, Baker HG. Insects as flower visitors and pollinators. Annual Review of Entomology. 1983;28:407-453

[11] Losey JE, Vaughan M. The economic value of ecological services provided by insects. Bioscience. 2006;56:311-323

[12] Robbins CS, Sauer JR, Greenberg RS, Droge S. Population declines in North American birds that migrate to the neotropics. Proceedings of the National Academy of Sciences USA. 1989;86(19):7658-7662

[13] Free JB. Insect Pollination of Crops. London: Academic Press; 1970. pp. 544

[14] McGregor SE. Insect pollination of cultivated crop plants. USDA Handbook 496. Washington: US Department of Agriculture, Agricultural Research Services; 1976. pp. 411

[15] Pesson P, Louveaux J, editors. Pollination et Productions Vegetables. Paris: INRA; 1984

[16] Free JB. Insect Pollination of Crops. 2nd ed. London, UK: Academic Press; 1993

[17] Cane JH. Alkali Bee. In: Shimanuki H, Flottum K, Harman A, editors. ABC & XYZ of Bee Culture. 41st ed. A.I. Root Company: Medina, OH; 2007. pp. 11-12

[18] Elfattah MSA. Sustainable use of leafcutting bee hives for alfalfa pollination. Munis Entomology & Zoology. 2010;5(2):807-811

[19] Mader E, Spivak M, Evans E. Managing Alternative Pollinators: A Handbook for Beekeepers, Growers, and Conservationists. Beltsville: Sustainable Agriculture Network; 2010. pp. 167

[20] Richards KW. Alfalfa leafcutter bee management in Western Canada. Ottawa: Agriculture Canada; 1984. pp. 51

[21] Torchio PF. Use of non-honey bee species as pollinators of crops. Proceedings of the Entomological Society of Ontario. 1987;118:111-124
[22] Plowright RC, Laverty TM. Bumble bees and crop pollination in Ontario. Proceedings of the Entomological Society of Ontario. 1987;118:155-160

[23] Pellmyr O. Yuccas, yucca moths, and coevolution: A review. Annals of the Missouri Botanical Garden. 2003; 90:35-55

[24] Kevan PG. Pollination by animals and angiosperm biosystematics. In: Grant WF, editor. Plant Biosystematics. Toronto: Academic Press; 1984. pp. 271-292

[25] Tepedino VJ. The pollination efficiency of the squash bee (Peponapis pruinosa) and the honey bee (Apis mellifera) on summer squash (Cucurbita pepo). Journal of the Kansas Entomological Society. 1981;54:359-377

[26] Parker FD, Frohlich DR. Studies on management of the sunflower leafcutter bee Eumegachile pugnata (Say) (Hymenoptera: Megachilidae). Journal of Apicultural Research. 1985; 24:125-131

[27] Sanchez D. Ground nesting bee best for blueberries. Agricultural Research. 1989;37(6):16-17

[28] Bosch J, Kemp W. How to Manage the Blue Orchard Bee as an Orchard Pollinator. Beltsville: Sustainable Agriculture Network; 2001. 88 pp. Available from: www.sare.org/publications/bee/blue_orchard_bee.pdf

[29] Torchio PF. Diversification of pollination strategies for U.S. crops. Environmental Entomology. 1990; 19(6):1649-1656

[30] Torchio PF. Osmia ribifloris a native bee species developed as a commercially managed pollinator of highbush blueberry. Journal of the Kansas Entomological Society. 1990;63:427-436

[31] Syed RA. Studies on oil palm pollination by insects. Bulletin of Entomological Research. 1978;69:213-224

[32] Pouvreau A. Pollinisation du cacotier, du papayer, etucafeier. In: Pesson P, Louveaux J, editors. Pollination et Productions Vegetales. Paris: INRA; 1984. pp. 195-208

[33] Kral R. A revision of Asimina and Deeringothamus (Annonaceae). Brittonia. 1960;12:233-278

