

The global decline of pollination services

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Abstract. *Pollination, the transfer of pollen from anthers to stigmas achieved mainly by animals, is vital to plant reproductive biology in almost all terrestrial ecosystems. This process is critical for the conservation and sustainability of the world's flora and fauna. The decline of pollination services caused by chemicals, pests, extreme weather, habitat destruction and/or fragmentation, reduces the reproductive output of plants. In extreme cases this could cause extinction of plants and animals and ultimately lead to changes in the landscape and in ecosystem function. Conservation concerns for pollination have started to take on a greater profile over the past decade. However, there is still a need for policies that are sensitive to the importance of pollinators. More intensive efforts are required to widen the general understanding of the essential value of plant-pollinator interactions for agricultural and natural resource conservation.*

INTRODUCTION

Human life on Earth depends on several key biologically based processes called *ecosystem services*. These services maintain the diversity, abundance, and activities of organisms, as well as the production of goods upon which human life depends, e.g. food, fiber, forage, timber, biomass, fuels etc. In addition, ecosystem services include ecological functions such as atmospheric, aquatic, marine, and soil, mineral, and nutrient recycling. They also involve the cleansing of pollutants from the environment. All these involve the interplay of living organisms; the physical environment and pollination is one of these key processes.

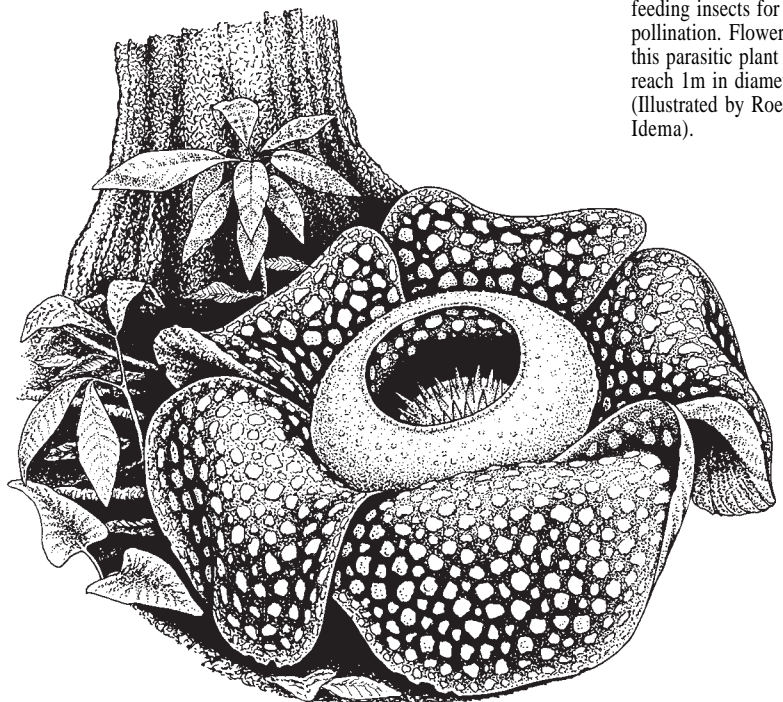
Pollination links the productivity of plants and animals in almost all terrestrial ecosystems. In most cases pollination is effected by animals, particularly bees and other insects. Simply put, pollination is the transfer of pollen from anthers to stigmas. It is one of the first events

that leads to fruit and seed production because through pollination the plant's gametes can come together in fertilization. This process is vital to plant reproductive biology, so it is no wonder that there is international consensus that pollination is critical to the conservation and sustainability of the world's flora and fauna. Moreover, the disruption of pollination can be expected to reduce the reproductive output of plants and could, in extreme cases, cause extinction of plants and animals and lead to changes in the landscape and ecosystem function. Broad-scale perturbations at the ecosystem and landscape levels could result in changes to the vegetation. Some plants' reproductive capacities and relative importance may decline while those of other plants may increase. Thus, changes in food chains would be expected as the animal and plant associations become re-organized. There is grave concern globally among pollination specialists over the extent to which pollination services have been disrupted in all ecosystems, from highly managed agriculture to natural ecosystems. Moreover, it has become evident that pollination in agricultural systems is under severe stress.

