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 restraints 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 pant 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 about52.2 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 (*Passifloraedulis* 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 laboriosa* (Fabr.)) [27], and *Osmia ribiflloris* 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 pruninosa* 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.	
	Trichotinius 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).

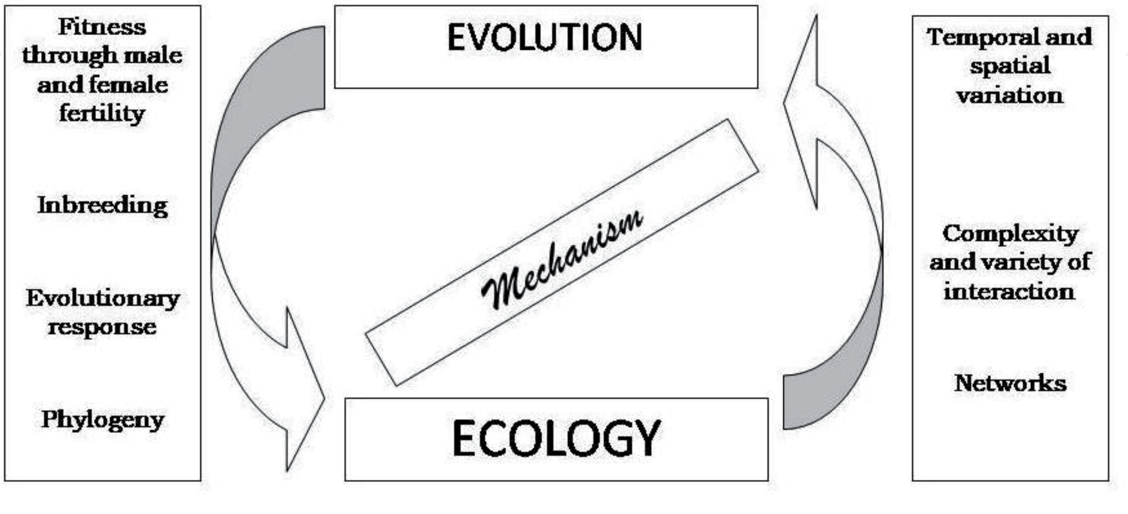

Figure 1.
Conceptual representation of the interplay between ecology and evolution in the study of plant-pollinator interactions.

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

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, nectare
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

Table 3.
Pollinators and resources requirements.

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].

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 Nitharwal[1*], Rashmi Rolania[2], Hanuman Singh Jatav[1], Kailash Chandra[1], Mudassar Ahmed Khan[1], Subhita Kumawat[1], Sanjay Kumar Attar[1] and Shish Ram Dhaka[1]

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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