[34] Norman EM, Clayton D. Reproductive biology of two Florida pawpaws; Asimina ovata and A pygmaea. Bulletin of the Torrey Botanical Club. 1986;113:16-22

[35] Grant V. The pollination of Calycanthus occidentalis. American Journal of Botany. 1950;37:294-297

[36] Dilley JD. The radiation of Calochortus: Generalist flowers moving through a mosaic of potential pollinators. Oikos. 2000;89:209-222

[37] Grant KA, Grant V. Flower Pollination in the Phlox Family. New York: Columbia University Press; 1965

[38] Bloch D, Werdenberg N, Erhardt A. Pollination crisis in the butterfly pollinated, wild carnation Dianthus carthusianorum? New Phytologist. 2006;169:699-706

[39] Ehrlich PR, Hanski I, editors. On the Wings of Checkerspots: A Model System for Population Biology. New York: Oxford University Press; 2004

[40] Halpern S. Four Wings and a Prayer: Caught in the Mystery of the Monarch Butterfly. New York: Pantheon; 2001

[41] Boggs CL, Smiley JT, Gilbert LE. Patterns of pollen exploitation by Heliconius butterflies. Oecologia. 1981;48:284-289

[42] Estrada C, Jiggins CD. Patterns of pollen feeding and habitat preference
among Heliconius species. Ecological Entomology. 2002;27:448-456

[43] Pellmyr O, Thompson JN, Brown JM, Harrison RG. Evolution of pollination and mutualism in the yucca moth lineage. American Naturalist. 1996;148:827-847

[44] Gregory D. Hawkmoth pollination in the genus Oenothera. Aliso. 1963-1964;5:357-419

[45] Lin S, Bernardello G. Flower structure and reproductive biology in Aspidosperma quebracho-blanco (Apocynaceae), a tree pollinated by deceit. International Journal of Plant Sciences. 1999;160:869-878

[46] Little KJ, Dieringer G, Romano M. Pollination ecology, genetic diversity and selection on nectar spur length in Platanthera lacera (Orchidaceae). Plant Species Biology. 2005;20:183-190

[47] Raguso RA, Henzel C, Buchmann SL, Nabhan GP. Trumpet flowers of the Sonoran Desert: Floral biology of Peniocereus cacti and Sacred Datura. International Journal of Plant Sciences. 2003;164:877-892

[48] Ananthakrishnan TN. The role of thrips in pollination. Current Science (Bangalore). 1993;65(3):262-264

[49] Kirk WDJ. Thrips and pollination biology. In: Ananthakrishnan TN, Raman A, editors. Dynamics of Insect-Plant Interaction. New Delhi: Oxford and IBH; 1988. pp. 129-135. [Chapter 10]

[50] Lewis T. Thrips: Their Biology, Ecology and Economic Importance. London and New York: Academic Press; 1973

[51] Terry I. Host selection, communication, and reproductive behaviour. In: Lewis T, editor. Thrips as Crop Pests. London: CAB International; 1997. pp. 64-118

[52] Terry I. Thrips and weevils as dual, specialist pollinators of the Australian cycad Macrozamia communis (Zamiaceae). International Journal of Plant Sciences. 2001;162:1293-1305

[53] Albrecht M, Schmid B, Hautier Y, Mueller CB. Diverse pollinator communities enhance plant reproductive success. Proceedings of the Royal Society B-Biological Sciences. 2012;279:4845-4852

[54] Davies TJ, Barraclough TG, Chase MW, Soltis PS, Soltis DE, Savolainen V. Darwin's abominable mystery: insights from a supertree of the angiosperms. Proceedings of the National Academy of Sciences, USA. 2004;101(7):1904-1909

[55] Labandeira CC, Dilcher DL, Davis DR, Wagner DL. Ninety-seven million years of angiosperm-insect association: Paleobiological insights into the meaning of coevolution. Proceedings of the National Academy of Sciences USA. 1994;91:12278-12282