Some of the first evidence for the demise of pollination in ecosystems comes from Canada. Salt and Stephen, in the 1940's and 50's, noted that reductions in alfalfa seed production in the Canadian prairies were associated with the enlargement of production fields and the concomitant reduction of field margin habitat for nesting and

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Figure 1. Flowers of *Rafflesia arnoldii* has carrion smell to attract carrion feeding insects for pollination. Flowers of this parasitic plant can reach 1m in diameter (Illustrated by Roelof Idema).





Figures 2-6: 2, Bee worker with pollen on body; 3, *Apis* on *Cereus mandacaru*; 4, *Antigonon*; 5, *Trigona* on *Pilocereus* sp.; 6, *Ceratina* on *Portulaca* sp. All photos courtesy of Rejane Carneiro except *Antigonon* by Dr. Peter Kevan.

pollinating bees. Kevan and co-workers in 1975, 1989, and 1997, documented the effect of the pesticide poisoning of bees on blueberry heaths in New Brunswick. Blueberries and other plants suffered diminished fruit and seed-set, and blueberry growers suffered crop and economic losses. Recently published books, especially the best selling and highly influential *The Forgotten Pollinators* by Buchmann and Nabhan (1996), have presented accumulating evidence that the problem is widespread and becoming increasingly severe. The journal *Conservation Ecology* devoted an entire issue to this matter (<http://www.consecol.org/vol5/iss1>).

Associations between economists and researchers in pollination are needed so that an evaluation can be made of the costs of declining pollinators in terms of food prices. Rigorous modeling for such studies is in its infancy. Existing simple models, based on costs and supply and demand, suggest that farmers and consumers could both suffer while the economic situations of the intermediaries remain neutral or improve. In short, a commodity in short supply, as a result of the scarcity of pollinators in one of several important regions of production, would command a higher price for the consumer. The higher prices would benefit growers who had good crops in regions without the pollinator shortage, but adversely affect growers where pollinators were scarce. The intermediaries maintain their profit margins according to the amount of produce and consumer-willingness to pay the higher prices.

Conservation concerns for pollination have started to take on a greater profile in the past decade. In 1995, the Convention of Biological Diversity (CBD), in the Conference of Parties Number 2 (COP2), introduced an agricultural biodiversity policy (designated Decision II/15). On that occasion, pollination was considered to be of major importance for the maintenance of agricultural biodiversity. In 1998 an international workshop was convened at the University of São Paulo, Brazil. It brought together 61 specialists from 15 countries and 4 international organisations to discuss the thematic areas that should lead the way to pollinator conservation. The themes are described in the “São Paulo Declaration on Pollinators” (<http://www.fao.org/biodiversity/docs/pdf/Pollinators.PDF>). A book documenting the scientific basis for the declaration has also been published.

The São Paulo Declaration was approved in the year 2000 by COP5 and validated by 187 countries. On that occasion, the results of the previous deliberations (designated Decision V/5) of the CBD were elaborated and the “International Initiative for the Conservation and Sustainable Use of the Pollinators” was initiated. That initiative (designated by the acronym IPI and described at <http://www.biodiv.org/programmes/areas/agro/pollinators.asp>), with its headquarters at the Food & Agricultural Organization of the United Nations (FAO) in Rome, is promoting, throughout the entire world, a coordinated action with respect to:

1. Monitoring the decline of pollinators, the causes and the impact on pollination services;
2. The reduction of the taxonomic impediment to pollinator identification; i.e. the fact that research institutions and universities are eliminating taxonomist positions and/or dropping courses in insect and plant taxonomy with the result that there are fewer and fewer people being trained in taxonomy.
3. Evaluation of the economic value of pollinators and the consequences of their decline in agriculture;
4. The conservation, restoration, and sustainable use of the diversity of pollinators in agriculture and related ecosystems.