[56] Simpson BB, Neff JL. Evolution and diversity of floral rewards. In: Jones CE, Little RJ, editors. Handbook of Experimental Pollination Biology. New York: Van Nostrand Reinhold Co.; 1983. pp. 142-159

[57] Bond WJ. Do mutualisms matter? Assessing the impact of pollinator and disperser disruption on plant extinction. Philosophical Transactions of the Royal Society of London Series B—Biological Sciences. 1994;344:83-90

[58] Ollerton J. Pollinator diversity: Distribution, ecological function, and conservation. In: Futuyma DJ, editor. Annual Review of Ecology, Evolution, and Systematics. Vol. 48. 2017. pp. 353-376

[59] Wilcock C, Neiland R. Pollination failure in plants: Why it happens and when it matters. Trends in Plant Science. 2002;7:270-277
[60] Ratto F, Simmons BI, Spake R, Zamora-Gutierrez V, MacDonald MA, Merriman JC, et al. Global importance of vertebrate pollinators for plant reproductive success: A meta-analysis. Frontiers in Ecology and the Environment. 2018;16(2):82-90

[61] Fort H. Quantitative predictions of pollinators’ abundances from qualitative data on their interactions with plants and evidences of emergent neutrality. Oikos. 2014;123:1469-1478

[62] Kaiser-Bunbury CN, Muff S, Memmott J, Muller CB, Caflisch A. The robustness of pollination networks to the loss of species and interactions: A quantitative approach incorporating pollinator behaviour. Ecology Letters. 2010;13:442-452

[63] Memmott J, Craze PG, Waser NM, Price MV. Global warming and the disruption of plant-pollinator interactions. Ecology Letters. 2007;10:710-717

[64] Roulston TH, Cane JH. Pollen nutritional content and digestibility for animals. Plant Systematics and Evolution. 2000;222:187-209

[65] Muller A, Kuhlmann M. Pollen hosts of western palaeartic bees of the genus *Colletes* (Hymenoptera: Colletidae): The Asteraceae paradox. Biological Journal of the Linnean Society. 2008;95:719-733

[66] Viana BF, Boscolo D, Neto EM, Lopes LE, Lopes AV, Ferreira PA, et al. How well do we understand landscape effects on pollinators and pollination services? Journal of Pollination Ecology. 2012;7:31-41

[67] Nicholls E, Hempel de Ibarra N. Assessment of pollen rewards by foraging bees. Functional Ecology. 2017;31:76-87

[68] Ruedenauer FA, Spaethe J, Leonhardt SD. How to know which food is good for you: Bumblebees use taste to discriminate between different concentrations of food differing in nutrient content. Journal of Experimental Biology. 2015;218:2233-2240

[69] Armbruster WS. The specialization continuum in pollination systems: Diversity of concepts and implications for ecology, evolution and conservation. Functional Ecology. 2017;31:88-100

[70] Cameron SA, Lozier JD, Strange JP, Koch JB, Cordes N, Solter LF, et al. Patterns of widespread decline in North American bumble bees. Proceedings of the National Academy of Sciences of the United States of America. 2011;108:662-667

[71] Cameron SA et al. Patterns of widespread decline in North America bumble bee. Proceedings of the National Academy of Sciences of the United States of America. 2011;108:662-667

[72] Goulson D, Lye GC, Darvill B. Decline and conservation of bumble bees. Annual Review of Entomology. 2009;53:191-210

[73] Kerr JT, Pindar A, Galpern P, Potts SG, Roberts SM, Rasmont P, et al. Climate change impacts on bumblebees converge across continents. Science. 2015;349:177-180

[74] Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. Global pollinator declines: Trends, impacts and drivers. Trends in Ecology and Evolution. 2010;25:345-353

[75] Aizen MA, Harder LD. Expanding the limits of the pollen limitation concept: Effects of pollen quantity and quality. Ecology. 2007;88:271-281

[76] Morse RA, Flottum K. Honey Bee Pests, Predators, and Diseases. 3rd ed. Medina, Ohio: The A. I. Root Company; 1997. 718 pp