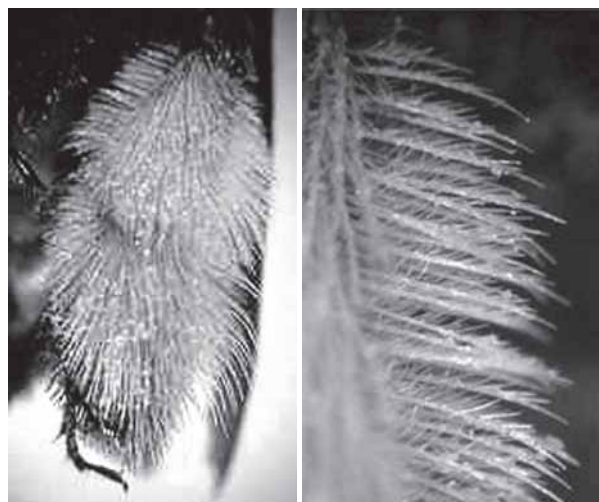
Subsequently, the Species Survival Commission of The World Conservation Union (IUCN) established a “Declining Pollination Task Force” to address the problems facing natural systems (temporarily at www.uoguelph.ca/~iucn). The International Network of Expertise for Sustainable Pollination (INESP) (www.uoguelph.ca/~inesp) is being formed to provide the capacity for scientists to share their knowledge and to provide reliable, up-to-date information to such organizations as the FAO, IUCN, and regional organizations concerned with pollination and pollinators. The African Pollinators Initiative (API) held its first set of meetings in 2002 and the Brazilian Pollinators

Initiative (BPI) was founded in September of the same year at the V Encontro sobre Abelhas at Ribeirão Preto, São Paulo. Plans are underway for more South American country initiatives as well as for others in Europe. The North American Pollinator Protection Campaign (NAPPC: <http://www.napcc.org>) grew from The Forgotten Pollinators Campaign. NAPPC has an active steering committee and is actively promoting pollinators, from bats to butterflies, birds, and bees from Mexico to Canada. An international workshop on “Best Management Practices for Pollinator Conservation” took place in South Africa in May, 2003.

At the local level there are numerous activities underway. For capacity enhancement, pollination courses are presented in various places (Mexico 1999, Costa Rica 2002, Brazil 2003). Projects to assess the variety of reasons for the decline of pollinators and the impact on pollination services are on-going in many places, for example in California (US), Costa Rica, Bahia (Brazil), Germany, UK, Canada, Nepal, and Israel. There are outreach programmes on the value of pollination directed to fruit growers in Canada, Brazil, Nepal, and parts of India and China. In Brazil, Canada, the US and elsewhere, there are projects on the management and conservation of pollinating bees in agriculture.

WHAT'S THE BUZZ ABOUT?

To recognize the importance of all this activity around the world and how it will impact future research, management and conservation of pollination, a better understanding of pollination processes and the cause of their disruption is sorely needed. Although pollination biology has scientific roots that span two centuries, much remains unknown. Herein, we focus briefly on the risks of disruption to pollination services in natural and agricultural ecosystems and how changes in plant-pollinator interactions may affect ecosystem functioning through habitat destruction, fragmentation and toxic chemicals.



Pollination is achieved by abiotic means (wind, water or gravity) or by biotic means (animals). Plants pollinated by wind or water would not be adversely affected by declines in animal pollinators of other plants, but many such plants still have animal associations with fruit and seed dispersal. Pollinators are anthophiles, or flower visitors. The degree to which pollinators and their flowers are specialized is highly variable. A few plants seem to be dependent for pollination on only a few species of pollinators, whereas others attract a wide array of species. Similarly, there are specialized pollinators that visit the flowers of only a few species of plants, and others that show little specialization. Anthophiles may or may not bring about pollination. Some anthophiles illegitimately remove the resources sought by pollinators or eat pollen needed in abiotic pollination. Other anthophiles may be innocuous and merely rest in flowers or glean residual resources after pollination is over.