[77] Barrett DP. History of American foulbrood in Michigan: Period
1927-1954. Gleanings in Bee Culture. 1955;83:460-461

[78] Evans JD. Diverse origins of tetracycline resistance in the honey bee bacterial pathogen Paenibacillus larvae. Journal of Invertebrate Pathology. 2003;83:46-50

[79] Gary NE Jr, Page RE, Morse RA, Henderson CE, Nasr ME, Lorenzen K. Comparative resistance of honey bees (Apis mellifera L.) from Great Britain and United States to infestation by tracheal mites (Acarapis woodi). American Bee Journal. 1990; 130:667-669

[80] Kevan PG, Greco CF, Belaoussoff S. Log-normality of biodiversity and abundance in diagnosis and measuring of ecosystemic health: Pesticide stress on pollinators on blueberry heaths. Journal of Applied Ecology. 1997;34:1122-1136

[81] Nasr ME, Otis GW, Scott-Dupree CD. Resistance to Acarapis woodi by honey bees (Hymenoptera: Apidae): Divergent selection and evaluation of selection progress. Journal of Economic Entomology. 2001;94(2):332-338

[82] Oldroyd BP, Wongsiri S. Asian Honey Bees: Biology, Conservation, and Human Interactions. Cambridge, Mass: Harvard University Press; 2006

[83] Decourtye A, Devillers J, Genecque E, Le Menach K, Budzinski H, Cluzeau S, et al. Comparative sublethal toxicity of nine pesticides on olfactory performances of the honeybee Apis mellifera. Pesticide Biochemistry and Physiology. 2004;78:83-92

[84] Desneaux N, Decourtye A, Delpuech J. The sublethal effects of pesticides on beneficial arthropods. Annual Review of Entomology. 2007;52:81-106

[85] Johansen CA, Mayer DF. Pollinator Protection. A Bee and Pesticide Handbook. Cheshire, Conn: Wicwas Press; 1990

[86] Thompson HM. Behavioural effects of pesticides use in bees—Their potential for use in risk assessment. Ecotoxicology. 2003;12:317-330

[87] Losey JE, Rayor LS, Carter ME. Transgenic pollen harms monarch larvae. Nature. 1999;399:214

[88] Malone LA, Pham-Delègue MH. Effects of transgene products on honey bees (Apis mellifera) and bumblebees (Bombus sp.). Apidologie. 2001;32:287-304

[89] O’Callaghan M, Glare TR, Burgess EPJ, Malone LA. Effects on plants genetically modified for insect resistance on non-target organisms. Annual Review of Entomology. 2005;50:271-292

[90] National Research Council (NRC). Status of Pollinators in North America. Washington, DC: The National Academies Press; 2007

[91] Kevan PG. Pollination: Plinth, pedestal, and pillar for terrestrial productivity. The why, how, and where of pollination protection, conservation, and promotion. In: Stubbs CS, Drummond FA, editors. Bees and Crop Pollination—Crisis, Crossroads, Conservation, Proceedings, Entomological Society of America. Lanham, Md.: Thomas Say Publications in Entomology; 2001. pp. 7-68

[92] Kearns CA, Inouye DW, Waser NM. Endangered mutualisms: The conservation of plant-pollinator interactions. Annual Review of Ecology and Systematics. 1998;29:83-112

[93] Gess FW, Gess SK. Effects of increasing land utilization on species representation and diversity of aculeate
wasps and bees in the semi-arid areas of southern Africa. In: LaSalle J, Gauld ID, editors. Hymenoptera and Biodiversity. Wallingford: CAB International; 1993. pp. 83-113

[94] Goulson D. Effects of introduced bees on native ecosystems. Annual Review of Ecology and Systematics. 2003;34:1-26

[95] Kevan PG. Pollinators as bioindicators of the state of the environment: Species, activity and diversity. Agriculture, Ecosystems and Environment. 1999;74:373-393

[96] Vinson SB, Frankie GW, Barthell J. Threats to the diversity of solitary bees in a neotropical dry forest in Central America. In: LaSalle J, Gauld ID, editors. Hymenoptera and Biodiversity. Oxon: CAB International; 1993. pp. 53-82

[97] Forister ML, Shapiro AM. Climatic trends and advancing spring flight of butterflies in lowland California. Global Change Biology. 2003;9:1130-1135

[98] Davis AR. Influence of elevated CO\textsubscript{2} and ultraviolet-B radiation levels on floral nectar production: A nectary-morphological perspective. Plant Systematics and Evolution. 2003;238:169-181

[99] Collins SA, Robinson GE, Conner JK. Foraging behavior of honey bees (Hymenoptera: Apidae) on \textit{Brassica nigra} and \textit{B. rapa} grown under simulated ambient and enhanced UV-B radiation. Annals of the Entomological Society of America. 1997;90(1):102-106

[100] Sampson BJ, Cane JH. Impact of enhanced ultraviolet-B radiation on flower, pollen, and nectar production. American Journal of Botany. 1999;86:108-114

[101] Crozier L. Winter warming facilitates range expansion: Cold tolerance of the butterfly

\textit{Atalopedescampetris}. Oecologia. 2003;135:648-656

[102] Walther GR. Plants in a warmer world. Perspectives in Plant Ecology, Evolution and Systematics. 2004;6:169-185

[103] Wilson R, Gutiérrez D, Gutiérrez J, Martínez D, Agudo R, Monserrat VJ. Changes to the elevational limits and extent of species ranges associated with climate change. Ecology Letters. 2005;8(11):1138

[104] Bhagwat S. Ecosystem services and sacred natural sites: Reconciling material and non-material values in nature conservation. Environmental Values. 2009;18:417-427

[105] Blicharska M, Mikusiński G, Godbole A, andSarnaik J. Safeguarding biodiversity and ecosystem services of sacred groves—Experiences from northern Western Ghats. International Journal of Biodiversity Science, Ecosystem Services & Management. 2013;9:339-346

[106] Bodin O, Tengo M, Norman M, Lundberg J, Elmqvis T. The value of small size: Loss of forest patches and ecological thresholds in Southern Madagascar. Ecological Applications. 2006;16:440-451

[107] ICCA. Bio-cultural Diversity Conserved by Indigenous Peoples & Local Communities—Examples & Analysis. 2012. Available from: http://www.cenesta.org/wp-content/uploads/2015/10/publication-ceesp-briefing-note-10-companion-en.pdf

[108] Batary P et al. Effect of conservation management on bees and insect-pollinated grassland plant communities in three European countries. Agriculture, Ecosystems and Environment. 2010;136:35-39

[109] Morandin LA, Winston ML. Pollinators provide economic incentive
Pollinators: Their Relevance in Conservation and Sustainable Agro-Ecosystem
DOI: http://dx.doi.org/10.5772/intechopen.100531

to preserve natural land in agroecosystems. Agriculture Ecosystems and Environment. 2006;116:289-292

[110] Cavigli I, Daughenbaugh KF, Martin M, Lerch M, Banner K, Garcia E, et al. Pathogen prevalence and abundance in honey bee colonies involved in almond pollination. Apidologie. 2016;47:251-266

[111] Moritz RF, Härtel S, Neumann P. Global invasions of the western honeybee (Apis mellifera) and the consequences for biodiversity. Ecoscience. 2005;12(3):289-301

[112] Ritter W. Good beekeeping practice—Knowledge in a Nutshell. Bees for Development Journal. 2013;107:3-5

[113] Roulston TH, Cane JH, Buchmann SL. What governs the protein content of pollen grains: pollinator preferences, pollen-pistil interactions, or phylogeny? Ecological Monographs. 2000;70:617-643

[114] Shepherd MD, Buchmann SL, Vaughan M, Black SH. Pollinator Conservation Handbook: A Guide to Understanding, Protecting, and Providing Habitat for Native Pollinator Insects. The Xerces Society in Association with The Bee Works. Portland: The Xerces Society; 2003. 145 pp