The diversity of anthophiles probably numbers in the millions of species; however, demonstrating that an anthophile is a pollinator requires care. A pollinator must visit the flower in such a way, and within such a period, that viable pollen is transferred from anther to stigma. Associated with these requirements are the anatomical and behavioral fit of the pollinator and the flower, the appropriateness of the floral advertisement to the pollinator's sensory capabilities, and the matching of floral resources to the pollinator's needs.

Buchmann & Nabhan (1996) reviewed the number of invertebrate and vertebrate animal species known to be effective pollinators. They estimated that there are more than 1,200 vertebrate species involved in pollination. Roubik (1995) states that there are more than the 100,000 invertebrate pollinator species present in the tropics. It is also estimated that there are around 220,000 species falling within the taxonomic groups dominated by pollinators of flowering plants.

Bees are the most important and highly adapted anthophiles and pollinators. Their mouthparts are especially adapted for imbibing nectar, and their bodies have characteristic plumose hairs for carrying pollen. They are numerous and highly diverse structurally, behaviorally, and taxonomically.

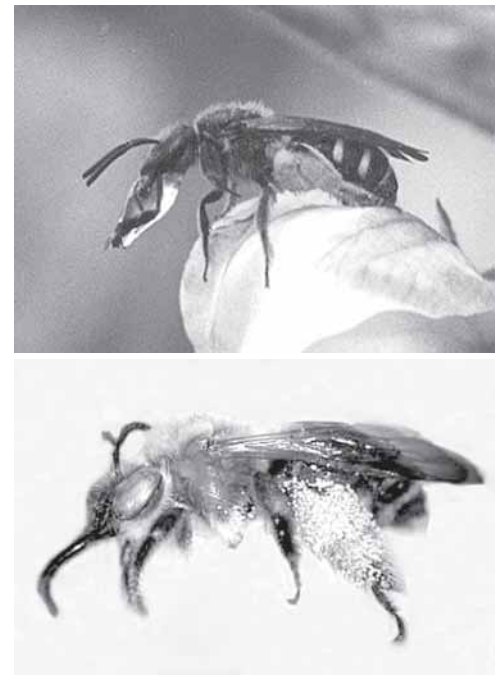


Figure 7 (top).
Lasioglossum sp.
Showing
mouthparts.
By Peter Kevan

Figure 8 (bottom).
Melissoptila with
pollen sac.
By Sylvia Maria
Matsuda

Figure 9 (left).
Bee plumose hairs.
Figure 10 (right).
Close-up.
Photos by Sylvia Maria
Matsuda



The degree of dependence flowering plants have on plant-pollinator interactions for reproductive services varies greatly. The flowers of 90% of plant species are visited by animals that are potential pollinators. Some plants set fruit and seed without the “assistance” of pollinators. Self-pollination is widespread in nature and in crop plants (e.g. soy beans, field beans, peas, sunflowers, and tomatoes). Some can even produce fruit, often seedless (e.g. bananas, pineapples, and some cultivars of grape), without fertilization.

In agricultural ecosystems crop pollination research has demonstrated the importance of pollination. Native, wild, exotic, and managed pollinators play a great role in providing pollination services to agriculture. The monetary value from this service has been estimated at US \$65-70 billion per year in the US. In modern agriculture, a third of agricultural crops that are used as human food and fibre need pollination for seed and fruit-set. Most crops, depending on where they are grown, can be pollinated by one or more of the 25,000 known bee species. According to Buchmann & Nabhan (1996), at least twenty genera of animals other than honeybees provide pollination services to the world’s hundred most important crops, and they collectively pollinate at least as many crop species as do managed

Figures 11-16 (from top to bottom): 11, Hawk moth on *Eucalyptus*; 12, Honey Possum on *Eucalyptus*; 13, *Heliconius* sp. on *Asclepias* flower; 14, Rufous Hummingbird in Monkeyflower; 15, Honeyeater on Green Kangaroo Paw; 16. Bat on *Agave palmari*; All photos courtesy of Carolina Biological Supply Company.

honeybee (*Apis* spp.) colonies. An important issue in pollinator conservation is the increasing recognition of non-honey bees as crop pollinators. These include leafcutting bees, orchard bees, and bumble bees.

ENVIRONMENTAL STRESS & POLLINATION

The reproductive success of half of the world’s plants may be more limited by pollinators than by other resources. Vagaries in weather and various environmental stresses have contributed to the loss of pollinators. Chemicals, particularly pesticides, have had a major impact on the world’s ecosystems, including through their effect on pollination services. The dangers and losses associated with agrochemicals and pollinators are well known with respect to honeybees, especially in agricultural systems, but in natural and semi-natural ecosystems the effects are poorly documented. One of the best documented cases of the demise of pollinators from the wide scale use of agrochemicals comes from New Brunswick, Canada. Native pollinator populations of blueberry fields were severely reduced by the application of Fenitrothion, aimed at spruce budworm infestations in the forests surrounding commercially operated wild blueberry lands. Fenitrothion is highly toxic to bees and pollinator populations were so reduced that there were serious economic losses in the blueberry harvest (Kevan and Imperatriz-Fonseca 2002).

Introduced pests, especially parasitic mites of honeybees, have had major impacts on pollinator availability in agriculture. Native pollinators suffer from diseases, parasites, and predators, but the importance of these factors in the regulation of their populations is unknown. Competition interactions of alien (and sometimes invasive) species with native pollinators have had adverse effects in various parts of the world. For example, the Africanized honeybees which spread into Central America and the feral and managed honeybees in Europe seem to have caused declines in wild bee populations. In Australia, honeybees stealing floral nectar from naturally bird-pollinated flowers seem to have caused reduced seed-set in some plants. Introduced bumblebees in Israel and Tasmania have caused declines in populations and the activities of native pollinators and changed seed-set in some plants.

It is predicted by many that the loss of pollinators will cause populations of native plants to decline and eventually become extinct. Habitat fragmentation also accelerates the extinction of local plant populations through inbreeding, genetic drift, and other stochastic (chance) processes. The general reduction of species richness and relative abundance that occurs through habitat fragmentation changes the foraging behaviour of flower-visiting insects, disrupts biotic interactions and reduces seed-set and gene-flow in isolated plant populations. Habitat destruction affects pollinator

populations by the removal of food sources when crops are not in bloom, the elimination of nesting and oviposition sites, and of resting or mating sites. Pollinator-limitation has been shown to reduce seed output by 50-60% in rare plants or plants in fragmented landscapes. The IUCN predicts a global loss of 20,000 flowering plant species within the next few decades and undoubtedly, this will lead to the decline of co-dependent pollinators.



At the biocenotic level, the ecological importance of pollinators in their communities is critical. If a keystone plant species loses its pollinators, the entire structure of the biotic community could be dramatically and irreversibly changed. For example, figs (*Ficus* spp.) are a key-stone group of trees in many tropical ecosystems. They are strong competitors for light, are involved in the creation of light windows in the forest, and produce abundant fruit that is consumed by many birds and mammals. Figs depend on highly specialized pollination by minute wasps. Clearly, the loss of these wasps would have a major effect on the structure and function of tropical forests. As another example, *Eriope blanchetti* (Lamiaceae) is a keystone nectar source for many species of solitary bees in the coastal sand dune communities of northeast Brazil. Urban and recreational development threatens the abundance of this shrub so that the bee community, on which many other plants depend for pollination, is threatened. If disruptions of pollination are highly localized and the pollinators are vagile, it is expected that the recovery would be rapid as on the blueberry lands in New Brunswick. However, widespread disruptions of regionally significant and restricted interactions could be irreversible as is the case for bat pollination systems in the South Pacific. Over-hunting of bats has resulted in lack of pollination of various plants that are dependent on them. Thus, these plants fail to fruit and re-establish themselves, with a resultant loss of diversity in vegetation. Some of these plants are also important traditional foods of the islanders.