[115] Michener CD. Bees of the World. Baltimore and London: The Johns Hopkins University Press; 2000. 913 pp

[116] Burkle L, Marlin J, Knight T. Plant-pollinator interactions over 120 years: Loss of species, co-occurrence, and function. Science. 2013;80:1611-1615

[117] González-Varo JP, Biesmeijer JC, Bommarco R, Potts SG, Schweiger O, Smith HG, et al. Combined effects of global change pressures on animal-mediated pollination. Trends in Ecology and Evolution. 2013;28:524-530

[118] Fox R. The decline of moths in Great Britain: A review of possible causes. Insect Conservation and Diversity. 2012;6:5-19

[119] Maes D, Van Dyck H. Butterfly diversity loss in Flanders (north Belgium): Europe’s worst case scenario? Biological Conservation. 2001;99:263-276

[120] Biesmeijer JC et al. Parallel declines in pollinators and insect pollinated plants in Britain and the Netherlands. Science. 2006;313:351-354

[121] Kosior A et al. The decline of the bumble bees and cuckoo bees (Hymenoptera: Apidae: Bombini) of western and central Europe. Oryx. 2007;41:79-88

[122] van Engelsdorp D et al. A survey of honey bee colony losses in the U.S., fall 2007 to spring 2008. PLoS ONE. 2008;3:e4071

[123] Kevan PG. Pollination and environment conservation. Environmental Conservation. 1975;2:222-227

[124] Kevan PG. Pollination and flower visiting insects and the management of beneficial and harmful insects and plants. In: Hussein MY, Ibrahim AG, editors. Biological Control in the Tropics. Serdang, Selangor, Malaysia: University Pertanian Malaysia; 1986. pp. 439-452

[125] Kevan PG, editor. Alternative pollinators for Ontario’s crops. Proceedings of the Entomological Society of Ontario. 1987;118:109-170

[126] Boyle-Makowski RMD. The importance of native pollinators in cultivated orchards: Their abundance and activities in relation to weather conditions. Proceedings of the Entomological Society of Ontario. 1987;118:125-141
[127] Aguilar R, Ashworth L, Galetto L, Aizen MA. Plant reproductive susceptibility to habitat fragmentation: Review and synthesis through a meta-analysis. Ecology Letters. 2006;9:968-980

[128] Montero-Castano A, Vila M. Impact of landscape alteration and invasions on pollinators: A meta-analysis. Journal of Ecology. 2012;100:884-893

[129] Morales CL, Traveset A. A meta-analysis of impacts of alien vs. native plants on pollinator visitation and reproductive success of co-flowering native plants. Ecology Letters. 2009;12:716-728

[130] Edge DA, Mecenero S. Butterfly conservation in Southern Africa. Journal of Insect Conservation. 2015;19:325-339. DOI: 10.1007/s10841-015-9758-5

[131] Mecenero S, Ball JB, Edge DA, et al. Conservation Assessment of Butterflies of South Africa. Lesotho and Swaziland: Red List and Atlas; 2013

[132] Nieto A, Roberts SPM, Kemp J, Rasmont P, Kuhlmann M, Biesmeijer JC, et al. European Red List of Bees. Luxembourg: Publication Office of the European Union; 2014

[133] Anderson DL, Trueman JWH. Varroajacobsoni (Acari: Varroidae) is more than one species. Experimental and Applied Acarology. 2000;24:165-189

[134] Sammataro D, Gerson U, Needham G. Parasitic mites of honey bees: Life history, implications, and impact. Annual Review of Entomology. 2000;45:519-548

[135] McMahon DP, Fürst MA, Caspar J, Theodorou P, Brown MJF, Paxton RJ. A sting in the spit: Widespread cross-infection of multiple RNA viruses across wild and managed bees. The Journal of Animal Ecology. 2015;84:615-624