Extreme weather, such as that effected by global climatic change, also influences pollination systems. In highly unpredictable environments, generalist pollinators fare better than specialists. Some plants may adapt to self- or abiotic pollination, or they may adapt to the new conditions, along with their pollinators.

Recent studies on pollinator assemblages have been done to evaluate ecosystem stress and health. Use of pollinator diversity and abundance has rigorously demonstrated that pollinators serve well as bioindicators of ecosystem function and disruption.

CONCLUSIONS

The central role of pollination in sustaining natural and agricultural ecosystems is now well recognized by researchers and many farmers around the world. Nevertheless, there are disciplinary areas in agriculture, forestry, biology, and ecology where the importance of ecosystemically sustaining mutualisms, such as pollination, remain overlooked. Similarly, for the general citizenry, the actual importance of these biotic interactions is not always appreciated.

Pesticide use has been declining in agriculture practice, but probably not enough. In many developing countries, pesticide use is on the rise. Pesticide labels often carry warnings about effects on pollinators, generally only honeybees, but are quite inadequate when pollinator communities are at risk. The incidences of pesticide problems in pollination are all too common. In agricultural ecosystems, monocultures and fence-to-fence cultivation eliminate small patches of pollinator nesting habitat. The destruction of hedgerows, small patches of trees, and general intensification of agriculture has the same effect. Plantation forestry is similar and produces pollinator hostile environments. Deep cultivation on fields may also reduce pollinator populations by destruction of nests that could otherwise persist.

RECOMMENDATIONS

Policies that encourage landscape diversity, soil conservation, wind-break plantings, hedgerows, biological pest control and integrated pest management would go far to reverse the patterns of pollinator declines. There is clearly a need for policies that are sensitive to the importance of pollinators in pest management regulation, agricultural and forestry practices, as well as in natural resource conservation and sustainability programmes.

The recognition that the loss of biodiversity is likely to have negative impacts on ecosystem function, combined with the uncertainty about current and future roles of many species in almost all ecosystemic processes,

Figure 17. (left)
Bee on mustard
flowers.

Figure 18. (right)
Mustard field with
bee hives; Photos by
Peter Kevan.

presents a strong argument for a precautionary approach in conservation. To reach the objectives set forth for the management, conservation and restoration of pollinators and pollination, more intensive efforts are required to widen the general understanding of the essential value of plant-pollinator interactions in our ecosystems and to life on Earth.

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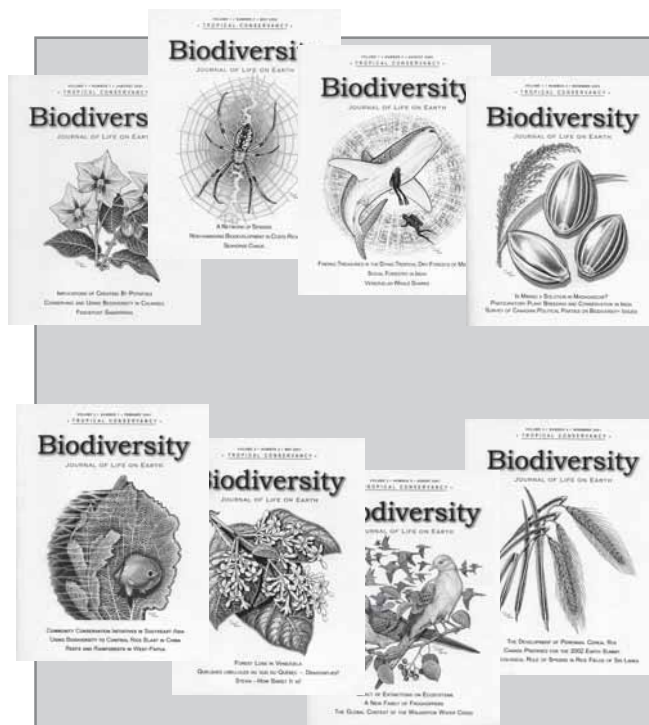
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